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

EW4ALL

Second Order Draft

June2024

This publication has been developed as part of the EW4All initiative of the UN 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 first pillar (Disaster Risk Knowledge and Management) of the Initiative, coordinated by 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 Early Warning Systems. UNDRR has engaged CIMA Foundation to develop this deliverable.

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Full citation

Table of content

1. Introduction

1.1. General context

Natural hazards and disasters have had and continue to have a devastating impact on the lives and well-being of many people and on the economies of countries around the world. Between 2002 and 2022, the EM-DAT database recorded about 7,800 disasters, which caused an average annual death toll of 60,000, at least 200 million people affected (Figure 1) and 190 billion US$ of economic losses per year (CRED, 2023). While the share of economic losses per continent is the largest in the Americas, the affected population is disproportionately concentrated in developing countries, with the combined figures of Africa and Asia regularly exceeding 90% of the total. Climate change is increasing the frequency and intensity of some natural hazards, including floods, droughts, and heat waves, making future projections of disaster impacts even more daunting. The most common types of disasters related to natural hazards in the past two decades were floods, storms, droughts, and earthquakes, though 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 northeastern Libya caused widespread flooding and the collapse of two dams, resulting 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.

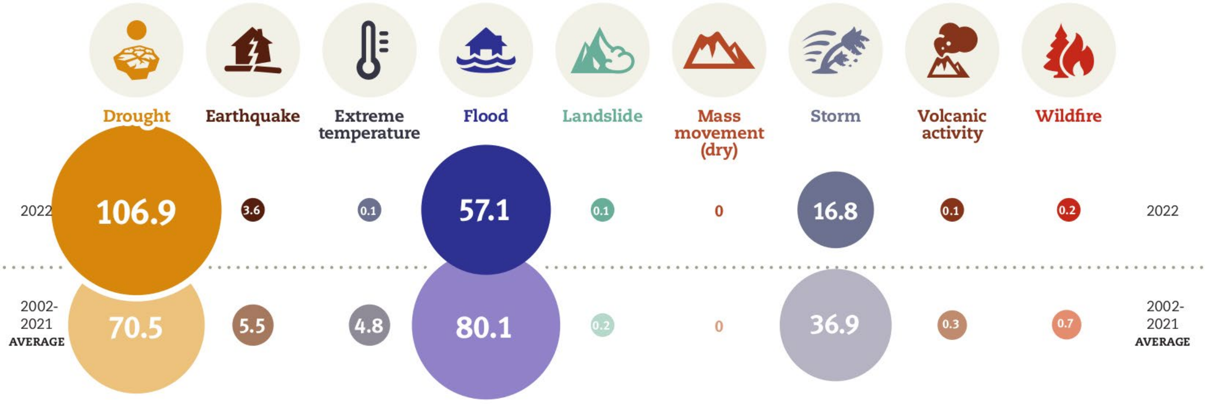

Figure 1*: Number of people affected (million) by disaster type: 2022 compared to the 2002-2021 annual average.*

1.2. EW4ALL context

The Early Warnings for All (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 early warning systems. The initiative is led by the United Nations Office for Disaster Risk Reduction (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 wide range of partners from governments, international organisations, civil society, and the private sector. Early warning systems are a critical adaptation measure for reducing disaster risk and saving lives. Their usefulness is motivated by the high cost-effectiveness, with an average tenfold reduction in disaster impacts in comparison to their implementation cost, with specific figures varying across the different hazards and regions of application (Global Commission on Adaptation, 2019; WMO and GFDRR, 2015). They can help people to take action to protect themselves and their property before a hazard strikes. The EW4All initiative aims to strengthen early warning systems 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 early warning systems in place by 2027.
- Improve the quality and timeliness of early warnings.
- Increase the use of early warnings by decision-makers and the public.
- Build the capacity of countries to manage early warning systems.

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

Early Warning Systems (EWS) are essential in disaster risk reduction, 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 of Early Warning for All: Risk Knowledge, Monitoring and Warning, Dissemination and Communication, and Response Capability.

Risk data and information underpin all 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, 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 calibrating 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 developed within a risk assessment include:

- The 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 clearly identified along with their causal links to possible predictors.

These scenarios inform EWS processes in several ways:

- They identify the appropriate variables to monitor and forecast within the EWS and establish triggering thresholds for warning development.

- They determine the nature of possible impacts and potential impact hotspots, both in terms of location and sectors to consider.
- They help define the impact information to be communicated, ensuring it resonates with the perceptions of those receiving the warnings.
- They allow targeted messaging for different functions (e.g., institutional advisories 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 early warnings, enhancing the readiness of communities and institutions. Anticipatory actions, such as evacuations and resource mobilisation, are triggered by early warnings and are 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.

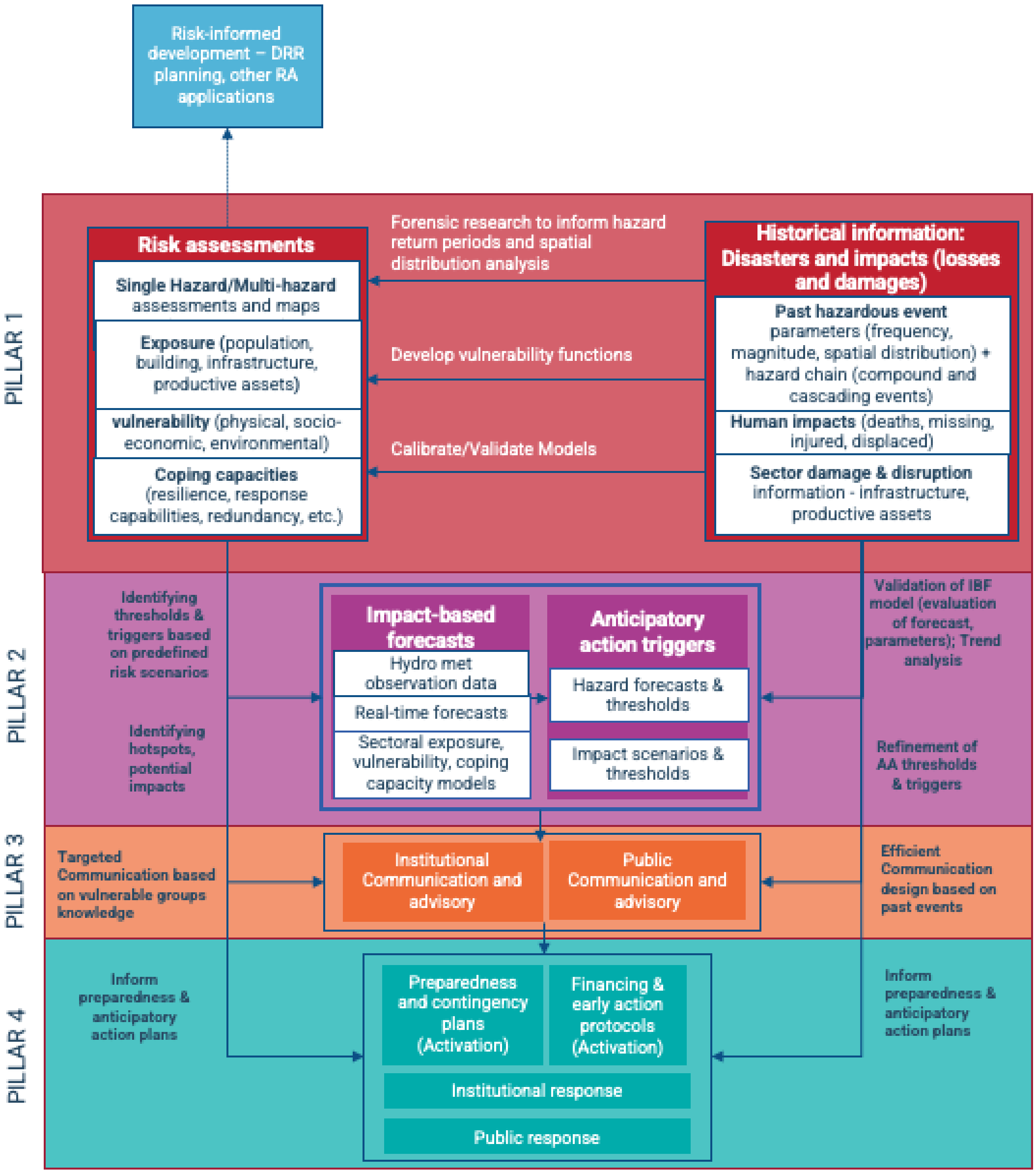

Figure 2: The importance of risk knowledge (built from historical disaster loss and damage information) for all EW4ALL pillars and the developments of impact-based forecasts and Anticipatory Actions (modified after UNDRR)

1.4. Scope and structure of the handbook

Target users

The main target users of this handbook are national institutions, meteorological and hydrological services, Disaster Risk Management (DRM) authorities and International organisations. Indirect beneficiaries of this handbook are foreseen to be the public and the media. The handbook mainly intends to address the National and Subnational levels, with an incentive for national actors to build the capacity at community level. While the primary target users are national agencies, the handbook addresses different levels, scales, actors, and perception of risk information. EWSs can be national, regional scale or community-based, and developed for a single or multiple hazards. It is therefore important to stress that risk information must be generated in a multi-scale and multi-temporal fashion, could address multiple hazards, and be communicated through multiple channels.

This handbook is intended to guide DRR practitioners in the use, role and application of risk information to support the effective implementation of the four key pillars of the EW4ALL initiative. Rather than focussing on the production of risk knowledge, the handbook documents how best risk information can feed the different processes that compose the Early Warning Systems (EWS) by emphasising the interconnected nature of EW4ALL across the four pillars. More specifically, it covers the processes represented by arrows in Figure 2. This handbook takes a practical approach aiming at assisting various actors and stakeholders engaged in EWS implementation for hydro-meteorological hazards. It serves as a valuable 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 in all the EWS development phases, as well as a summary of the key risk information needed for the implementation of each pillar. A practical angle has been chosen for countries to understand where they stand in the EWS implementation as well as to support them in advancing in the implementation itself.

The handbook 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 linked to the 4 EW4ALL pillars as described in Figure 3.

- **Process 0** How to use risk information to define proper reference risk scenarios?
- **Process 1** How does risk information support the definition of hazard thresholds?
- **Process 2** How to produce warnings that include relevant and actionable risk information?
- **Process 3** How to use risk information to build technically sound impact forecasts?
- **Process 4** How to use risk information to define/design warnings that are clear and understood?
- **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 the communication flow and strategy?
- **Process 7** How can risk knowledge support a progressive activation of early actions and emergency coordination arrangements?

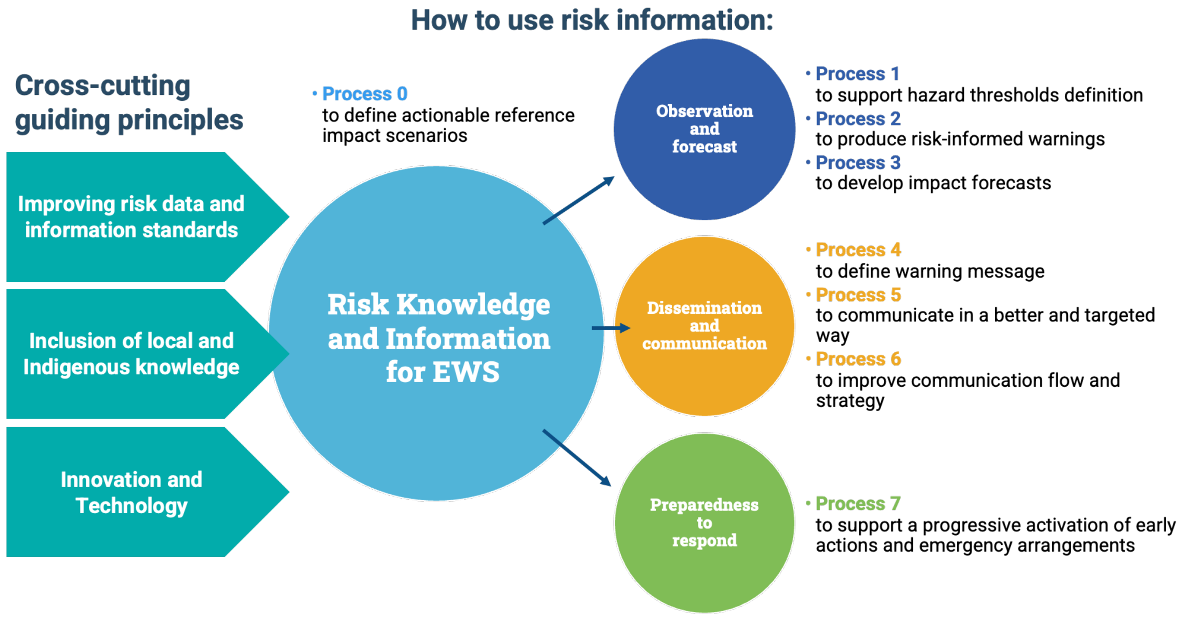

Figure 3 : Handbook structure and workflow

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

1.5. The Early warning processes

EWS generally refers to a system of processes, activities and actors that supports the generation and use of early warning for early actions. The handbook is built around the concept that impacts are embedded in the definition of EWS and that early warnings must be connected to impact information, through a process that enables:

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

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

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

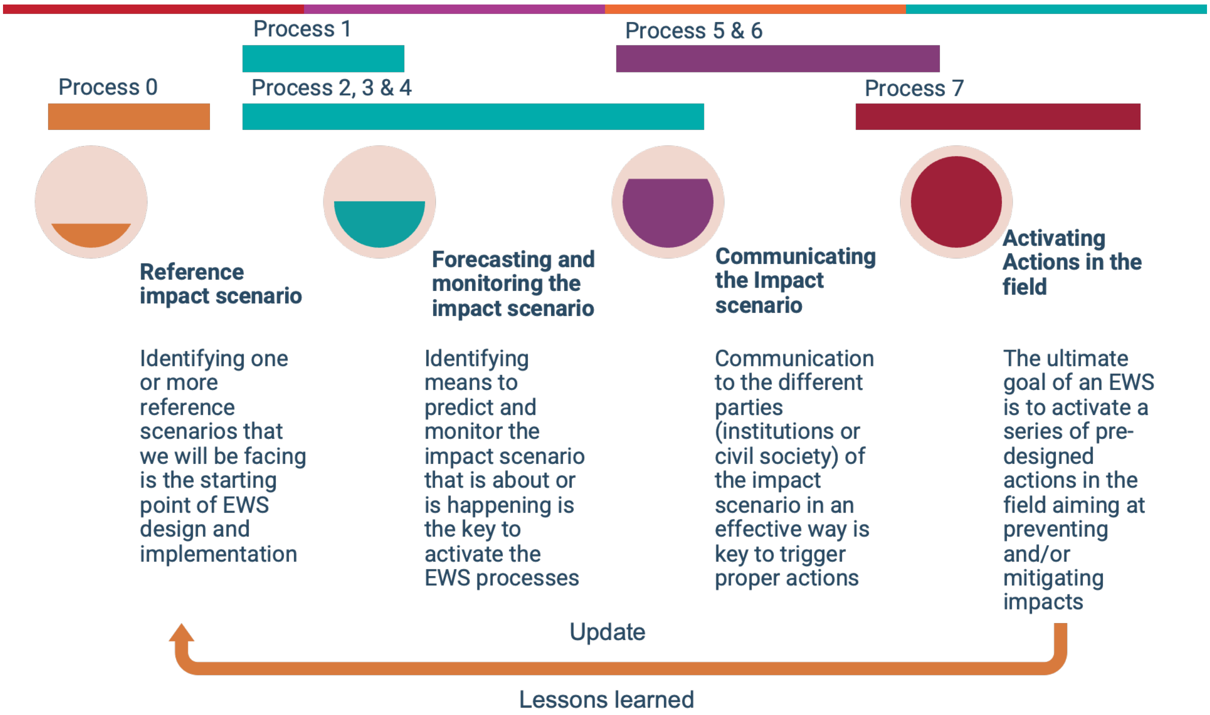

Figure 4: The early warning concept and processes

An EWS is a set of structured processes designed to detect and communicate potential threats or hazards before they escalate, 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 early actions.

Prefiguring impact scenarios on the basis of scientifically sound risk information should be the starting point of an EWS design (Process 0). The identification of the possible hazardous events and the impact that those might have on the different sectors of society is essential to understand what are the actions that can be designed and triggered in order to protect people and values from the pending hazardous events. This approach contributes to the definition of a people-centred and action-based early warning system. More specifically, 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 the possible early actions 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 (i.e. nature, level of disaggregation, temporal and spatial resolution, format) that needs to be used to inform the overall EWS process.

When the reference impact scenarios are clearly identified in partnership with scientific actors, such as National Hydro-Meteorological Services (NHMS), the ability of forecasting and monitoring them becomes essential. In this context it is possible to utilise various tools and methods, such as observations, meteorological models, statistical analysis, to forecast the likelihood and severity of specific impact scenarios (Process 1, 2 and 3). Forecasting involves continuous monitoring of relevant indicators and variables to update predictions as new inputs become available, with the goal of providing decision-makers with reliable and timely information about the potential threats, allowing them to make risk-informed decisions.

Once these potential threats are identified and warnings are generated, effective communication channels are crucial for disseminating this information to relevant stakeholders (Process 4, 5 and 6). Communication may involve various means, such as alerts, notifications, reports, or briefings, depending on the nature of the threat and the target audience. Clarity, timeliness, and accessibility are essential in communication to ensure that the information reaches those who need it and can act upon it. The content of the warning should consider risk information and be connected with the reference scenario identified (Process 3 and 4).

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

An effective EWS includes a feedback loop to assess the accuracy of predictions, the appropriateness of early response actions, and the 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 Early Warning System 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 or a series of them is to ensure the consistency among the different processes composing the EWS. Having the same reference scenario on one side to drive the identification of the actions on the field and on the other defining the warning characteristics able to trigger them for different stakeholder groups should be at the heart of an efficient EWS.

It is however recognised that because of the interinstitutional nature of the EWS and the consequent fragmentation in responsibility related to the different components, we frequently experience investments in EWS that are not always coordinated. In some cases the driving force comes from the urgent need of organising an efficient response, in some other cases it is driven by technological and infrastructural investment enabling an efficient forecast. As a result parallel initiatives are often put in place and the coordination among the different processes is imposed only at a later stage with clear difficulties in connecting components that have not been harmonically designed. The vision proposed in this handbook aims on the one hand to eradicate this approach, but on the other, by setting a clear line of design for the EWS processes, to give a pragmatic reference to institutions holding responsibilities in the EWS implementation and operational use, so that the different processes can be consistently connected even in a later stage of development.

2. Standards and Cross-cutting Guiding Principles for the production and use of risk knowledge and information specific to EWS (Pillar1)

There are several standards and key cross-cutting guiding principles that need to be considered in the production and use of risk knowledge for EWS, referenced in the EW4ALL Executive action plan (CDEMA, 2020 - p15). This section is outlining and summarising the information of the most relevant standards and principles, aiming at ensuring the quality, availability, accessibility and use of risk information at the continental, regional, national and local scales specific to impact-based Early Warning Systems (AUC DRR, 2020).

There is a lot of material and guidance proposing checklists to generate risk information specific to EWS, and baseline data collection for risk knowledge (EWC III, 2006; WMO, 2018). This handbook completes these materials by providing a practical list of the minimum information required to build relevant risk knowledge specific to each EWS pillar, organised according to the main components of the risk assessment process (section 3.1).

General guidance is provided on the standards for risk knowledge production, by listing in section 3.2 the criteria necessary to generate standardised and sustainable risk information with specific focus on EWS. The section also emphasises the importance to better include and communicate uncertainties related to risk information.

As stated in the EW4ALL executive action plan (2023-2027)[2], it is crucial to include Indigenous and Local Knowledge (ILK) into risk knowledge production as well as in all steps of the development and implementation of EWS. Section 3.3 describes the most common practices of ILK inclusion, within the Community Engagement (CE) objective framework (FAO, 2023), for each of the EWS implementation steps. In addition, specific attention has to be given to ensure an EWS is equitable so that differential impacts can be reduced. For example, during the 2004 Indian Ocean Tsunami four times more women died compared to men (MacDonald, 2005). This means that an EWS must make sure that the most vulnerable populations are reached and that the messages are tailored to these specific groups. It includes children and youth, people with disabilities, and the consideration of gender issues in the production and use of local knowledge specific to the design and implementation of EWS.

Innovation and technology is indispensable in bolstering the production and effective utilisation of risk information within Early Warning Systems (EWS). Section 3.4 highlights the relevance of satellite information, artificial intelligence (AI), and big data. 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 weel as the characterization of vulnerability adding the possibility of mapping those 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. Moreover, 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 certainly represent an important tool in future EWS. Big data analytics empowers EWS to process large volumes of diverse information rapidly, enhancing decision-making capabilities. Embracing innovation and technology is essential for advancing Early Warning Systems to effectively address the complexities of today's dynamic risk landscape. Innovation and technology contribution to

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

EWS will be diffusely treated in (CITE HANDBOOK ON I&T). In this Handbook some possibilities will be discussed in section 3.4.

Finally section 3.5 summarised the seven processes identified for the use of risk knowledge in the development of EWS, and their inter-linkages.

2.1. Minimum information required to build risk knowledge mapped to each EWS pillar

Building knowledge on disaster risk and impacts is an essential step of the EWS development. Indeed, it is primarily used to prioritise hazards and identify hotspots where populations are the most at risk. In addition, understanding how hazards affect people in different places helps to tailor the development of effective EWS, containing comprehensive and actionable information, and to reduce the time between an early sign of a disaster and its realisation.

Risk Information is analysed using the classical components of the risk equation: Hazard, Vulnerability, Exposure and Capacity (UN, 2015). The historical information on Impacts, being a fundamental step in all risk assessment methodologies, is analysed separately as a first step in the risk assessment process when an EWS needs to be implemented. These components are not analysed in full but only in respect to their relevance for the development of an EWS. Indications are given about the importance of the risk information elements for each Pillar of the EWS.

Highlight box : Risk data for conflict and fragile context - displaced population

The forthcoming Handbook on 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 acts as an enabler to ensure fragile- and conflict-affected countries are supported within the wider ecosystem of EWS stakeholders. This is badly needed because 19 of the top 25 most climate vulnerable countries are fragile and/or conflict-affected. This illustrates the critical importance of extending early warning systems to 'last mile' communities that include conflict-affected and displaced people.

However, the aim of last-mile connectivity becomes harder with conflict-affected populations who often become displaced or are on the move, may have lost assets including mobile phones, and may be highly mistrustful of any information sources stemming from government or authority figures. There is a need for better and more dynamic data collection on the number, location, and needs of displaced people in FCV contexts, to better understand current and projected hazard exposure. The volatility and significant everyday challenges inherent to many FCV contexts may also affect the uptake of warning messages if they are received, as the risk perceptions or competing priorities of affected populations may necessitate tailored and trauma-informed messaging.

There is a further strong need for EWS in refugee and IDPs camps due to key challenges that these populations often face. For refugees in particular these include restrictions on freedom of movement, meaning that evacuating camps during extreme weather events is often impossible, and on the type of building materials and infrastructure permissible in camps, which host governments often restrict to temporary rather than durable material. These factors can increase refugees' vulnerability to natural hazards. At the same time, the often large humanitarian presence in camps presents the opportunity to establish or strengthen EWS through making use of existing humanitarian responses and coordination systems.

Learn more about the Handbook and wider initiative through a policy paper available here: https://www.preventionweb.net/publication/early-warning-systems-and-early-action-fragile-conflict-and-violent-contexts-addressing

2.1.1. Historical Impacts

It is of paramount importance to gather historical data on past and current incidents or events related to specific hazards recurring in an area. In the case of EWS, historical disaster records are needed for the validation of the risk knowledge produced, but it can also be used to build simplified reference impact scenarios. The retrospective analysis of disaster data is particularly important for risk assessment and Impact Based Forecast calibration, to inform detailed preparedness planning, identify emergence of new risk patterns and trends. The analysis of historical impacts is also necessary to build the correct perception of pending risk on the geographical scope of the EWS in all relevant EWS sectors.

To this purpose, efforts should be made to collect and share all disaster losses and damage data and statistics, disaggregated by accurate hazard typology, location and impact categories. Efforts to develop Disaster Loss Database compliant with the Sendai Framework for Disaster Risk Reduction 2015-2030 monitoring minimum requirements have been made, defined as a set of systematically collected records about disaster occurrence, damages, losses and impacts. Example of global source of information for disaster related impacts are Desinventar[3], EM-DAT[4], NatCatSERVICE[5] (Munich Re) databases, Swiss Research Institute Sigma Explorer[6]. DesInventar is particularly relevant in the development of EWS as it collects since the 90' a broad range of impact data (including physical damage to housing, agriculture, infrastructure, schools, and health facilities) on all disaster magnitudes and at the local scale, and is available (at different level of completeness) for 110 countries. These datasets could to be completed manually by online media (e.g. floodlist[7]) , humanitarian reports (e.g. webrelief[8]) and information from emergency appeal (IFRC-Go[9]) or post disaster need assessments (Preventionweb[10]).

At present, UNDRR, UNDP and WMO are encouraging National Hydrological and Meteorological Services (NHMS) to enrich and maintain disaster catalogues including losses, damages and impact information with a new disaster data information system under development, known as the hazardous event, disaster losses and damages tracking system (DTS for short) including the new methodology for Cataloguing of Hazardous, Weather, Climate, Water and Space Weather Events (CHE)[11] . The CHE model will provide records of hazardous events which can be linked with related observed disaster impacts. Recognizing the need for an upgraded, comprehensive, and interoperable system, UNDRR, UNDP and WMO, hence, are collaborating to develop a new generation tracking system for hazardous

[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/disaster-losses-and-damages-tracking-system

events and disaster losses and damages (DTS). The new system will enhance country capacities to better understand disaster data value chains, support data governance, enable actionable information, and facilitate knowledge brokerage for positive change.This new disaster data information system comes as an upgrade of Desinventar, in order to address growing data needs and interoperability, 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. The DTS also implies leaving sufficient room to incorporate the results of ongoing development on methodological and technical aspects, such as the advancement of accounting methodologies for environmental losses assessment, the development of a new disaster-related statistics framework, or the adaptation of post-disaster needs assessments to slow-onset events.

See Table 1 on Historical impact elements needed for EWS

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 for 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 warning messages, and inform response strategies. The hazard-related informations detailed in the table are particularly relevant for EWS developments. In case of multi-hazards scenarios, in addition to retrieving data for each hazard, schematic of compound effects should be analysed. The access to hazard information will soon be facilitated by the implementation of the Cataloguing Hazardous Events standards by WMO (WMO-CHE) that will help identifying relations between hazard and impact magnitude in the specific environments analysed. The possibility of linking impacts to a single event identifyier wil aslo a crucial step forward in alowing the analysis at event level which will inform the design of reference risk scenarios in all the needed complexity.

See Table 2 on Hazard elements needed for EWS

Table 1 - Historical impact elements needed for EWS

Variables	Description	Use in each pillar	Disaggregation	Resolution	Sources
Historical event dates and location	List of past and current incidents or events related to specific hazards occurring in an area	Pillar 2 : Understand frequency, identify hotspots, model validation. Pillar 3 : Refer to past events in warning messages Pillar 4 : Reference scenarios definition.Tailored plans that consider seasonality and geographical distribution of past disasters.	Importance to include the different typology of disaster (e.g. flash flood, dam break…) and the causality nexus (e.g., rainfall induced, snow-melt induces, Cyclonic surge) Importance of including the timeline of the event and the sequence of possible primary and 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 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 events occuring in the area, on different assets 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 :The level of preparedness and response needed can be sized based on historical impacts. 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, environment…). Forensic approach to the impact, it is important to clearly link the different impacts to the causes of such impacts.	Depending on the Scope of the EWS. 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 events	Pillar 2 : Understand hazard severity and identify hazard variables, define thresholds Pillar 3 : Possibility to refer to past impactful events in warning messages.	Information should be as quantitative as possible, 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 form mandated institutions or from the Humanitarian sector, online media (e.g., floodlist)
Assessment of Exposed elements and 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 events close in time or specific condition of the population, displaced population, food security conditions, epidemics.	Pillar 2: Update and modification of the reference scenario according to the current level of Coping Capacity, exposure and vulnerability levels. Pillar 3 : Prepare impact-based forecast warnings Updated on the changed Coping Capacity, exposure and vulnerability levels. Pillar 4 : Update and modification of the level of preparedness and response needed as well as of 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 to risk and warnings, as well as trust to 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 : Adapting actions to risk perception and past response	Importance to disaggregate the information per demographic groups (including gender and vulnerable groups...) as well as spatially	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 the local/community level	At the highest administrative divisions possible (community levels)	Should be gathered by local communities or through Focus Group Discussions or Key Informant Interviews

Table 2 - Hazard elements needed for EWS

Variables		**Description**	**Use in each pillar**	**Disaggregation**	**Resolution**	**Sources**
Temporal Characterization	Speed of the Onset	information on the time lag between the first precursor sign and the 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…) Pillar 4 : Define duration of the potential window of opportunity (between a 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)
	Hazard duration	Duration of hazardous conditions	Pillar 2 : define disaster time-space scale Pillar 3 : Informs the content of warning messages (duration…) Pillar 4 : Understanding of the level of preparedness required, prioritise 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 (SEE 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…) 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 (SEE 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 (SEE 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, local and indigenous knowledge (LIK)	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 (SEE 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 (SEE 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 : tailored 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 (SEE WMO Words into Action MHEWS

2.1.3. Exposure elements

Exposure-related risk information is key to inform risk assessments, and also crucial for all the Early Warning Systems (EWS) chains. Exposure, as defined by the United Nations Office for Disaster Risk Reduction (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. It is also important for the development of effective warning and response strategies. capturing the appropriate level of disaggregation of the exposure elements as well as its fast (e.g., day/night or seasonal population distribution, IDPs) and slow dynamic dimension (e.g., Urbanization, changes in urban development, changes in land use).is crucial for an appropriate and useful asssessment of risk.
The priority components for risk exposure analysis should be the knowledge about where people live, and where they are moving over time. The other risk factors can be layered on top of this information in order to understand and gauge the exposure to an upcoming hazard.

See Table 3 on Exposure elements needed for EWS

2.1.4. Vulnerability (and coping capacity) elements

Vulnerability refers to the predisposition for any exposed element to be adversely affected (IPCC, Annex B., 2012). Vulnerability-related risk information improves the assessment of the potential impact of hazards on populations, infrastructure, and ecosystems, and is essential for enhancing 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 the way people can prepare, experience and recover from hazards. The vulnerability of population cannot be directly observed or measured, however data can be combined into indexes able to quantitatively estimate relative vulnerability from available proxy variables characteristics (Bucherie et al., 2022a). For instance, population vulnerability information related to the identification of vulnerable groups (e.g. disability), the demography (e.g. age and gender), the health status, the education level, the poverty level (income, inequality levels..), and the coping capacity (such as the access of population 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. Indeed, vulnerability assessments for infrastructure consider factors like construction quality, building codes compliance, and maintenance practices which help determine the resilience of infrastructure to various hazards.

See Table 4 on Vulnerability and coping capacity 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) or other upcoming efforts (e.g. Microsoft, Planet Labs, and the University of Washington's IHME working together on a global population map [12])
		Pillar 3 Help understand how the population potentially affected is distributed spatially to adapt communication channels. Essential for developing accurate and context specific warnings	Vulnerable groups: gender, religion, langage, age, disabilities.	Census Tracts	
		Pillar 4: Guiding resource allocation for shelters, medical facilities, and food distribution centres. Essential for planning evacuation orders in high-risk areas		Census Tracts, Communities level	
Working/studying population (where people work/study)	Population distributed with reference to working/studying places and related livelihoods	Pillar 2 :Understanding 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 administrative level	
		Pillar 3: Warnings to be disseminated effectively to the areas with high concentration of labour forces during the day etc.			
		Pillar 4: Leverage the networks of the private sectors and communities to deliver support necessary; also prepare for the 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, langage, age, disabilities.		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 : Adapted plans to migration patterns			
Infrastructure data					
Exposed settlements and buildings	Information on any infrastructure that is at risk and their characteristics including location, materials used, its	Pillar 2 : Estimate the number of building or households about to be affected (for IBF)	Disaggregation per sector such as industry, housing, commercial…	At the highest possible resolution (building footprints or point location)	Official building databases, cadastral databases, census data and field surveys Building footprint from OpenStreetMap (https://www.openstreetmap.org/)
		Pillar 3: Tailored sector-specific warnings at different administrative levels			

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

	purpose, and economic recovery value.	Pillar 4: Planning preparedness and response plan in space.			Global Exposure Socio-Economic and Building Layer (GESEBL) Copernicus Global Human Settlement Layers[13]
Places of cultural value		Pillar 2: Estimate the place of cultural values about to be affected (for IBF) Pillar 3: tailored warnings to cultural tradition and habits. Pillar 4: Adapted preparedness and emergency planned (e.g. evacuation).	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
Exposed services and critical infrastructure: e.g. hospitals, schools, shelters, roads, protection walls, evacuation routes, bridges, transportation hubs, energy/electricity systems and other utilities…		Pillar 2: Calculate potential upcoming damages on each sector while considering resilient infrastructures (for IBF) Pillar 3: Important for communicating potential disruptions to critical infrastructure (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.	Disaggregation per sector and economic characteristics		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
Land-Use Land-Cover data					
Land-Use map	Maps representing the different types of land use (e.g. which crops, livestock), as vector or raster format.	Pillar 2 : estimating upcoming impacts on livelihoods, food security, and economic activities. Pillar 3: Tailored sector specific warning at different administrative levels. Pillar 4: Tailored sector-specific strategies and plans depending on contexts of land-use change.	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]
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. Pillar 3: Messages relating to environmental impact are of importance in some context (e.g. ecosystem services, including natural resources for tourism…). Pillar 4: Reflect on policy and implementation for nature conservations, management and nature-based solutions	Disaggregation per type of land-cover : forest, wetlands, coastal areas...		GlobalLand 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/

[13] https://human-settlement.emergency.copernicus.eu/copernicus.php

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 about the 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 vulnerable 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 administrative level	Census data National bureau of statistics databasis Humanitarian Data Excgange (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: the relative degree of coping capacity of population can help refining impact forecasts Pillar 3 : tailored warning messages based on the relative accessibility of people to service allowing to cope with disasters (e.g. remoteness...) Pillar 4 : Adapted 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 network (e.g. mobile, internet, radio ...)	At the lowest possible administrative 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 built-up to various hazards.	Pillar 2: Building type and standard used to estimate potential upcoming damages and warning thresholds Pillar 3: tailored messages including potential damage to build-up and infrastructure. Pillar 4: Tailored 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/vulnerability JRC Flood-depth damage curve https://publications.jrc.ec.europa.eu/repository/handle/JRC105688
Functionalities of services	Information relative to the level of functionality and resilience of services	Pillar 3: Tailored warning for the (potentially) impacted service; Importance to know if communication channel might be affected Pillar 4: planning 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 institutions in charge of critical infrastructures

2.2. Improving risk data and information standards

Improving risk data and information standards for Early Warning Systems (EWS) is crucial to enhance the accuracy, effectiveness, and interoperability of these systems (UNDRR, 2016). It is a continuous process that requires collaboration, adherence and commitments to best practices, such as standardising data formats and metadata, adopting common data collection and sharing protocols, collaboration with data providers, 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. 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. This section aims to develop the following points, by providing references and good practices to improve risk knowledge production for EWS :

- Promote the development of quality standards (e.g. in data collection, analysis, assessment and certifications) particularly at national and regional levels.
- Ensure that the EWS sensors, databases, analysis tools and communication platforms can interoperate and exchange data effectively, following data format standards, to ensure real-time and near real-time access to reliable data ;
- Improve the understanding and communication of uncertainties in risk information.

2.2.1. Data quality and sufficiency criteria

The data required for assessing disaster risk (within the hazard, exposure, and vulnerability components) are not managed through a widely accepted approach for collecting, reviewing, storing and sharing such information. However, effective EWS rely on data of sufficient availability and quality to produce accurate risk information and provide timely warnings.

There are five dimensions of data quality (Cai and Zhu, 2015) that can be adapted and applied in the context of disaster risk and EWS. These encapsulates key data criteria and standards to help prioritise and organise efforts for ensuring data quality effectively.

The main criteria for data quality and sufficiency in the context of EWS include:

1- Availability : data accessibility and timeliness

- This includes the accessibility of the data (if they are public, for purchase or need authorizations) and if they are regularly updated.
- In addition, the timeliness of data is crucial for EWS, especially in fast-changing situations. Collecting, processing, and disseminating risk data in a timely manner is necessary to support early warning and decision-making. For instance, real time population flows can significantly change exposure on a sub-daily scale. Delayed data can result in delayed warnings, reducing their effectiveness. Real-time or near-real-time risk data (including hazard data) is therefore of paramount importance.

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

- Accuracy: Disaster risk data always have an inherent degree of error (CRED and UNDRR, 2020), therefore it is crucial to know the expected accuracy and limitations of available information (see Section 3.2.3)
- Data quality assurance processes are important to implement 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.
- Precision: The data should be presented in known values, using consistent standards, units of measurement, and methodologies to collect data accurately.
- Completeness: Ensure data covers all relevant aspects of disaster risk (relative to hazards, impact, exposure, as well as physical and socio-economic vulnerabilities), and all relevant groups (especially most vulnerable groups, persons with disabilities, children/youth, etc…), leaving no critical gaps.
- Consistency: Data 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 retrieved match the users' needs; in the case of EWS, only data sources and parameters that are related 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. It is important that the spatial and temporal resolution of the data must be commensurate with the spatial and temporal resolution of the hazard that EW is being provided for.
- EWS data should have redundancy to ensure that even if the accessibility to one data source fails, there are backups or alternative sources available to provide the necessary information.

4- Security, Privacy, and Ethical Considerations:

There is a need to ensure that data collection and usage comply with legal and ethical standards, including security, privacy, consent, data ownership, and transparency, particularly when dealing with sensitive information. As an example, the "do no harm" principle needs to be applied when generating risk information, taking into account that there may be contexts where risk data and information (particularly related to social vulnerability) need to be collected and shared taking into account its contents' sensitivity.

Example of good practices :

The Disaster-Related Statistics Framework (DRSF)[14] is a guideline developed by ESCAP (Economic and Social Commission for Asia and the Pacific) to improve countries' capacity 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 COREQ Checklist (COnsolidated criteria for REporting Qualitative research) has been developed to ensure the quality control of qualitative data collected through surveys, interviews and Focus Group Discussion.
https://cdn.elsevier.com/promis_misc/ISSM_COREQ_Checklist.pdf

[14] https://www.unescap.org/sites/default/d8files/event-documents/Factsheet_DRSF.pdf

2.2.2. Standards for risk data interoperability and exchange

Achieving seamless interoperability of risk data stands as a cornerstone for the robust development of Early Warning Systems (EWS). This involves ensuring not only the compatibility among EWS organisations and their components but also facilitating effective data exchange among sensors, databases, analysis tools, and communication systems. Moreover, fostering data exchange among various stakeholders and sectors within EWS networks, including governments, meteorological institutes, and local communities, is crucial. One exemplary approach to promote data interoperability is through the establishment of Application Programming Interfaces (APIs) for real-time data sharing. For instance, national initiatives like the Italian open data meteorological portal MISTRAL[15] (the Meteo Italian SupercompuTing PoRtAL) allows to provide and archive meteorological data from various observation networks and forecasts (Bottazzi et al., 2021). To that end, the Open Geospatial Consortium (OGC) also spearheads efforts in standardising geospatial content, location-based services, sensor web, and Internet of Things (IoT), alongside GIS data processing and sharing, with dedicated working groups aimed at harmonising interoperability standards within the disaster management community [16].

The imperative for data openness cannot be overstated, as it serves to democratise 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[17]. In Indonesia, the National Disaster Management Agency (BNPB) and the National Statistics Indonesia (BPSStatistics Indonesia) jointly develop the Satu Data Bencana Indonesia (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 georeferenced 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[18] 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)[19], 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 interoperability and exchange within early warning systems worldwide.

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[15] https://www.mistralportal.it/

[16] https://www.ogc.org/about-ogc/domains/eranddm/

[17] Risk data open standard : https://www.rms.com/risk-data-open-standard

[18] https://rix.undrr.org/

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

2.2.3. Understanding and communicating uncertainty related to risk information

Uncertainty emerges as a pivotal consideration across all components of Early Warning Systems (EWS). Hazard forecasts, even when meticulously crafted within a deterministic framework and leveraging detailed data and models, inherently harbour elements of uncertainty. This uncertainty invariably permeates through impact-based forecasts, warning generation and dissemination, and into preparedness and response phases. For instance, studies like those conducted by Tate (2012) underscore the inherent uncertainty in disaster risk analysis, highlighting the challenges of quantifying risk across various dimensions.

The rarity of high-magnitude events presents a formidable challenge, as they are seldom observed and, when they do occur, are often challenging, if not impossible, to reconstruct with requisite detail. Consequently, caution must be exercised in interpreting risk information derived from such events. In addressing this challenge, Indigenous and Local Knowledge (ILK) can play a pivotal role in mitigating uncertainty. ILK offers valuable insights by providing additional information on past events and enhancing the reliability of hazard models. Moreover, ILK often conveys qualitative information through narratives and stories, which complements the 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. For instance, research by Smith et al. (2018) delves into the challenges of incorporating uncertainty into hazard forecasts and its implications for decision-making in the context of early warning dissemination. As another example, the UK Met Office uses the Met Office Global and Regional Ensemble Prediction System (MOGREPS) to account for the uncertainty due to the starting conditions and the forecast model. Furthermore the influence of exposure and vulnerability components can be factored in the overall uncertainty of impact-based forecast (Cloke and Pappenberger, 2009; Merz et al., 2020).
The communication of forecast uncertainty can be addressed through an appropriate use of risk matrices, using the likelihood of the forecasted event to incorporate the available information on uncertainty. Preparedness and response measures have to be robust and designed to deal with the possibility of missed events and false alarms, especially important to built non-regrets approach for early actions. 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 understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings[20]. While there is no consensus on the definition and use of the three 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 ties 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 local context and surroundings, ILK includes the identification and monitoring of indicators leading to hazards, the knowledge of local vulnerability, coping and adaptation strategies to disasters, as well as the means of risk communication (Dekens, 2007).

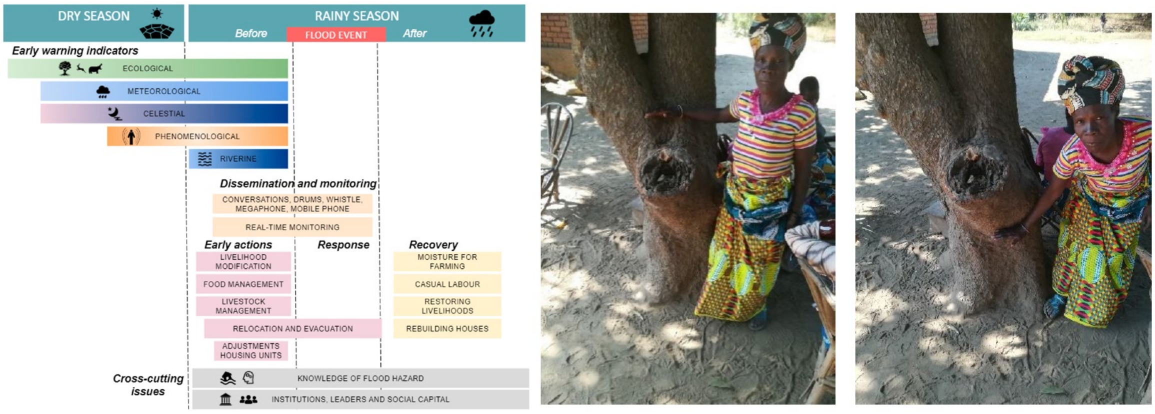

Figure 5: *(left) ILK dimension about flood risk in Malawi* (Trogrlić et al., 2019)*; (right) A woman indicating water levels during extreme and annual flooding in her community* (Trogrlić, 2020)

Indigenous peoples and local communities have developed methods to anticipate, prepare for, and respond to disasters, based on traditional knowledge and experience of surrounding context, that have been successfully used for generations well before the development of computer based early warning systems. While ILK is often described as a separated type of knowledge, this handbook raises the importance to promote the plurality of knowledge in risk information, moving from an opposition between local/traditional and science-centric risk knowledge, toward a learning process across knowledges (including the perspective of all vulnerable groups and marginalised communities): women, childrens and youth, economically disadvantaged communities, persons with disabilities, different ethnic groups, etc…). ILK can also be characterised by the way they generate their local knowledge (Raymond et al., 2010). Local knowledge holders not only include communities, but also professionals working at the local level, who acquire their knowledge through a structured or formalised, though not a scientific process. In the context of an EWS, this can be e.g. the local meteorologist or hydrologist, the agricultural extension worker or member of a disaster management committee. Multiple ILK holders are involved in the generation, communication and dissemination of early warning information that is travelling along the EWS value chain from the weather modellers at the national or regional level to the community or citizen at the local level (I-CISK, 2023). The more these intermediaries at the local level are involved the better the adaptation and translation of the risk information to the local context will be.

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

During the last decade, people-centred Early Warning Systems have been a main focus for global DRR Policies and practices (IFRC, 2021; Gaillard -Waipapa et al., 2022). There are strong incentives to better include Indigenous and local knowledge (ILK) and the perceptive and need of vulnerable groups in all the steps of EWS design and operation to make EWS effective at the national to local levels, and to develop bidirectional process of ILK exchange between the data providers/modellers, the intermediaries and the end users (I-CISK, 2023). Community-Based EWS (also referenced as community or people centred EWS) are the key to providing understandable, timely and actionable information to people at risk. Particularly, the integration of ILK and scientific knowledge makes EWSs more appropriate for local contexts and enables the warnings to reach the last mile (Hermans et al., 2022). Indeed, ILK is necessary for the scientific knowledge to be grounded and relevant to the local context.

Building inclusive EWS requires extensive and long-term community engagement within all the development phases (pillars) of the EWS development, together with a commitment of all institutions to follow a co-production approach (ICPAC, 2021) in the development of EWS[21]. Moving away from top-down approaches (only training or gathering risk information from local people), community engagement and co-production approaches empower the population in the EWS development, bringing value to the entire EWS chain (Facilitating Power, 2020). Community Engagement tools should be used to both inform, consult, involve, collaborate with and empower the population in the development of Early Warning and Anticipatory Action Systems (Figure 5). Indeed, by enabling an inclusive space of exchange, participation and co-production of knowledge, people are empowered in the EWS development and not only considered 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 it encompass indigenous and endogenous knowledge and technologies (Šakić Trogrlić et al., 2021).

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, efforts are still necessary to make the use of community engagement systematic within all the phases ofEWS development and to tackle the following challenges (Sufri et al., 2020):

- the sustainability of community engagement in EWS, and how to maintain participation of local institutions and individuals to keep ILK alive in the long-term;
- the combination of local and scientific knowledge into EWS design and operation;
- the inclusion of all vulnerable groups in the system.

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

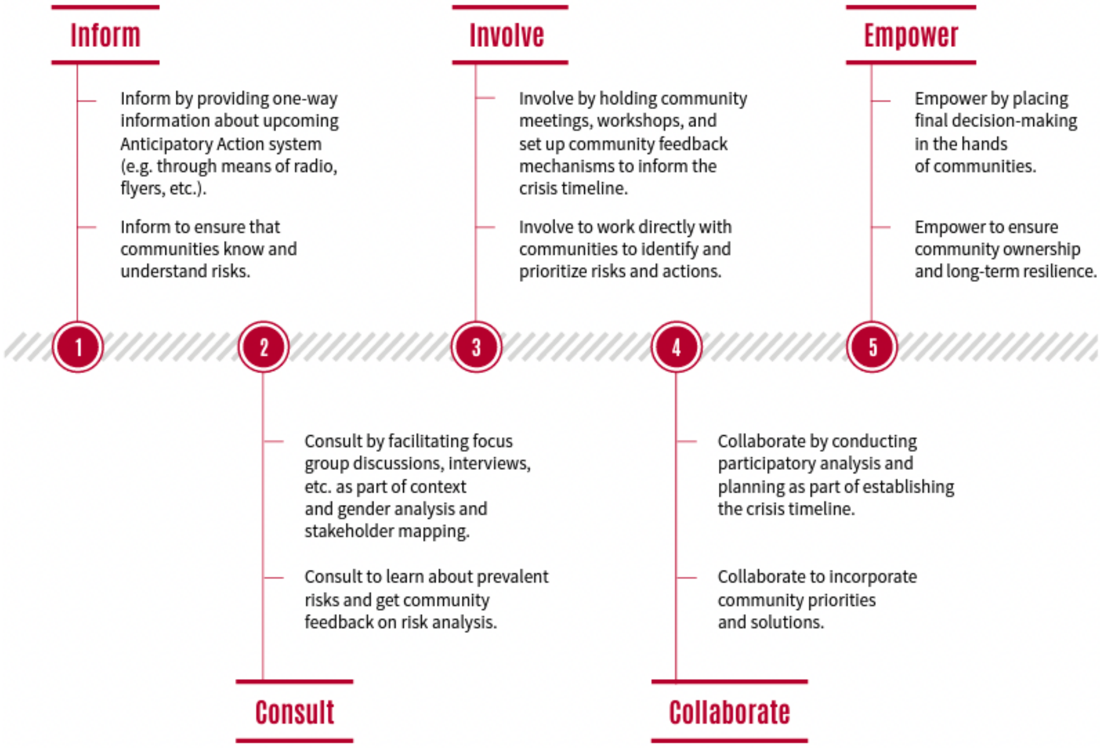


Figure 6: *Example of community engagement objectives and outcomes across the Anticipatory Action system* (FAO, 2023).

How to include ILK into risk knowledge production for EWS ?

The inclusion of ILK into risk knowledge and risk assessment production (pillar 1) is critical to build an inclusive risk knowledge basis that is useful for the implementation of other EWS pillars. However, documenting ILK is not enough. ILK should never be dissociated from its geographical, social, political, and cultural contexts. The following steps are identified for the successful inclusion 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 build a shared and inclusive knowledge base relative to hazard, impacts, 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.
- Use opportunities to embed disaster risk knowledge trainings 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 focus group discussion (FGD)[22] and Key informant interview (KII)[23] with community leaders to gather information about historical events, magnitude and impacts on communities. For instance, the indigenous knowledge can be used to improve early warning systems anticipating landslide damage in tribal communities (Lin and Chang, 2020).
E.G. Malawi Red Cross Society followed community consultation in the northern district of Karonga, to gather historical records of flash floods events and impacts, and express the perception of frequency, and magnitude of events locally. Combined with disaster database records, this consultation participated in building the flash flood risk understanding in the region toward flash Flood Early Warnings (Bucherie et al., 2022b).

INVOLVE
It is of paramount importance to involve communities in the long term, possibly on a yearly basis. Four common participatory practices are suggested below to address the prioritisation of hazards, areas and targeted population for the implementation of EWS.

- Conducting **participatory risk mapping** at local levels as a process to identify hazards, exposed assets and past impacts including, as well as risk perception (Cadag and Gaillard, 2012). **Crowdsourcing approaches** could be implemented to map exposed assets (roads, water points…) using OpenStreetMap platforms (Gebremedhin et al., 2020). See practical guidelines : Good practices in participatory mapping (IFAD 2022[24]) and Participatory mapping toolkit (HOT[25])
- **Assessing the population vulnerability** is recommended through livelihood surveys. Often conducted at households levels, local testimonies are used to identify community needs (e.g. Enhanced Vulnerability and Capacity Assessment - IFRC[26])
- Engaging communities in exploring what are the **local adaptation and disaster risk reduction strategies** in place to cope with disasters and environmental change.
- Ensure that all groups are included in the development and validation of the above risk assessment process (UNICEF, 2016). For instance Children and youth have different response needs and different vulnerabilities to map (e.g. school infrastructure) than persons with disabilities.

[22] https://www.ifrcvca.org/_files/ugd/7baf5b_bb97b862b57c4c33b02d6e8ac9b44dc7.pdf
[23] 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
[24] https://www.ifad.org/documents/38714170/39144386/PM_web.pdf/7c1eda69-8205-4c31-8912-3c25d6f90055
[25] https://www.hotosm.org/resources/participatory-mapping-toolkit/
[26] https://www.ifrcvca.org/

unicef for every child

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

In Kenya, UNICEF is engaging with young people in the co-development of the subnational climate and disaster risk assessment model, using UNICEFs 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:

- in the assessment of children's local exposure to multiple hazards, shocks, stresses and vulnerabilities. Based on this evidence, 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.
- in the development of the National Climate Change Action Plan (NCCAP) 2023 -2028 in partnership with the Kenyan 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 become resilient

Figure 7*: Rania Dagesh, Deputy Regional Director, ESARO and Edwin Odhiambo, CCRI-DRM youth champion, discussing the value of defining risks for childrens in Kenya, and intergenerational solidarity at the African Youth Climate Assembly 2023. ©2023 UNICEF Kenya*

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

Summary of good practices:

- Engage with young people (present or future DRM champions) and youth-led organisations and networks throughout the DRM cycle through a formal and coordinated process
- Ensure the inclusion of specific children and youth related disaster risk knowledge and related responses into national frameworks and plans will result into 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 considered as a key outcome of Pillar 1 and expected to "drive rapid change" toward building disaster risk knowledge, particularly across the use and application of risk data and information. To this matter, The UN Climate Change Technology Executive Committee[27] (TEC) has partnered with the Group on Earth Observations[28] (GEO) through the Early Warnings for All initiative[29] 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. Indeed, innovation and technology play critical roles in enhancing the generation and effective utilisation of risk information within Early Warning Systems, particularly through :

- **Satellite imagery and remote sensing:** The use of advanced technologies such as satellite imagery and remote sensing can enable the collection and generation of vast amounts of data and information about the environment and potential hazards, with global coverage. Indeed, satellites equipped with remote sensing instruments (such as radar, optical sensors …) allow for the real-time monitoring of various environmental parameter changes such as weather patterns, land cover, geological phenomena, soil moisture, river water levels and extent, as well as population movement (BOX 2). 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 after disasters, allowing to build knowledge on disaster damage and costs for past disasters, critical to build impact-based forecasts. For instance the Copernicus Emergency Management Service[30] provides global flood monitoring based on remote sensing and useful risk information for emergency response and disaster risk management.
- **Big data:** 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.
- **Artificial intelligence (AI):** Satellite and other big data can be analysed using artificial intelligence and machine learning algorithms to 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 predict 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 early warnings and inform disaster preparedness efforts in future EWS. In addition, AI can be used to extract already produced risk information using text mining in numerous source of information to support risk scenario building (BOX 1)

Other technologies have already proven to be very useful for risk data and information generation for the development of EWS and will certainly increase their weight while the supporting technologies advance. Two examples are detailed below : crowdsourcing and citizen science

[27] https://unfccc.int/ttclear/tec
[28] https://earthobservations.org/index.php
[29] https://unfccc.int/news/powering-climate-action-through-earth-observations-technology
[30] https://emergency.copernicus.eu/

1- crowdsourcing and citizen science represent powerful approaches for leveraging the collective intelligence of communities to address complex challenges like disaster risk management. In the context of EWS, crowdsourcing platforms enable citizens to report real-time information about 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 can contribute firsthand observations, experiences, and insights that may not be captured through traditional scientific methods alone. For example, residents living in flood-prone areas can provide valuable information about historical flooding events, local topography, and informal coping mechanisms employed by communities during emergencies. By amalgamating these diverse sources of information, researchers and decision-makers can gain a more nuanced understanding of disaster risks, leading to more informed planning, preparedness, and response efforts. One of the key advantages of crowdsourcing and citizen science is their ability to capture the nuances of local contexts and community perspectives. 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.

2- 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 preparedness and response. In particular, social media platforms such as Twitter, Facebook, and Instagram have become indispensable tools for communication during disasters. These platforms 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 preparedness and response 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 loved ones.
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, nonprofit 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 interoperability 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.

Innovation and Technology BOX 1

Enhancing Risk Knowledge Production with Large Language Models (LLMs)

Recent advancements in artificial intelligence (AI), particularly in the domain of large language models (LLMs), 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 LLMs:

Large language models (LLMs) are AI systems trained on vast datasets to generate coherent, contextually relevant text outputs based on the input they receive. Unlike their predecessors, which were often limited to interpreting visual data or classifying 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 LLMs to assist significantly in the interpretation of risk knowledge and information, enabling a wider range of stakeholders to participate in the development and refinement of multi-hazard early warning systems (MHEWS). As the presence of LLMs becomes increasingly prominent across various sectors, the challenge for the coming years will be for industries to harness their potential effectively. The focus will likely shift towards developing tailor-made applications, or AI copilots, that build on the core capabilities of LLMs to address specific needs within distinct domains, such as the integration of risk knowledge in MHEWS. 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 disaster risk management, 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 LLMs in MHEWS:

Two techniques stand out in their potential to tailor LLMs for MHEWS: Retrieval-Augmented Generation (RAG) and fine-tuning.

- Retrieval Augmented Generation (RAG): RAG is a technique that enhances the responses of a language model by integrating a retrieval component. This component searches a large corpus of documents to find relevant information that is then used to inform the model's output. In the context of MHEWS, RAG can enable LLMs 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: Fine-tuning involves adjusting the pre-trained parameters of an LLM on a

smaller, specific dataset to specialise its responses to particular topics or requirements. For MHEWS, fine-tuning LLMs 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.

Potential Use Cases of AI Copilots in Risk Knowledge and MHEWS

Using datasets from the agricultural industry, a 2024 study by Microsoft researchers demonstrated that systems built using LLMs 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 disaster risk management — both requiring precise, localized knowledge and specialized technical expertise — suggest that AI copilots could similarly impact the integration of risk knowledge into MHEWS.

1. **Suggesting specifications for MHEWS**: AI copilots could be instrumental in recommending specifications of MHEWS by utilizing localized risk data to suggest appropriate triggers and thresholds for warnings or even early actions based on the warnings. For a set of warnings, AI copilots could suggest potential early actions tailored to the local context or the capacities in terms of local response. These might include evacuation routes, temporary shelter locations, and pre-disaster resource allocations. Based on historical data, technical guidelines, research literature and other data, AI copilots could also recommend specific environmental or situational thresholds that should trigger early warnings.
2. **Enhancing Communication and Reporting**: AI copilots could automate and enhance the communication processes within MHEWS, ensuring that all stakeholders — from local authorities to the general public — receive timely, accurate, and understandable information. Information could be tailored to the specific needs of different audiences, such as technical reports for operators and straightforward, actionable advice for the public.
3. **Generating risk-based scenarios**: AI copilots could be used to generate detailed, realistic risk scenarios based on local data.

In conclusion, AI copilots, particularly those enhanced through advanced techniques such as Retrieval-Augmented Generation (RAG) and fine-tuning, have demonstrated positive results in fields that necessitate an understanding of technical domain knowledge and localized context-specific information. Such specialized applications of LLMs promise to enhance the precision and relevance of the outputs they generate, thereby making them more effective tools in critical fields like the integration of risk knowledge in MHEWS.

Innovation and Technology BOX 2

HME, Microsoft, 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 residents 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 map population and risk more clearly. Planet's high-resolution satellite imagery that gathers data for the entire earth every day provides a unique, foundational dataset. Microsoft's AI for Good Lab applies machine learning algorithms to analyze 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 the United Nations Office of Disaster Risk Reduction (UNDRR) to understand where populations and crops are threatened by historical flood risks. Partnering with the International Telecommunications Union (ITU), they are working to understand where people live without any connectivity or ability to receive early warnings. These are just two of the many risks that AI can and will help countries understand 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.

You can find more information about and stay up to date on this project here:
https://www.ihmeclientservices.org/populationinsights.html

Innovation and Technology BOX 3

myDewetra: when technology fosters inter-institutional cooperation

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 of an Agreement among the Italian Department of Civil Protection and the World Meteorological Organization and is available to every country under 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 early warning system. Developed hand in hand with the Italian National Civil Protection Department and Cima Foundation, myDewetra acts as a digital nexus, bringing together hydro-meteorologists and decision-makers to exchange vital information seamlessly. This collaborative approach ensures that all stakeholders are equipped with the insights they need to make informed decisions in times of crisis.

Through myDewetra, National Disaster Management Agencies (NDMAs) and Hydromet services worldwide engage in a continuous dialogue, sharing expertise and resources to enhance the effectiveness of early warning systems. By fostering such collaboration, the intention of myDewetra is 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; it's a process based on the collaborative spirit that underpins effective disaster risk management.

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

Guidance on how best to use risk information for EWS is articulated around the eight processes structuring the handbook. All processes are interconnected and mutually reinforce one another as described in figure 7.

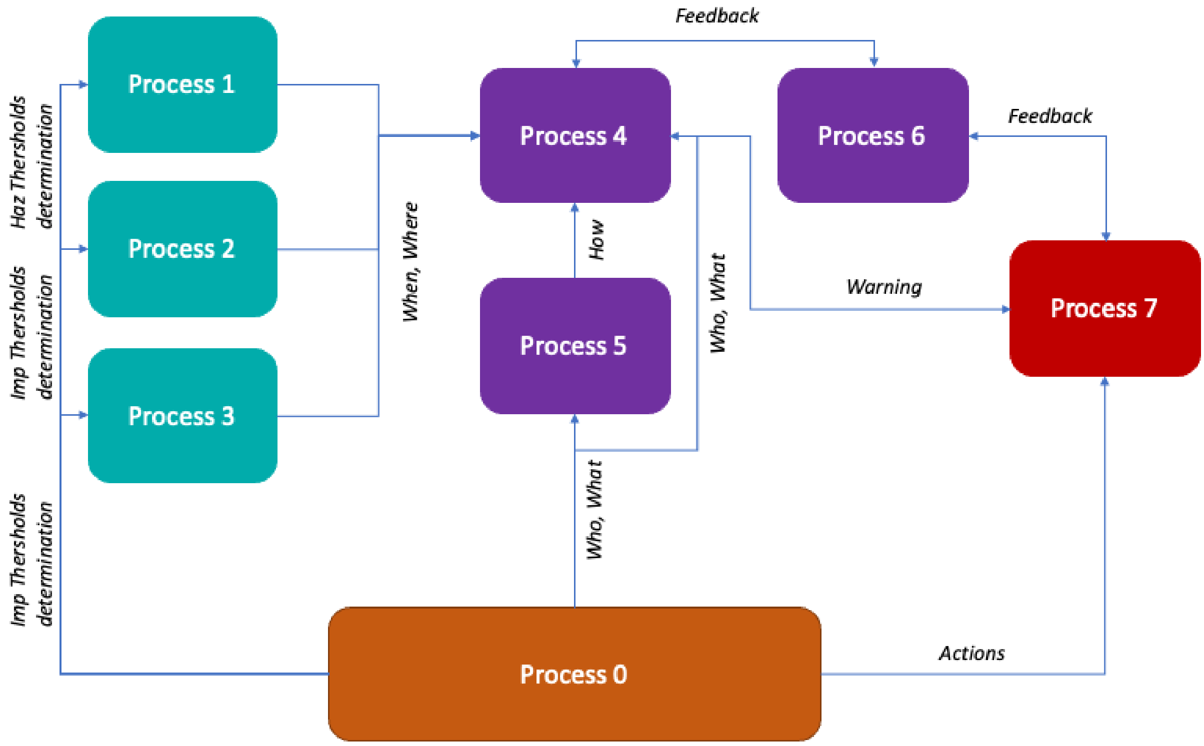


Figure 7 - risk information for EWS: workflow, processes and linkages

Process 0 holds a pivotal position as it establishes one or more reference scenarios for the Early Warning System (EWS), entirely grounded in risk knowledge. Process 0 furnishes critical information to Processes 1, 2, and 3, enabling the definition of key data for identifying hazard thresholds or impact thresholds depending on the chosen EWS paradigm: hazard-based, impact-based, or impact forecast-based. Processes 1, 2, and 3 delineate when and where a specific event is foreseen to produce a certain level of impact. This information is used in Process 4 to construct warning messages in the most effective manner. Process 4 leverages insights from Process 0 to assess who will be impacted and which actions can be initiated to mitigate the anticipated event's impact. Moreover, Process 4 is supplemented by Process 5, which, based on disaggregated information provided in Process 0, instructs on how the message should be crafted and tailored to 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 Early Warning System, 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. Consequently, effective action-oriented and people-centric Early Warning Systems (EWS) can be designed and implemented.

Impact scenarios combine data on hazards, historical impacts, exposure, vulnerability, and capacity into a cohesive narrative outlining potential impacts of hazardous events. This narrative aids disaster risk management stakeholders in formulating preparedness and response (P&R) strategies, including early actions (EA). Additionally, it's crucial to assess in the scenario description the time required to execute these early actions. The reference impact scenario must also align with the ability to forecast and monitor such events with sufficient lead time for a coherent and effective operational activation of the EWS (refer to 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 occurs independently from the design of EWS processes closely tied to early warning production and communication. This fragmentation arises because they may receive separate funding and be overseen by different entities, leading to limited communication until later stages of design or implementation. It is imperative to prevent this and ensure that early warning scenarios align with risk scenarios to plan early actions 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 all processes.

Some key steps can be identified for the reference scenarios definition.

1. Choose the most appropriate approach for describing and characterizing the reference scenarios
2. Assess the useful risk information and their availability
3. Develop the impact scenarios through the analysis of hazard, historical impacts, exposure, vulnerability and capacity for early actions

2.6.1. Choice of the reference impact scenario approach

In the process of choosing and developing scenarios, there are some characteristics common to preparedness and response as well as to early actions that should be considered: (1) they have a protective intent, (2) they are highly time-sensitive, (3) they rely on pre-agreed and risk-informed triggers and (4) they count on actual capacities and provision of funding to support them (Adapted from ASEAN, 2022).

The approach to be followed for the definition of a scenario can be different considering specific hazards and their characteristics.

Guiding questions on how to choose the most appropriate approach might be:

- What is the time horizon and hazard onset to address?
- What are the geographic scope and territorial scale to adopt?
- What is the potential user/decision maker and so the typology of mitigation measures to activate?

There are several methods and approaches for developing impact scenarios around specific planning objectives such as the ones reported in Table 5. While these approaches can be applied in a flexible and hybrid way, it is crucial to keep in mind from the very beginning the planning objective to choose the most suitable one.

Approach	Advantages	Best use
Specific scenario approach (best, most likely and worst case approach)	● Provides a basis for planning for different scales of problem ● Easy to understand and discuss	● Planning for a single situation ● When scenario development involves many actors
Augmentation approach	● Good for planning for situations which increase in magnitude over time ● Easy to build plans which allow expansion of operations	● Displacement situations (internally displaced persons and refugees)
Timeline approach	● Allows planners to adapt operations over time while a crisis evolves	● When rapid-onset crises occur, response needs can change very rapidly in the initial days and weeks ● Good for planning for slow onset hazards facilitating a phased approach and the adaptation of anticipatory action options to the evolving hazard context
Operationally representative approach	● Allows for a greater focus on operations ● Can be used to develop more flexible plans ● Can be used to identify preparedness actions that help in multiple situations	● Situations that are difficult to predict

Table 5*: Different approaches to risk scenario development (Adapted from IFRC, 2012b)*

Among the various methodologies available, the "specific scenario approach" emerges as the most prevalent and adaptable, particularly in multi-stakeholder environments (IFRC, 2012b; UNDRR, 2017). This approach typically involves formulating scenarios tailored to specific circumstances, such as the "most probable" or the "most severe" ("worst-case") scenarios, which are frequently employed. Embracing this approach entails analysing multiple scenarios 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 scenarios that could push its limits. Conversely, the "best case" scenario evaluates routine operations that the emergency system should handle upon activation within the EWS. 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 entails significant demands in terms of time, resources, and expertise, necessitating careful evaluation within the EWS context. Given PRA's versatility across various sectors (as outlined in UNDRR-Regional Office for Africa et al., 2020), leveraging its utility across sectors could render its integration into EWS implementations cost-effective.

Due to its simplicity and focus on a limited number of scenarios (sometimes just one), this approach allows for the evaluation of potential cascading or compound events, providing planners with a comprehensive understanding of potential situations, including quantified effects. This quantitative information is invaluable for designing early actions based on available capacities.

This 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 gain the ability to identify areas that may not be susceptible to risks and can strategically plan access routes accordingly.

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

An alternative perspective on interpreting best, most likely, and worst-case scenarios involves aligning them with different organisational tiers responsible for managing them. At the local level, where initial responses to early warnings or ongoing 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 early warning (Adapted from Choularton, 2007). This kind of approach can address the time-sensitive characteristic of early actions and its connection to forecasts and early warnings that needs to be linked to specific thresholds. It is one of the most used and suggested approaches (e.g. by OCHA[31], FAO[32]) especially for slow onset hazards.

As an example, impacts of slow onset hazards on agricultural livelihoods and food security maybe interdependent, and they are distributed over a non-negligible time window; understanding the distribution in time of such impacts presents a certain level 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 impacts materialises (FAO, Building a crisis timeline Version 1.0.).

The timeline allows planners to visualise and define what actions their organisations need to take - depending on the hazard and context - and when to take them, to adequately respond to the situation considering also early warnings and specific triggers for early actions. This kind of approach facilitates a phased approach that deals with uncertainties associated with early warning information and helps adapt the selection of anticipatory action options to the

[31] https://anticipatory-action-toolkit.unocha.org/

[32] https://www.fao.org/3/cb7145en/cb7145en.pdf

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 unimodal rainfall regime with associated anticipatory actions. (Choularton, 2007) reported also 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 unimodal rainfall regime with selected anticipatory actions for drought. Source: (FAO, 2022)*

An additional method employed in scenario-building is the "augmentation or step scenario" approach. This approach delves into 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 finds utility in contingency planning, especially in contexts like displacement crises. In these situations, the number of individuals affected tends to increase progressively as the crisis unfolds.

In essence, the augmentation or step scenario anticipates and plans for the evolving dimensions of a crisis, reflecting the dynamic nature of its impact. Choularton's insights underscore that this method is particularly apt for scenarios where the crisis unfolds incrementally, resulting in a growing number of affected individuals. 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 well-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.

2.6.2. Assess useful risk information and impact scenario development

The risk scenario development is strongly interconnected with the identification of useful and already available risk information. The specific choice of information connected to the various risk components to be considered, as well as its optimal combination, depends on some preliminary considerations:

- When talking about risk information, there is not a choice that is optimal a priori; the proper risk information must fit the specific purpose of the study, and this is true also when dealing with risk information for EWS. The first source of risk information should be the available data that may need to be adapted in order to be suitable to the scope of EWS.
- From the field of application, it is important to delineate the potential early action that can and should be implemented. The possibility of implementing a specific action is linked to the ownership and accountability of the user/decision maker in reference to the connected decisions. The opportunity of implementing it depends instead on the needs of reducing impacts, and thus on risk conditions.

Impact scenarios development relies on a detailed and accurate evaluation of the hazards, historical impacts, as well as the analysis of the vulnerability, exposure and capacities of the elements in the geographic area that is being analysed in a certain time horizon.

Guiding questions might be:

- What are the values to protect according to the role and mandates of the decision makers?
- What is the potential user/decision maker and so the type of mitigation measures to activate?
- How information on risk components can help shaping measures?

Hereafter, the potential contributions of the specific risk components to define the reference scenario are examined – in accordance with standard risk assessment.

<u>Historical impact</u>

The examination of historical events serves as an essential initial phase in any risk analysis. It forms the indispensable foundation for risk identification, comprehension, and the refinement of models and risk assessments. Historical information plays a crucial role, particularly in early warning systems, as it provides valuable insights into the severity and repercussions of past hazards and incidents. This understanding aids in determining the requisite level of preparedness necessary to mitigate such events through timely actions and effective preparatory measures. By scrutinising historical data pertaining to analogous crises, valuable lessons can be extracted, facilitating a retrospective analysis that illuminates crisis escalation patterns and the efficacy of response measures. This retrospective analysis is integral for discerning the evolution of scenarios, identifying successful strategies, and pinpointing areas for improvement in terms of preparedness and proactive measures. However, the characteristics of historical events to be collected for the purpose of EWS implementation might be different from the ones essential for loss accounting or generic risk assessment modelling.

Key information on past events includes:

- the date of the past event, and its duration determined according to identifiable parameters;
- its location, including both the trigger location and the location of impacts to the best disaggregation level possible;
- its timing and evolution;
- its severity and frequency estimation in absolute terms according to objective and measurable parameters or in relative terms with respect to 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 the performances of EWS if any was in place.

The analysis of past events aids in prioritising the types of impacts that should be addressed during the preparedness and response phases, shedding light on those impacts amenable to avoidance or reduction through early action (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 traditionally did not consistently integrate hazard parameters alongside impact data, upcoming advancements in the tracking system for hazardous events, losses, and damages promise to enhance this linkage. The refinement of such systems will contribute to a more comprehensive understanding of the interplay between hazards and their resulting impacts, thereby fortifying preparedness and response strategies.

Two critical dimensions of historical disaster data collection, particularly for incorporation into Early Warning Systems (EWS). The first is the inclusion of the temporal dimension, which encompasses the evolution of events over time. While this temporal aspect might not be prioritised in applications like loss accounting or risk assessment, it holds immense significance for understanding the progression and dynamics of disasters. The second is the forensic dimension, which is pivotal for EWS applications, emphasising the cause-and-effect relationships of impacts, encompassing secondary and cascading effects. This dimension delves deeply into the intricate interplay of factors that contribute to disaster outcomes, offering valuable insights into the root causes and mechanisms behind the impacts experienced, thereby enriching the effectiveness of EWS and enhancing disaster preparedness and response strategies. 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 especially in terms of impacts. If a precise location of the impacts is available, it can facilitate the identification of specific critical hot spots that need to be monitored and managed through specific early actions. As an example, critical areas for flood risk can be subways, topographically depressed areas and/or areas with particular drainage difficulties (Fabi et al., 2021).

Past information can be invaluable for assessing vulnerability to specific hazards in both physical and socio-economic contexts. After a hazard event, conducting thorough assessments of the damage and impacts can provide valuable insights into the vulnerabilities exposed by 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 helps identify vulnerabilities that were exploited during the event, such as weak building structures, inadequate infrastructure, or ineffective emergency response systems.

Overall, debriefing after events involving the key actors of the EW-EA system might be crucial for identifying all these elements and including lessons learnt into planning, in a continuous process of improvement. This process allows planners to further tailor preparedness and response plans as well as to adapt early actions, also taking into account the community risk perception and the reaction of the entire system of actors to early warnings.

Hazard

Early actions should be built upon a deep understanding of the impending hazards. It is crucial to know where a hazard may occur (in terms of location and extent), its temporal characteristics (in terms of frequency, duration and season), what is the reference scale, its intensity and what is the probability of occurrence (IFRC, 2012). For this reason, all the above-mentioned characteristics should be explicitly described in the reference scenario. Depending on the methodology chosen to build the reference scenario, some of this information might be especially critical.

As an example, to create both worst-case and most likely scenarios for preparedness and early actions, it's crucial to have information about the probability of occurrence and access to hazard maps detailing intensity. If a timeline approach is followed, understanding factors such as hazard duration, frequency, and seasonality, often gleaned from historical event analysis, is essential for developing a timeline for crisis response, particularly for slow-onset hazards. This approach essentially relies on a seasonal hazards calendar, where hazard data are overlaid with impact data to inform the design of early interventions. Table 6 details some hazard information that are crucial for the reference scenario development within an EWS framework with an indication of why that information is considered essential.

Table 6 *: required hazard elements*

Hazard Information	Application
Hazard maps including intensity and specific hotspots	• Guide resource allocation for response and preparedness efforts and the scale of counteractions
Hazard duration, frequency and seasonality	• Support the understanding of the level of preparedness required • **Critical for building up the timeline crisis for designing early actions**
Hazard onset	• Define the duration of the potential window(s) of opportunity to take early actions. (See also Process 7)
Probability of occurrence	• Guide resource allocation for response and preparedness efforts and support the understanding of the level of preparedness required • Guides the prioritisation of early actions • **Critical for building up “worst case” and “most likely” scenario and/or a combination of them**
Schematic of compound and cascading effects	• Tailored 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, thus susceptible to potential losses. When analysing exposed elements for early actions and preparedness, the following key questions should be addressed:

- What are the primary targets of early actions, and consequently, what values need protection, including consideration of secondary impacts?
- Where are these targets located, and how many of them are there?

Anticipatory action aims to protect people and assets expected to be affected, thus highlighting the importance of assessing exposure, vulnerability, and capacity (ASEAN, 2022). In this context, it is essential to review risk information pertaining to various types of assets, critical infrastructure, services, businesses, and populations to establish protocols for minimising damage or loss upon issuance of a warning (adapted from Scaling up Early Warning Systems: Checklist for Gap Analysis).

During exposure analysis, it's important to recognize that certain types of assets may be considered as exposed elements, but also they can intervene as active assets in the response scenario. For instance, critical facilities such as strategic hospitals, healthcare facilities, and headquarters should be considered for:

- Planning tailored early actions to protect them, treating them as elements requiring safeguarding.
- Evaluating them as active assets (e.g., shelters) for preparedness and response, ensuring effective emergency management (see also Process 7). Assessing their value contributes to defining the overall capacity of the system.

In addition, the impact on some exposed elements could cause cascading effects – such as critical production plants, that could pose further hazard to the surrounding area in case of severe damages – or indirect effects on the population – such as the loss of agricultural production, leading to potential food security issues.

Understanding the dynamic aspect of exposure is crucial for effective Early Warning Systems (EWS). This involves recognizing population fluctuations throughout the day or across seasons, as well as those caused by underlying fragility conditions 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 for their elaboration are becoming more and more available. Remote Sensing is another source of data that can play a crucial role in capturing the dynamic nature of exposure. Satellite imagery and aerial photography can provide valuable insights into changes in land use, infrastructure, and population distribution over time (see e.g., the newly developed population distributions that are now characterised not only in space, but also 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.

A possible classification of exposure categories to be considered was elaborated starting from (Fabi et al., 2021).

- people and settlements: census of the resident population and estimate of the floating population considering migration; census of the people with fragility's conditions and disabilities; a list of residential settlements potentially affected by the phenomena;
- critical facilities: census of the strategic hospital and healthcare facilities (e.g. hospitals, nursing homes, clinics, health agencies), the headquarters of central and regional administrations, prefectures, provinces, town halls and barracks;
- areas of aggregation: census of relevant settings such as public buildings, public and private nurseries and schools of all levels, houses of worship, sports facilities and prisons;
- areas of cultural value: census of cultural heritage, museum centres, places of culture such as museums, archives and libraries; delimitation of historical centres and aggregates;
- economic activities: location of production and commercial facilities, with particular reference to shopping centres and medium to large production activities, farms and livestock farms, as well as kennels and catteries;
- location of facilities at risk of major accidents; location of dams and power plants, chemical plants;
- critical infrastructures: identification of mobility infrastructures and essential services (electricity, water, telephone, ports, airports, road network);
- assets relevant from the environmental standpoint: delimitation of green, wooded and protected areas.

The selection of exposure categories to be considered is closely tied to the role and responsibilities of the end user who will utilise the scenario, particularly concerning the early actions they can implement. It is essential to focus on categories directly or indirectly impacted by the user's early interventions. Similarly, spatial resolution and data disaggregation should align with the user's 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 health system at the district level might require insights into the system's potential damage during disasters, the status of transportation networks (for reaching health facilities), and the 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 proposes some guiding indications for users to link exposure elements with possible Early protection Actions, and helps evaluate them in terms of assets for preparedness and response, assets potentially leading to cascading effects and assets potentially leading to secondary impacts on population. As sometimes representation of exposure is strictly connected to vulnerability evaluation, some cross-references among the two different risk components could be present in the table.

Table 7 : Exposure elements, early actions and spatial dimensions

Exposure category	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	Evacuation, temporary relocation, relocation in shelters, auto-protection measures	NA	NA	NA	Residential population, number of households, touristic (or other) flows, presence of vulnerable groups (see next section)	Representation at building level (number of people per building), or at census/ district level
Settlements	Adjustments to 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 next 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)	Check of 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	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., cultural heritage sites)	Temporary relocation of movable elements; installation of temporary protection elements for the sites; evacuation of non-essential personnel			x	Typology of sites, typology and number of valuable elements (e.g., artworks), number and typology of non-movable elements	Single area identification
Critical infrastructures	Check of 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, Infrastructure level of functioning, number of potential users	Depending on the infrastructure typology, network representation, or single element representation
Production/ industrial sites	Evacuation of non-essential personnel, monitoring, installation of temporary protection elements		x		Site typology, possible presence of hazardous components, dimension of the site	Single site identification

Exposure category	Possible Early protection Actions (non-exhaustive list)	Assets for prepared ness and response	Assets potentially leading to cascading effects	Assets potentially leading to secondary impacts on population	Indicators for exposure quantification	Representation of spatial distribution
Agriculture production areas	Anticipation of seeding or harvesting periods, storage of extra seeds for replanting, livestock evacuation			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
Permanent protection assets (e.g., levee for floods or rockfall nets)	Monitoring, strengthening of the assets (e.g., placing sandbags close to the levees)		x		Typology of asset	Single element identification (point or linear)

Vulnerability

A further step in the definition and planning of early actions is the characterization of assets in terms of vulnerability, that can describe and measure the susceptibility of an individual, a community, assets, or systems to the impacts of hazards (adapted from UNDRR terminology, 2017). Even if vulnerability is a complex concept, and there is no agreement among different sectors on its operational definition, in the context of DRR usually it is described from two main points of view, namely physical vulnerability and social vulnerability. Both are key elements for the prioritisation of early actions; in fact, the vulnerability component can help in differentiating – among single assets categories – the specific assets on which the intervention is at most needed (or urgent). For instance, when defining where to place temporary flood protection measures for settlements, the choice can be made taking into account both physical vulnerability – e.g., giving priority to those settlements that have low resistance construction typology – and to social vulnerability – e.g., giving priority to settlements with a high presence of elderly people, who could be incapacitated to evacuate in short time if needed.

In addition, the characterization of vulnerability can help in the design of specific interventions. The differentiation of population according to marginalised or vulnerable groups could help in the definition of specific needs, and thus in the identification of specific actions to be implemented; for instance, one could define communication actions for the generic population, but identify the need for multilingual messages when a linguistic minority is present.

In general, for planning early action it is crucial to evaluate the factors that contribute to the vulnerability of each exposed element. Table 8 categorises the factors contributing to vulnerability into four main categories: People, Infrastructure, Economic Activities, and Environment. Under each category, a non-exhaustive list of specific factors related to vulnerability is specified.

Table 8 : factors contributing to the vulnerability of exposed elements

Category	e.g. of factors
People	Age, Gender, Disabilities, Legal status (e.g., migrant worker vs national/permanent residents), Socio-economic status, Access to services
Infrastructure	Design considerations, Construction period, Maintenance, Number of floors
Economic Activities	Level of dependence on vulnerable infrastructure or location, Diversification of economic sectors
Environment	Fragility of ecosystems and species

It is important to highlight that vulnerability analysis can be as detailed and as comprehensive as required. The amount of detail in the vulnerability analysis and the assessment methodology itself depends on the time and resources available to gather and keep data updated (Adapted from IFRC, 2012b), and on the scale of the early action to be taken. It is crucial that the information is regularly updated and of good quality. The vulnerability might be expressed through qualitative and/or quantitative indicators in the case of early actions at regional or national scale.

For instance, the use of the INFORM Risk indicators relevant to vulnerability could be a suitable choice when working at regional level, to have the comparison of the potential effects of large-scale events on different countries. Similar indicators, but defined based on sub-national information, should be adopted for a user working at national scale, while a deeper and georeferenced analysis would be required for early action to be carried out at local level. As an example, at the national level poverty analysis can be used to define hotspot areas even if the hazard is relatively uniform, or when the local level is considered the composition of the households, and their characteristics can help planners in designing evacuation strategies or designing shelters.

Index-based approaches are the ones normally employed to characterise socio-economic aspects of vulnerability and they are normally able to condense complex information into easily understandable indices, facilitating communication and decision-making. They are often able to provide quantitative measures of vulnerability at least in relative terms, allowing for comparisons across different regions or time periods and often employ standardised methodologies, enabling consistent assessments and benchmarking. On the other side 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 they might involve a certain degree of subjectivity in the selection of indicators and weighting schemes in index construction, which may 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 preparedness and response 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 early action.

When it comes to community capacities, the level of 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. Early actions 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 early warnings, will be better equipped to handle a hazard than one that lacks awareness of local risks. This understanding also shapes the approach to designing early actions. For instance, in areas with low community capacity, early evacuation measures might need to be initiated at the first signs of flood precursors.

When considering institutional and organisational capacities, planners must ensure that early actions align with the resources and capabilities available. This is a key challenge highlighted by Tozier de la Poterie et al. (2023). If the necessary capacities for early action cannot be sustained, it may be necessary to develop more flexible, less technical anticipatory action systems that reduce barriers to implementation. Additionally, if local actors alone cannot manage the risk and its associated early actions, 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 about institutional and governance capacities and resources is crucial for identifying weaknesses, gaps, and opportunities for optimization. This capacity analysis process can also be strategically used to identify areas for capacity enhancement to meet anticipated needs during potential disasters (Adapted from IFRC, 2012b).

For collecting vulnerability and capacity information several methodologies and tools can be utilised, including questionnaires, interviews, meetings or surveys. In this regard, especially at the local level, it is worth mentioning the Enhanced Vulnerability and Capacity Assessment (VCA)[33] method used by IFRC and providing an extensive set of resources for undertaking this exercise. In addition, to review gaps and strengths of institutional preparedness capacities, IFRC developed the Preparedness for Effective response framework which could also be helpful for other organisations and governments to explore their response preparedness system holistically.

Guiding questions for scenario development

In synthesis, the development of the reference scenario is a complex process that cannot be seen separated from the specific user and from the early actions that he/she can put in place. Moreover, the scenario's utility hinges on its seamless integration with a forecast, necessitating careful consideration of this aspect throughout the development process. To aid readers, a practical series of step-by-step questions is provided, tailored to the specific user's needs for the scenario in the table 9. These questions centre on leveraging existing risk information pertinent to the area of interest. The integration with the forecast will be further 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's goals, and the possible related early actions)	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 early actions	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 early actions? (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

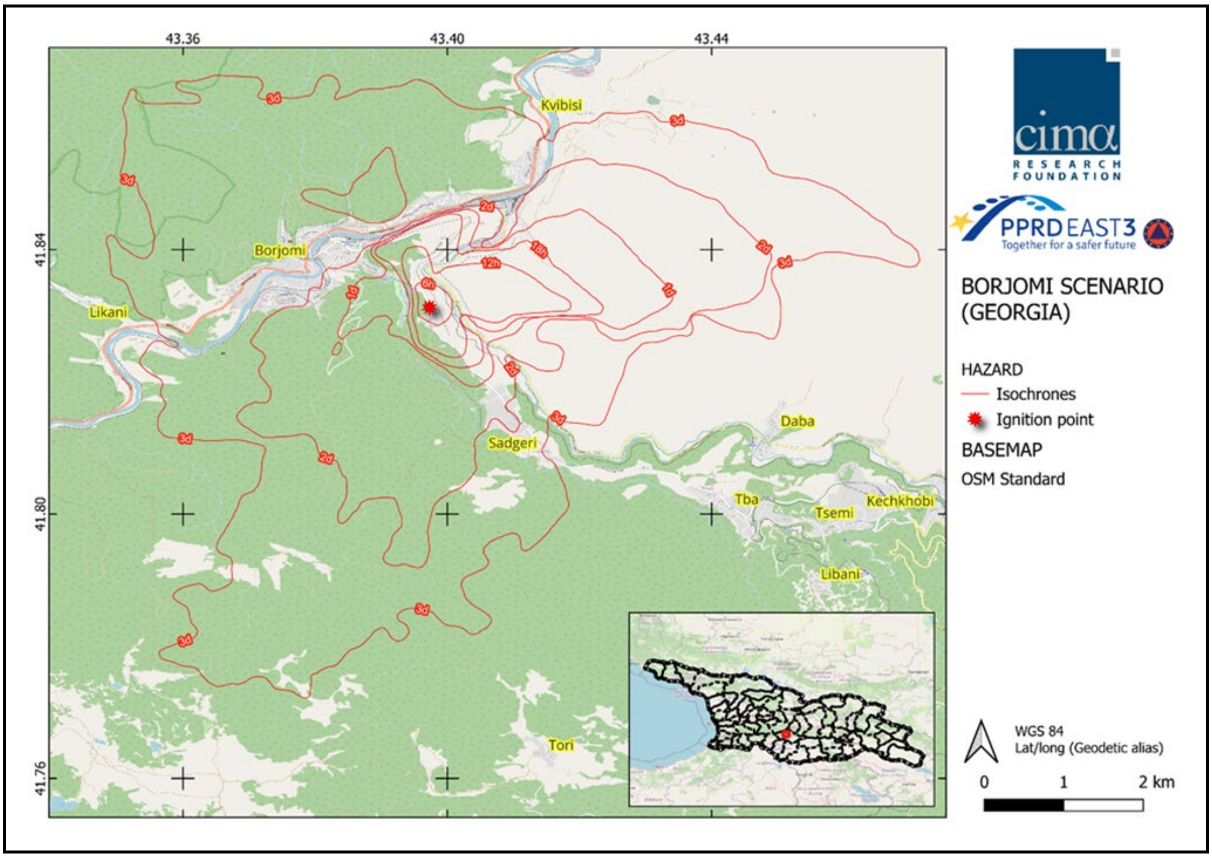
The questions in the table should be the basis for defining some practical outputs, useful to support the early action planning, and to be shaped according to the specific user and the chosen typology of scenario:

33 https://www.ifrcvca.org/

- Maps showing the expected spatial distribution of major hazards. The different hazards and intensities should be presented in separate maps.
- The spatial distribution of all exposed elements that need to be protected - such as population, infrastructures, naturally protected areas etc. Separate maps for different elements can be prepared and combined using Geographical Information Systems.
- The 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).
- These elements provide the basis for the preparation of prioritisation maps combining likelihood and impact of a single or aggregated hazard.
- If relevant for the specific scenario type, a timeline of the potential events and effects; it is important to guarantee the possibility to link the components identified in the timeline with the different spatial distributions described by the previous maps.

In the case the risk analysis refers to community-based EWS, outputs should also encompass the perception of risk and community early warning and early action systems, and identification of key local/community leaders as key stakeholders in times of early warning.

An example of output of this process is reported in Figure 9. They have been delivered within PPRD East 3 programme[34] for a pilot case in Georgia and represent some of the outputs from the development of a worst-case scenario related to wildfire in a pilot case.



[34] https://www.pprdeast3.eu/

DAYS	HOURS	ISO ISOCHRONES	ENVIRONMENT	RESIDENTIAL	PEOPLE	ROADS	POINTS OF INTEREST
1st day - Friday	20:00	0 h	Fire starts after a multiple explosion in a camping in the mountain area around Borjomi				
	02:00	6 h	+5 ha forested area	+1 ha low residential area around Borjomi	+9 persons	+680 m tertiary road (ბორჯომი-ბალი-ტბა-ცემი - Borjomi) +350m railroad – Borjomi	+1 cafè +1 campsite
	08:00	12 h	+25 ha forested area		+134 persons	+1200 m secondary road (თორის ქუჩა - Borjomi) +1200 m tertiary road (ბორჯომი-ბალი-ტბა-ცემი - Borjomi) +1100m 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 ბორჯომის ცენტრალური პარკი	+1 ha low residential area around Borjomi	+255 persons	+450 m secondary road (თორის ქუჩა - Borjomi) +1500 m tertiary road (ბორჯომი-ბალი-ტბა-ცემი - Borjomi) +200m tertiary road (პლატოს აღმართი- Borjomi) +1000m railroad	

Figure 9: Example of a risk scenario development.

More specifically, it includes:

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

For further details on risk scenario choice and development and for examples, please see:

- Choularton, R.: Contingency planning and humanitarian action: a review of practice, 2007.
- IFRC: Contingency planning guide, Geneva, 2012b. Available at: https://www.ifrc.org/document/contingency-planning-guide
- IFRC: IFRC Contingency Plan supporting document. Available at: https://preparecenter.org/resource/contingency-planning-guidance/
- FAO: FAO elearning on Building a crisis timeline Version 1. Available at: https://elearning.fao.org/course/view.php?id=884
- Enhanced Vulnerability and Capacity Assessment (EVCA). Available at: https://www.ifrcvca.org/how-to-do-evca
- UNICEF: Children's Climate risk Index-Disaster Risk Model CCRI-DRM. Available at: https://www.unicef.org/documents/CCRI-DRM
- Guidance Note on Using the Probabilistic Country Risk Profiles for Disaster Risk Management, CIMA Research Foundation - 2020 International Centre on Environmental Monitoring. Available at: https://www.undrr.org/publication/guidance-note-using-probabilistic-country-risk-profiles-disaster-risk-management

3. Risk information for monitoring and forecasting (Pillar 2)

In essence, an Early Warning System (EWS) constitutes a well-defined workflow facilitating the anticipation of potential impacts on target values, encapsulated within a scenario. The objective is to communicate this scenario promptly and effectively to institutions and individuals, empowering them to take organised preventive and mitigative actions against the foreseen effects.
The ability to forecast and monitor such scenarios is a critical element of EWS, emphasising the importance of establishing a clear link between warnings and associated impact scenarios (Harrison et al., 2022), (IFRC, 2020). The World Meteorological Organization (WMO) distinctly outlines three paradigms commonly employed in EWS implementation and related to the specific content of the warnings that are issued:

- Paradigm 1 – Weather forecasts and warnings (hazard only):
  This paradigm 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”)
- Paradigm 2 – Impact-based forecasts and warnings (IBF, hazards and vulnerability):
  These forecasts and warnings aim to articulate the expected impacts resulting from anticipated weather conditions. Usually, impact-based warnings 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”),
- Paradigm 3 – Impact forecasts and warnings (hazard, vulnerability, and exposure):
  This paradigm delves into the provision of detailed and specific impact information at individual, activity, or community levels.[35] 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 considered 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, it is crucial to underscore that 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 discussed 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 does risk Information support hazard-based monitoring and warning? (Paradigm 1)
- Process 2 - How to produce risk-informed warnings that include relevant and actionable risk information? (Paradigm 2)
- Process 3 - How to use risk information to build technically sound impact forecasts? (Paradigm 3)

[35] Adapted from UNDRR 2023: Words Into Action: A Guide To Multi-Hazard Early Warning Systems

3.1. Process 1 - How does risk Information support hazard-based monitoring and warning?

Monitoring and forecasting variables that exhibit correlation with ground-level impacts are pivotal components of an effective early warning system. 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 aids in comprehending 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 unfolds across three key steps, briefly outlined in the following, with a specific focus on the role of risk information:

1. Identify a variable suitable as a predictor for the considered hazard.
2. Identify the source of information for the considered variable.
3. Identify hazard thresholds coherent with the monitored variable and the potential impacts.

The integration of risk information within these three key steps enhances the scientific robustness of early warning systems, 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 early warning 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 foreseen to exceed predefined threshold levels within the temporal range of interest. The choice of the representative variable (or set of variables) should be driven by the knowledge of the driving processes that determine hazard and risk conditions in a specific climatic, morphologic, socio-economic context, as well as by data availability.
Table 10 provides a non-exhaustive list of dynamic variables commonly used as predictors of different natural hazards, indicating also 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 km^2	Few hours to weeks
Flash flooding	Precipitation, soil moisture, river discharge, probability of precipitation / discharge, runoff index	few to hundreds km^2	Minutes to few hours
Coastal flooding	Total water level, wave height, recurrence interval of storm surge/wave height	few to thousands km^2	Few hours to weeks
Pluvial flooding	Precipitation, soil moisture	few to tenths km^2	up to 12 hours
Meteorological drought	Standardised Precipitation Evapotranspiration Index (SPEI), Standardised Precipitation Index (SPI) (Merz et al., 2020)	hundreds to several thousands km^2	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 km^2	days to 1 year
Agricultural/vegetation drought	FAPAR, Combined Drought Index (CDI)[36], Evapotranspiration (ET), Normalized Difference Vegetation Index (NDVI), Vegetation Health Index (VHI)	hundreds to several thousands km^2	1 month to 1 year
Tropical cyclones / Extratropical windstorms	Wind speed,wind gust, precipitation, storm surge	tenths to thousands km^2	few hours to 1 week
Avalanches	Composite indicators (e.g. avalanche danger scale[37])	few km^2	few seconds (hazard signs up to days)
Heat/cold waves	Air temperature,relative humidity	hundreds to several thousands km^2	few days up to 2 weeks
Forest fires	Composite indicators[38]	few to hundreds km^2	up to few hours
Landslides	Precipitation, snow melt. soil moisture anomaly	few km^2	few seconds to minutes (hazard sign up to days)

In this integral process, the analysis of historical disaster events and risk models are crucial in discerning the critical variables that exhibit correlation with the severity and impact of a specific hazard. As an example, in several river basins in Europe, snow melt 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, Early Warning Systems can extend their predictive capabilities and provide a longer window of opportunity to put in place adequate actions. Communities can benefit from a more proactive response, allowing for e.g. orderly evacuations and strategic allocation of resources well in advance of the hazard's impact (see examples related to Process 8). Also, more information on past severe events enables assessing the uncertainty in hazard-impact links, which is crucial to find an appropriate tradeoff between accuracy and early information.

In addition to the causal relationship between hazard predictor and impact that can be derived from the historical analysis, the choice of the dynamic variable used for hazard detection is influenced by several additional factors. Priority should be given to variables having the following characteristics:

- Seamless availability within the area of interest (e.g., national or regional level) with spatial resolution adequate to characterise its spatial extremes (see for instance WMO recommendations on the density of monitoring networks).
- Uninterrupted temporal availability, with temporal resolution adequate to characterise its temporal extremes and derive hazard thresholds (e.g., long enough historical record to analyse the variable climatology and its relations with historical events with impacts). Importantly, available information on historical extreme events should be leveraged to

[36] https://edo.jrc.ec.europa.eu/documents/factsheets/factsheet_combinedDroughtIndicator.pdf
[37] https://www.avalanches.org/standards/avalanche-danger-scale/
[38] https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports

extend measured records and increase the knowledge of conditions leading to impacts. For instance, 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 early actions in the endangered regions. This implies, for instance, accurate selection of the 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 considered variable

The constraints listed above determine which source of information can be used, or is more appropriate, to infer predictor variables for the hazards of interest. Essentially, the distinction is 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)[39] model output, NWP-derived variables are key candidates for use in monitoring and forecasting several hazard processes (see WMO, 2023). Some output variables (e.g. temperature, precipitation, wind speed and direction) can be directly compared with hazard thresholds to estimate the hazard levels (e.g., for pluvial flooding, windstorms, cold waves), while for other hazards these are used as input to computer models and processing tools to generate the desired variable (e.g., to obtain river discharge, inundated area, combined drought index, soil moisture).
Thanks to the NWP, most weather-related hazards have consolidated procedures to detect upcoming extreme events with sufficient lead time to inform decision makers and implement early action and warning of people at risk. However, hazards that are also strongly related to ground and land use conditions (e.g. landslides and avalanches, but also wildfires) have larger forecast uncertainty, especially regarding the precise timing and magnitude of upcoming events.
Some hazard types are typically detected on the basis of observed rather than forecast variables. This can occur:

1. when impacts take place with a sufficient delay after the observation, which guarantee enough time to issue early warning messages, or
2. when the forecast variables for the considered hazard are nonexistent, have poor skill or are highly uncertain.

Examples of the first category are riverine flooding in the downstream sections of large rivers where the risk of inundation can be accurately predicted from the propagation of flood waves originating upstream, or slow onset hazard such as droughts that develop over time periods that enable effective action based on observations. Relevant examples for the second category are coastal flooding triggered by tsunamis, earthquakes and volcanic activity. As an example, 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).

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[39] 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).

The choice of the most appropriate source of information is not only guided by the physical processes determining the hazard, but also the window of opportunity determined by the actions to be put in place as a function of the impact and risk conditions analysed in the reference risk scenario (see Process 0).

3.1.3. Identify hazard thresholds

Establishing threshold values aligned with the monitored variable is a key aspect. This step involves defining levels at which the variable's values are linked to an impending hazard, emphasising the importance of risk information in this determination.
Once the variable identified as a predictor is established, the next critical step involves defining hazard thresholds that serve as the foundation for issuing timely warnings. Hazard thresholds represent a set of values associated with observed/forecasted variables, effectively distinguishing between normal conditions and escalating levels of hazard conditions that can be linked to impacts on the territory. These thresholds are inherently specific to each geographical location and should be periodically reassessed, especially in response to climate variations or human interventions that might alter risk conditions (e.g. the construction of a dam upstream a river section, or construction of a road over a slope at risk of instability).
Deriving hazard thresholds is a nuanced process, and various methods can be employed:

1. literature values: Drawing from 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) in the area of interest or in areas that present similar characteristics to the one object of the study. For instance, the flood decision support system of the Vaisigano River in Samoa (Williams et al., 2021) uses rainfall thresholds developed for nearby islands fo Western Samoa, due to the absence of local time series.
2. reference values from past major events: using reference values obtained from observations during past significant events. This approach offers practical insights into the historic performance of the variable under extreme conditions. However, measurements during extreme events might be highly uncertain (e.g. failure or malfunctioning of wind/discharge gauges) and vulnerability and/or exposure conditions may have changed, thus altering the level of hazard causing impacts. Therefore, an attentive analysis considering all these factors should be always put in place. As an example, the National Meteorological Service of Argentina has developed its heatwave EWS based on a detailed study of the health impacts of the heat wave that hit Argentina in 2013-2014 (https://www.smn.gob.ar/smn_alertas/olas_de_calor).
3. long-term statistics: Employing 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 the associated risks, providing a robust foundation for threshold determination.Cautions similar to the ones discussed in the previous bullet point should be considered such as varying exposure and vulnerability conditions.

The choice of the methodology depends on the specific context, data availability, and the nature of the hazard being considered. While all methodologies offer valuable insights, the use of literature values alone (1) should be kept only if no information about the local conditions of the area analysed are available. The relations between hazard and impacts can be complex and are connected with local conditions, therefore the use of generic threshold values might end up in systematic biases outside the regions where such values were derived. The use of reference values from past events (2) has the advantage of being grounded on concrete experience (easy to communicate), but has downsides: i) worst scenarios might not have occurred yet; ii) past conditions that led to recorded events might have substantially 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 (3) can be widely applied up to global contexts as it relies on analysis of the hazard statistics as observed or produced by the model used for the forecast (see e.g., the GloFAS system[40] for riverine floods and the review by Guzzetti et al., 2020, for landslides). However, it often relies on an analysis of past events only and implies a relation between the hazard severity and the expected impacts that could be sensibly different 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 (see e.g., Rossi et al., 2023). Furthermore, the risk modelling approach 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 the other methods.

Defining the hazard level identified as the maximum threshold exceeded in the period of interest is a common practice. Usually, 3 or 4 hazard classes are considered, as shown in the review by Neußner (2021). The period of interest depends on several factors, such as the type of hazard, the preparedness of the population, the capacity of the emergency system, as well as on the actions that can be put in place (see Process 0 and Process 7). For instance, the period of interest is typically the subsequent 1-2 days for national civil protection agencies, but it can extend to longer time windows, particularly for existing hazards with large impacts foreseen in the future (e.g., tropical cyclones, river flooding in large rivers).
The quantification of the hazard uncertainty is key to achieve an accurate identification of the hazard class. Several sources of uncertainty can affect the prediction, depending on the variable of interest, including uncertainty in the initial conditions, in the modelling processes, in the input data, and the uncertainty due to spatial and temporal sampling. Here, the availability of risk-based information is crucial to quantify the different components of uncertainty. For instance, the forecast uncertainty due to NWP is usually accounted for by considering a range of possible predicted scenarios, through probabilistic or ensemble forecasts (e.g., Cloke and Pappenberger, 2009). Furthermore, information about past damaging events might help in finding the best compromise between minimising uncertainty while maximising lead time.
Setting thresholds should be done in view of the operational assessment of threshold exceedances within the desired range of interest to identify potential hazards. This additional step involves a continuous assessment of data and relies on risk information to identify hazards potentially leading to impacts and trigger timely warnings.

3.1.4. Clarifying examples / References to existing literature

The IFRC Anticipation Hub provides a repository of country-level examples of trigger system for Early action, describing how hazard thresholds were defined using risk information (https://www.anticipation-hub.org/experience/triggers/trigger-database). For instance, the Ecuadorian Red Cross has created an early action protocol for extreme rainfall related to the El Niño phenomenon along the coast of Ecuador[41]. It is a tool to guide the timely and effective implementation of early actions which are triggered by a range of weather forecasts. The plan was designed with technical contributions from several national and regional institutions. Selection of rainfall thresholds (and related early actions) is based on the experience gained

[40] https://www.globalfloods.eu/
[41] https://reliefweb.int/report/ecuador/ecuador-extreme-rainfall-related-el-ni-o-phenomenon-early-action-protocol-summary

by national entities and Ecuadorian Red Cross from historical response 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)[42] and ground data to evaluate drought-induced crop failures, and inform the Inter-Ministerial monthly integrated multi-hazard early warning bulletin (news) (https://www.necoc.opm.go.ug/bulletins.php), to activate disaster risk finance. For instance, the Ugandan government can estimate how much to invest in public works to provide additional employment opportunities for vulnerable communities and to calculate the number of households affected by drought, the estimated coverage of the social safety net programme, and the estimated costs for each district[43].

3.2. Process 2 - How to produce risk-informed warnings that include relevant and actionable risk information?

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 have proven effective to some extent, there is a growing acceptance of the need to transition towards impact-based warnings. 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).

1. Identify impact indicators coherent with the considered hazard (see Process 1).
2. Identify data and methods for the considered indicator(s)
3. Identify relevant impact thresholds to classify the warning severity

According to WMO (2015), Impact-based warnings (IBW) are designed to express the expected impacts resulting from hazardous weather conditions. This is done by combining hazard forecast and monitoring (see Process 1) with information on the vulnerability of population, vehicles, buildings, critical infrastructures, crops, and in general all elements 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 modelling of all relevant processes related to potential impacts (see Process 3 for details). In case detailed impact forecasts are not available, impact-based information can be derived by linking forecasted hazard conditions with reference risk scenarios (see Process 0). As such, impact-based warnings generally provide a qualitative description of expected impacts from forecasted hazardous conditions, based on generic vulnerability models. The goal, as in all EWSs, is to minimise impacts by enabling the triggering of early action.

3.2.1. Identify impact indicators coherent with the considered hazard

The process of identifying relevant impact indicators should always start from the examination of the risk information available from reference scenario(s) and historical events. A good starting point is the IFRC guide for impact-based forecasting which provides an exhaustive list of possible impacts for each hazard (IFRC, 2020). The examination should include past

[42] https://glam.nasaharvest.org/

[43] https://earth-observation-risk-toolkit-undrr.hub.arcgis.com/pages/drought-early-warning-in-uganda

experiences of emergency management stakeholders on the ground, impact information from national repositories (e.g., DesInventar (https://www.desinventar.net/) as well as other relevant sources to understand the impacts on the local communities lives and livelihoods.
Common indicators used to trigger impact warnings are related to population, given that a crucial 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 the impending hazard(s). Other important indicators regard the potential impacts on transport networks, roads in particular (e.g. the possibility of flooding of underway crossings, falling of debris/tree branches over roads) which are often connected with risk conditions for people or heavy secondary impacts on society. The choice of impact indicators should be guided not only by data availability, but also by the information that will be included in warning production and dissemination (i.e., different end-users might want to receive different information, see process 5 for more details), 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 wide 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 also in impact-based warnings to assess potential impacts of forecasted hazard conditions. It is recommended that vulnerability models that are used for risk profiling and ultimately for determining the reference risk scenario are consistently used also in the construction of the warning to be delivered.
As an example, vulnerability methods are applied to evaluate the following impacts:
for population:

- 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 instance, the South Africa Weather Service has implemented an impact-based warning and advisory service that provides information on potential impacts due to severe weather conditions[44]. 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[45] and on tropical cyclone warnings in Malawi[46].

3.2.3. Identify relevant thresholds to classify the warning severity

Impact-based warning classes are established using specific thresholds that delineate various levels of anticipated impacts. It's important to recognize that these thresholds are tied to forecasted or monitored hazard variables and should align with those identified through

[44] https://www.weathersa.co.za/home/warnings
[45] https://reliefweb.int/report/papua-new-guinea/early-warning-system-drought-implemented-png-crews
[46] https://www.metmalawi.gov.mw/

process 1. In process 1, vulnerability and exposure elements are indirectly factored in by establishing hazard thresholds connected to potential impacts in the area through analogy. Conversely, in process 2, these elements are explicitly considered and contribute to determining the thresholds.

In instances where hazard thresholds are not appropriately linked to contextual impacts, disparities may arise between the thresholds identified in the two processes and thresholds might be distinct from those used to define hazard levels in process 1. This discrepancy emerges because impact-based warnings integrate information about exposure and vulnerability alongside the hazard itself. For example, a hazard with the highest severity level might not lead to significant impacts and, consequently, no issuance of warnings 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:

- beginning of impacts: condition when localised impacts may begin occurring in the area of interest (e.g. flooding of roads or buildings)
- significant/severe impacts: conditions when impacts can extend over a large part of the area of interest, and/or when local impacts become severe
- extreme impacts: conditions 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 the warning level involves not only assessing forecasted disaster impacts but also considering prediction uncertainty or the likelihood of occurrence (Figure 10). Ideally, this uncertainty should be evaluated through 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. The expertise of forecasters and disaster managers plays a crucial role during this phase. Their 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. 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 (see Processes 7-8). For instance, the UK Environment Agency makes use of two sets of thresholds; operational thresholds, which are linked to an action (e.g. issuing a warning) and impact thresholds, which are linked to an impact, for example 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 for the effect of the 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).

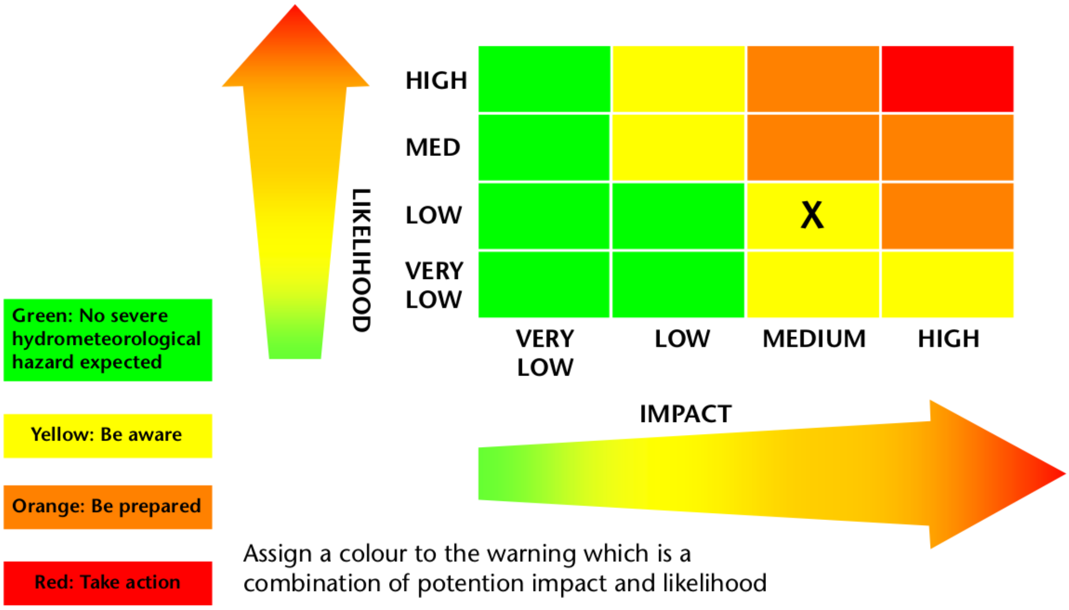

Figure 10*: Example of colour-coded risk matrix to derive the severity of warnings. Source: UK Met Office.*

<u>Examples of good practices:</u>

In Indonesia, the BMKG (Meteorology, Climatology, and Geophysical Agency) and BNPB (Indonesian National Board for Disaster Management) have jointly developed the System for Multi Generation Weather Model Analysis And Impact Forecast (Signature[47]), using a national-scale database DIBI (https://dibi.bnpb.go.id/) to produce and calibrate impact-based forecasts for different hydrometeorological hazards (floods, landslides, land & forest fires, severe weather such as heavy rain).
Within the Africa Multi-hazard Early Warning and Action System (AMHEWAS), twice per 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 activation of the Continental Situation Room and Anticipatory Action meetings to coordinate efforts among the key institutes involved in disaster response at the continental, regional and national level.

3.3. Process 3 - How to use risk information to build technically sound impact forecasts?

Transitioning to impact forecasting is important because 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. This process can be complex because of the

[47] https://signature.bmkg.go.id/

articulated nature of the models to be put in place and the large 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 need to be adapted for impact/risk evaluations in real time.
To accomplish this, 3 key steps can be identified.

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

Impact forecasts and warning services extend standard forecasts of hazard characteristics (intensity, duration, and spatial extent) by estimating the expected impacts on the elements potentially affected, including information on their exposure, vulnerability and coping capacity (Figure 11). Warnings based on impact forecasts are also an enhancement from impact-based warnings in that they can provide quantitative information on impacts and identify specific elements at risk.
In the following, the basic steps to produce impact forecasts are described, including suggestions to derive IBF from impact forecasts, as part of the steps for production and dissemination of risk-based warnings.

3.3.1. Identify indicators of exposure and vulnerability

Setting up an impact forecasting system requires the availability of accurate exposure and vulnerability datasets. These datasets are also crucial to identify relevant indicators for triggering impact warnings.

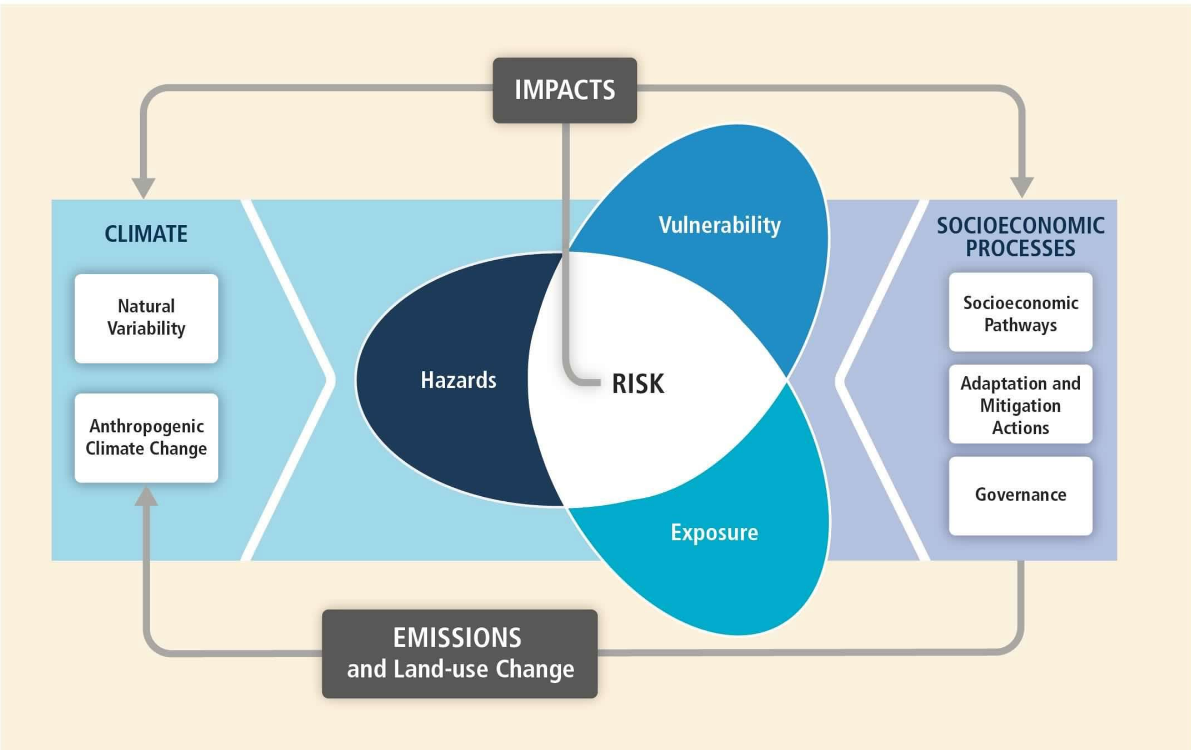

Figure 11*: The IPCC AR5 conceptual risk assessment framework* (IPCC, 2014).

The analysis of reference risk scenarios, as well as quantitative information on past weather-related impacts, are extremely helpful to identify appropriate indicators for determining the severity of an event. Quantifiable variables related to population, such as the number of people affected by an upcoming hazard, often serves as a key indicator for determining the severity of a disaster, hence warning thresholds can be defined as specific values of people affected corresponding to increasing emergency conditions and response capacity needed to cope with the situation. The expected impacts on people can also be assessed in terms of estimated individuals displaced, or estimated number of victims, although such indicators are more complex to forecast. Other important indicators regard impacts on transport networks, roads in particular (e.g., the 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 the relevant 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 is in use in the Greater Horn of Africa, where relative impacts on population are used to better understand regional priorities for humanitarian interventions (Alfieri et al., 2024).

The choice of impact indicators should be guided also by the information that will be included in warning production and dissemination. Furthermore, the indicators should be suitable for continuous update, 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, and the indicator is 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 the datasets collected and applied in the risk analysis processes. Similarly important is the availability of data and methods for characterising vulnerability and quantifying potential impacts (as discussed in Process 2). Exposure data should account for specific cases such as informal settlements (e.g., refugee camps etc) which are usually not mapped in standard statistics and may need dedicated mapping activity, also motivated by 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 forecast 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 or complete loss of crop yield). Impacts on population are usually 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 for floods, heat strokes for heat waves etc). As already outlined for Pillar 2 (Section 4.2), the methods applied for characterising vulnerability in risk scenarios are usually applicable also to 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 they are rarely explicitly accounted for in EWS, indirect impacts can take on a large proportion of the total impacts, have longer lasting effects, and affect 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 further impacts due

to service disruptions. Although this is rarely possible to be explicitly included in the impact computations in real time, the impact forecast can be augmented by reference scenarios that can be built off line and that include secondary and cascading effects that could be experienced in the area of interest. 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 presents an opportunity to include 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). Therefore, impact chains can be studied offline and properly referred to in the warning messages (see Rossi et al., 2023[48], 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 related thresholds (based on exposure and vulnerability indicators) to produce risk-informed alerts (see also Process 2) and select preparedness actions (Processes 7 and 8). In the case of impact-based forecasts, the quantitative information calculated from impact models may be synthesised to create simple and concise risk-based warnings, aimed at specific end-users. Here, the use of dynamic risk information (e.g. including historical and recent events, as well as 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 in the areas potentially affected. Also, impact thresholds need to be periodically reviewed to account for changes in coping capacity and for the effect of the risk reduction measures (e.g. improved water management practices against severe droughts, flood barriers and flood storage areas, see Processes 7 and 8). EWS themselves, when enabling early action, are an effective adaptation measure and contribute to reducing exposure and vulnerability to disasters (Pappenberger et al., 2015).

Example of good practices :

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

Integrating flood hazard data with risk assessments available at 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 straightforward visualizations to facilitate understanding among end-users, empowering them to proactively 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

[48] 53. 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.

and Meteorology. This adaptability allows BIPAD to quantify the potential impact levels associated with flood warnings having different, 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.

How to include ILK into monitoring and forecasting ?

Local populations have extensive knowledge on the early signs in their environment leading to natural hazards. Local communities and players/institutions are therefore generating 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 have sophisticated techniques to forecast flood and heavy rainfalls, producing information adapted to the local context, using triangulation 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 forecasts 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 methods to use local knowledge in EWS, such as how to generate input maps for validation or strengthening of forecasting models, or to support appropriate scientific variables inclusion in models.
- Sharing knowledge on the benefits and needs of combining modern and local knowledge to predict hazards[49]

CONSULT

- Consult to understand the local knowledge system in place for hazard monitoring and forecasting through Key informant interviews (KII) at different levels from local knowledge holders, community leaders to local disaster management council members ;
- Consult communities to reference the local knowledge on the precursor signs leading to a specific hazard through focus group discussion (FGD). For example, in Malawi (Trogrlić et al., 2019) or in Zimbabwe (Dube and Munsaka, 2018) the knowledge of communities on flood early warning indicators is extremely rich and could inform scientific knowledge; For instance, 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)
- Consulting the local practitioners/experts. An example is the process of Climate Outlook Fora, where at regional level, such as with SARCOF, scientific forecasts are discussed with national/local level experts and downscaling takes place (https://www.clivar.org/panels-and-working-groups/africa/rcofs).

[49] https://www.climatecentre.org/scrollies/netherlands-red-cross/uganda/

INVOLVE

- Involve local communities in monitoring hazards, reporting environmental variables through crowdsourcing, for instance in community-based river water level monitoring activities. Examples of the use of WhatsApp or Telegram by community disaster management committees or local volunteers can be found 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. Examples of good practices for participatory modelling applied to urban flood management in Dar es Salam, Tanzania are presented by Gebremedhin et al., 2020.
- Involve local knowledge holders in the definition of impact thresholds (UNISDR, 2015), and local decision makers to correctly weigh in ILK to fit local contexts. 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 to a hazard should be entirely integrated in the process of identifying final 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).

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

The dissemination and communication of warnings should take into consideration key questions to ensure that the warnings are useful in informing preparedness. For example, how to ensure the warning reaches the at-risk population as well as if the warning is clear, understandable, and useful depending on the context of the intended users. In most cases, the effectiveness of the warning may be subject to a series of behaviour changes from the warning being noticed, understood, considered, trusted, confirmation and then action (Molinari and Handmer, 2011).The first chain of dissemination and communication comes from the hydrometeorological authorities who issue warnings related to weather variables and in some cases impact-based warnings. Once these warnings are issued, the other government actors (e.g., Disaster management authorities, civil protection etc) and sector specific authorities (agriculture, health, infrastructure) are required to coordinate with the hydrometeorological authorities to define context-specific warnings that clearly articulate the target audience and are specific on the timing and location of the hazard (WMO, 2021). In addition, the right communication channels should be identified from among the known conventional ones (phones, print media, informal gatherings, sirens among others).

Although this pillar requires coordinated and collaborative effort, the authority mandated through legal structures to issue the warnings to the population should remain so to avoid confusion and lack of trust from the recipients of the warning information. The role of other intermediary and boundary organisations in the communication of warnings should be taken into consideration as involving them ensures trust and uptake of the warning information by the recipients[50]. In addition, depending on the legal frameworks in place, the warning stages could be more than one based on the lead time and severity of the impending event.

Across the chain of communication and dissemination of warning messages, risk information should be considered to improve the various steps taken.

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

Risk information	**Possible sources**
Demographics information 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 used, community perception to risks and warnings, impacts	Community engagement and participatory approaches studies, 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/design warnings that are clear and understood.

[50] https://www.510.global/effectiveness-of-drought-warning-communication-dissemination-in-malawi/

- 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 the 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 the target population including their demographics, social-cultural backgrounds is required to tailor the warning messages and decide on the most appropriate dissemination channels. Once the warning information is issued (e.g., by the NHMS), it is the work of all the other relevant actors and most especially the National Disaster Management Authorities (NDMA) to work collaboratively with other competent institutions (e.g., NHMS, Geological Services) services to integrate the required risk information to design comprehensive warnings based on the user characteristics. Standardised formats for defining warning messages should be explored. For example, the Common Alerting Protocol (CAP) should be leveraged in designing the warning messages to ensure consistency especially if using multi-channel to disseminate and to also ensure there is an increased effectiveness of the warning issued. The CAP reflects 6 key facts (The Common Alerting Protocol, 2023) which have also been considered in the steps towards defining a warning message below. These include; What is it (the emergency), Where (affected area), How soon should actions be taken, How bad is the emergency, How accurate are the forecasts, and what should the recipient do?

Under this process, 4 key steps can be identified.

1. Identify the hydro-meteorological hazard type and when it is expected to happen(process 1)
2. Identify who is the recipient/users of the warning?
3. Identify where hazard impacts will occur?
4. Decide on the content of the warning message based on the user groups and their roles and include the actions to take.

4.1.1. Identification of the hazard type

Conventionally, a hazard warning message should answer the question on what, when, who, and where. An impact-based warning should then in addition to the above include information on the likely impacts and any precautionary measures that the specific user will need to take. These elements are based on the CAP and would ensure that the warning message across all hazards and over many dissemination channels is consistent. Risk information on past events and their impacts can be used to improve awareness of the expected impacts.

In defining warning messages that are targeted to a specific hazard (answers the 'what' question), these principles should be considered:

4.1.2. The user of the message

The question on who the audience is should set the stage. Once this is identified, risk data on demographics disaggregated to various variables including Literacy levels, occupation, livelihood source, language and socio-cultural background should be used to inform how the warnings should look like. In most instances, the risk information at this level should be used to delineate the various types of users and inform the likely impacts and the precautions that these user groups (see Figure 8) should take to avoid risks.

4.1.3. Where the hazard will occur

The geographic location where the hazard is likely to cause negative impact is important to ensure that the messages are directed to these risk areas.The location data will enable the use of mobile EWS which ensures the warning reaches/targets only the risk areas without causing any widespread panic. Geo-tagged messages also ensure that the various 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 the risk areas and priority risk areas, if not already included in the output of an impact forecasting system. For example, considering that warning messages already have a location tag, the risk information that is disaggregated to the lowest administrative level will help further identify the vulnerability levels and the characteristics of the exposed population or assets.To that purpose, capturing disaggregated data on losses, damages and impact would enable development of context-specific impact warning.

4.1.4. Content of the message

Conventionally, a warning message should at least include the characteristics of the threat (what, when, where), the expected impact and the recommended actions (WMO, 2021). Therefore, although the content of the warning message might vary depending on the user, the conventional way of representing 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 based on the user characteristics. In addition, when using colour schemes, the conventional way of representation should be maintained, where green means 'a normal' situation while 'red' represents a type of danger that requires a certain level of alert and action (Neußner, 2021). However, some of these colours such as green and red are not colour blind friendly, adjustments should therefore be allowed (e.g using other colours from the same palette) to enhance the comprehension and actions. Several other design factors which will influence the recipient to act on the message should also be used. These include a simple plain language, physical appearance of the message (alert levels, visuals etc), and the length of message (short and precise)- notably while adhering to the CAP guidelines.

Various key categories of impact-based warning messages user-groups have been identified (WMO, 2021) (Figure 12). These categories can be used to tailor the content of the warning messages to promote understanding and action among the users.

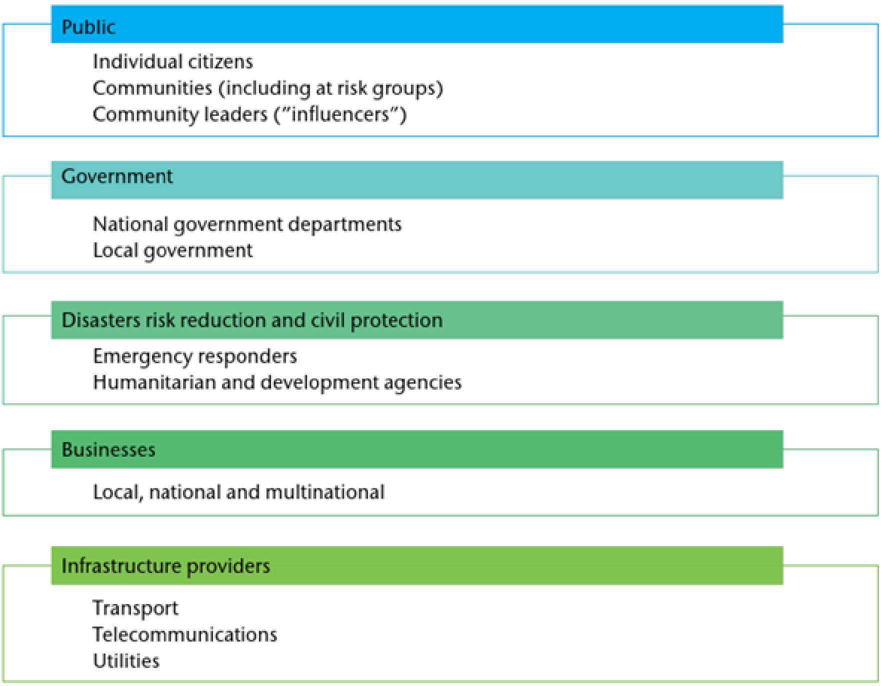

Figure 12*: Key impact-based warning message user-groups (WMO, 2021)*

Below we articulate how a warning message would look like for different users. In the example, we consider the threat to be for **floods**.

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

Characteristic of warning message	**('Who is the user')**		
	User 1 (Road's managers, motorists, pedestrians etc)	**User 2 (Local community-farmers, pastoralists etc)**	**User 3 (Emergency responder, humanitarian actors)**
What	Flooding caused by excessive rainfall is expected		
Where	A part of the southwest of the district ['names of districts/locality]. levels of neighbouring rivers ['names of rivers'] expected to rise		
When	For consecutive 'd' (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'] 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'] bridges. overflow in the drainage systems expected. Submerged croplands, flooding *of low-lying flood-prone areas., cut-off roads [name of roads]*
Precautionary/preparedness actions	*Don't drive on flooded water, turn around. Don't try to cross along flooded roads. Avoid roads ['names of roads']. Be cautious at night when it's hard to recognise flooded roads*	*Move to higher grounds, avoid flood waters. Dig trenches to drain water from farms and houses, store produce in water-tight containers, vaccinate your 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*]

Example of good practices :

The National Weather Service of the United States issues warning messages that are tailored to the specific hazards and answers to the who, where, when and the likely impacts. See (https://www.weather.gov/). Official warnings and alerts are also available on national weather services websites for different countries around the world (examples, https://www.smhi.se/en/weather/warnings-and-advisories/warnings-and-advisories/warnings, https://www.weathersa.co.za/home/warnings. A study in Uganda showed that local flood affected communities are not able to act based on the warnings issued from the National Meteorological Authorities because of the format and the language of communication used which affected early actions(Mitheu et al., 2022)

4.2. Process 5: How to use risk information to communicate in a better and targeted way

Warning messages will be effective if they reach the at-risk population at the right time, and that people can understand the alerts and act on them. To ensure dissemination to a wide audience, it is important to take into consideration the context-specific characteristics of the intended users to design user-oriented warnings (Kox et al., 2018). Risk information on demographics disaggregated to various variables including age, gender, disability status, literacy level, and social-cultural background should be used to inform the choice of the communication and dissemination method to ensure that the communication is better targeted. Based on the location, information on communication methods that have been used in the past and their effectiveness should further guide on the preferred and effective choice. In addition, mapping of the current coverage and accessibility of the available channels should be undertaken to understand what exists and their capabilities. A multi-channel approach should be used whenever possible to ensure needs of individual communities/ users are fulfilled.

1. Identify the specific characteristics of the user/users.
2. Identify the communication channels that best suit the user/users based on their location.
3. Identify communication channels that have been used in the past and their effectiveness.
4. Decide on the time of dissemination to reach all the intended/identified users.

4.2.1. Specific characteristics of the user

Specific user characteristics should be used to decide which communication and dissemination method/s are most effective. Consideration of factors such as literacy levels, age, gender, and disability status can help identify which method will be effective.

4.2.2. Communication channels

Based on their location, the right communication channels can further be determined while considering factors such as the coverage, reliability (in remote areas), format and timeliness (how long it takes to reach a user) of the messages (WMO 2021). Multiple communication channels that include media and informal communication (community gatherings etc) might be applicable and appropriate to ensure that the warning message is better targeted. For example, media such as radio and megaphones may exclude those who are hearing impaired and those with intellectual disability but flyers with simple and short text and pictograms might reach such an audience better. Information on the type of hazard (slow vs rapid onset) is important to understand the lead time required in communicating the warnings and should be used to determine the choice of the dissemination and communication channel. For example, faster methods of dissemination (such as radio, sirens, phones etc) should be considered for rapid onset hazards to ensure that warnings reach the recipient on time for preparedness.

4.2.3. Information used in the past

Information on past and current communication channels and their reliability (and first of all availability of each channel) can be used to limit the choice to the communication channels that work. A combination of all these factors will ensure that the right communication method is used.

4.2.4. Time of dissemination

The timing of dissemination of the warning messages is also critical to ensure reaching a wider and varied audience. Information gathered through community engagements and participatory approaches can be used. For example, what time are all household members likely to be at home (if media channels like radio are the mode of communication etc).This also applies to consideration of varying lead times of when warning information should be received by the various users to allow enough time for required operations.

Box 1: 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
Informal gatherings (local language)
Local radios broadcast
Simple flyers
etc.

Here we highlight an example of risk information used to decide on the effective and targeted communication methods.

The available communication systems should also be tested during pre-defined time to ensure that they work properly when needed. The tests and drills can be done through community participatory and simulation exercises which will improve public reassurance.

Example of good practices :

In a study on Cyclone EWSs in Bangladesh, socio-economic profile (gender, household composition, occupation, and roof type) of population in 2 districts in Bangladesh were used to assess the perception and interpretation of warnings. Results were used to identify the preferred communication and dissemination channel and the reasons why residents do not respond to the 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, providing the recipient the means to provide feedback. This will ensure more confidence among the users of the warning information and allow the warning providers to tailor their warning information further. In addition, past information on the access and use of warnings could help in developing improved strategies for communication and delivery of warnings.

1. Gather risk information on access, community perception, methods used and historical performance.
2. Develop a strategy on how to improve design and communication using past information.
3. Identify counter-measures in case of failure of the communication channels.

4.3.1. Gathering risk information

Historical/past information on the experiences of the population in the access and use of warnings (e.g., format, channel used, timeliness) is critical as it can be used to redefine how warnings are designed and communicated. Such information could be gathered through community engagements and participatory approaches. Engaging local NGOs who work directly with the at-risk population can also help shed light on how warnings are perceived. Information on the effectiveness of the communication methods used and the perception of population to the warning can also be gathered during these exercises to build a database of failures and successes. Promoting awareness campaigns at the local level can help the at-risk communities understand the risk which can then improve their perception.

4.3.2. Developing a strategy

In a collaborative approach, the warning and alerting institutions need to come up with a strategy that will guide communication and dissemination taking into consideration the learning agendas from the past. The strategy should be a living document that will need to be updated regularly. These learnings should then be used to improve how warning messages are designed and communicated to the at-risk population.

4.3.3. Measures identification

The resilience of the communication channels should also be documented. For example, if the systems will be able to withstand threats and which threats. The measures that should be used in case of failure of any of the channels should be known in advance to avoid delays which might bring confusion. For example, the strategy should be able to highlight situations such as in the case of strong winds affecting power lines, what other non-digital methods should be used to communicate warnings?

The international technical standards of the communication methods should always be adhered to allow comparability with other countries using the same standards (Rossi et al., 2018). This can help in the process of improving the resilience of the communication system. Some of these internationally known standards provide a way to test the efficacy of the communication system based on certain requirements (see Table 7). Such tests can be done to ensure that the choice of the communication methods is well informed.

The example on Table 7 below is drawn from Europe and highlights how the various types of notifications using for example the mobile devices can be tested while looking at what is required and the technology that each of the system uses. 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 *How to test various communication methods based on certain requirements. Source* (Rossi et al., 2018).

(Source: ETSI TS 102 182, 2010)

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	X	X	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	0	V	V	0	V	V	V	V	V = compliant 0 = compliant when phone is configured correctly

How to include ILK into warning communication and dissemination ?

The success of these processes will depend on the level of collaboration and engagement which should include not only the government sectors but also community leaders and vulnerable groups with specific needs as well as capabilities. Indeed, literature reveals that communication gaps (including language, formats, and content) in EWS are the main reason for decreased coping and response capacities among the most vulnerable groups affected by natural hazards (Mitheu et al., 2022). Everyone should have access to and understand the warning messages (Hermans et al., 2022). The use of appropriate local language and communication channels to disseminate the warnings is therefore of primary importance. In addition, surveys conducted in Ethiopia, Kenya and Uganda reveal that more than 80% of the population triangulate between local knowledge and external information received, and would trust external messages if they integrate and refer to local contexts, knowledge and experienced impacts (Trogrlić et al., 2023) .Therefore EWSs need to be flexible in design to accommodate local differences in access to information but still ensure standard information delivery.

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

CONSULT

- Hold community engagements and participatory exercises to identify critical communication channels and understand past challenges in the use of warnings. Maps the best combination of communication channels depending on local communication technologies[51], making sure that the needs of the most disadvantaged people are reached.
- Consult communities to understand how local knowledge based warnings are transferred between 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. For instance with the co-production of video clips with communities are communication tools that can improve the understanding of specific risk scenarios (Nakano et al., 2020) and therefore warning message contents.
- Co-design Warning Messages: Work with community members to co-design warning messages that are clear, culturally appropriate, and accessible to all community members. This may include using local languages (verbal/non-verbal), symbols, literacy consideration, and 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. For instance, in the Lower Mekong River,

[51] https://communityengagementhub.org/wp-content/uploads/sites/2/2021/12/TOOL-19.-Communications-methods-matrix.pdf

community members were trained to lead persons with disabilities and children to safety upon flood warnings (IFRC, 2012a).

- Collaborate with communities to create warning dissemination and communication feedback mechanisms after disasters to improve communication and dissemination processes.
- Co-design community centric EWS tools. For instance, the ITIKI[52] 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 is integrating local and scientific knowledge (Masinde et al., 2013).

EMPOWER

- Empower community leaders or mediators to take an active role in disseminating the warnings using informal channels and to provide feedback about warnings. For instance, local risk committees around the Zambezi Basin in Mozambique have been empowered to notify the population with colour-coded flags, whistles and loudspeakers about imminent hazards (IFRC, 2012a).

[52] https://urida.co.za/

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

When an early warning is issued, it is a call for actors on the ground, including national and local authorities, businesses, communities, NGOs, the International Federation of Red Cross Red Crescent Societies (IFRC), the United Nations (UN) and community groups to activate their respective preparedness and response plans to reduce the impact of the hazard (WMO, 2022b). This includes 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.

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

Preparedness and response planning include many aspects covered by this Handbook - such as early warning dissemination to the population, early warning procedure... - this chapter will address a topic that remain uncovered by the previous ones, but that is crucial to guarantee effectiveness and actionability of early actions; more precisely, the chapter will focus on one specific process:

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

For preparedness and response, it is crucial that each relevant actor builds on risk knowledge:

- the design of early actions[53] (EA) and preparedness measures for protecting people, assets and the environment.
- the definition of early actions' activation mechanism for a progressive activation of early actions and emergency coordination arrangements.

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

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

As mentioned in Process 0, anticipation necessitates (i) reliable impacts scenarios to guide action, (ii) related skilled forecasting and effective early warning, (iii) operational capacities of actors to deliver the early actions and (iv) a predefined financing mechanism to support the implementation of the early actions. Forecasts and early warnings provide probabilities about

[53] 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, 'early action' and 'anticipatory action' are used as synonyms.

when and where a hazard of a certain 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 anticipatory actions based on reference impact scenarios that rely on current priorities and resources (adapted from WMO, 2022a) and that are clearly linked to pre-agreed triggering mechanisms for an efficient activation of EAs.

This process will examine how risk knowledge - coming both from early warning information and reference impact scenarios - can:

- help decision makers understanding when it is the right time to act;
- support the development of a mechanism for a progressive and coordinated activation of early actions and the emergency system through a phased approach.

Key steps:

1. Evaluate the window(s) of opportunity
2. Design and plan the early actions
3. Define the activation mechanisms for early actions, taking into account the window of opportunity for early actions
4. If appropriate - design a progressive phased approach to early action and adapt the organisational arrangements.

5.1.1. Evaluate the window(s) of opportunity

Anticipatory actions occur within the window of opportunity between receiving an early warning and the onset of a hazard. This concept is closely tied to the timing of the hazard's onset and the lead time, which refers to the duration required by actors to implement early actions after receiving the early warning. In the case of rapid-onset events like floods, anticipatory actions typically occur prior to the hazard event. Conversely, for slow-onset events such as droughts, anticipatory actions may occur either before or after the initial hydrometeorological or climatic hazard event, but always before the impacts of the disaster materialise on communities or societies (ASEAN, 2022).

The Figure 13 below illustrates the differences in timelines between droughts and fast-onset hazards such as floods and cyclones.

Forecasts related to fast-onset hazards typically give a relatively narrow window of opportunity of a few days to several hours to act. As an example, the period within which physical impacts occur – from a cyclone making landfall or a land area being flooded – is usually short, from a few hours to days, sometimes weeks in case of severe and prolonged or repeated flooding (WFP, 2021). In this context, the choice of early actions that can be carried out is limited by time constraint and therefore the preparedness and response planning has to be more efficient, and actors and communities more prepared to timely act upon a warning. This might be addressed also through exercises to test the plans and the EW-EA system by the means of a realistic scenario and by involving at risk communities.

On the other hand, slow onset disasters that build up gradually over time give a longer window for anticipatory actions and multiple windows of opportunities during which to undertake specific early actions, before the peak of the negative impact is reached.
The window of opportunity (or windows of opportunities) should be also evaluated in relation to actual available capacities and resources (see Step on activation mechanism). In this

regard, also the time needed to implement anticipatory actions must be considered in anticipatory action planning (ASEAN, 2022) together with the reference impact scenarios.

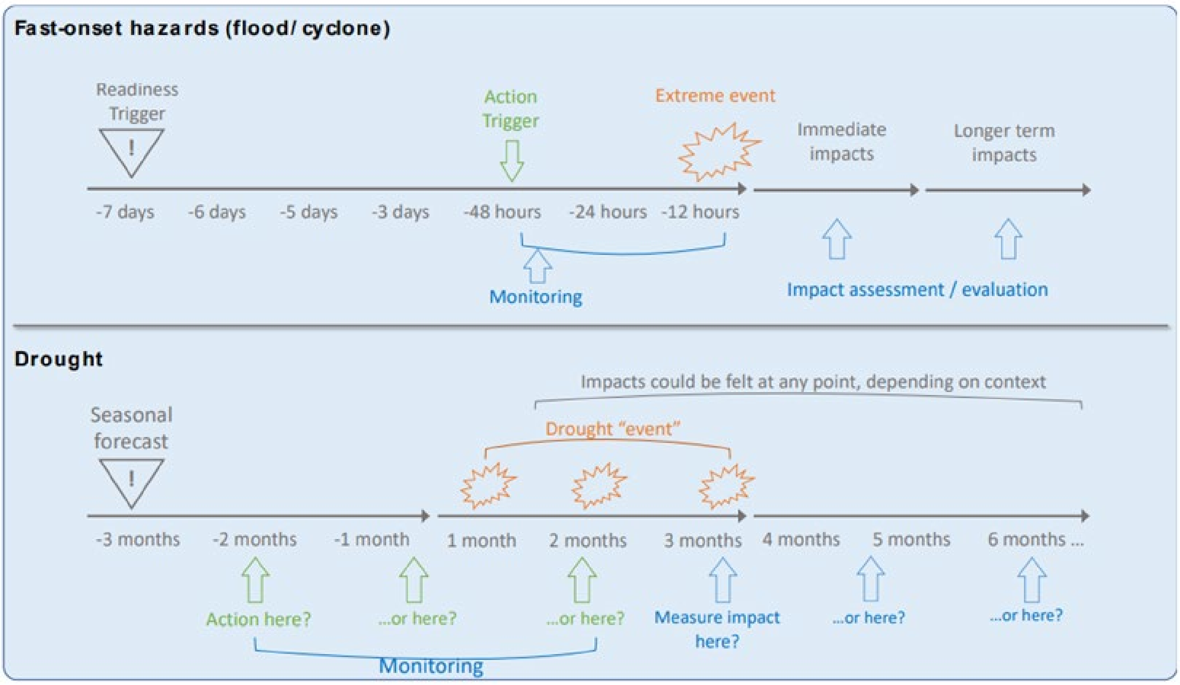

Figure 13: Differences in timelines between fast-onset hazards (flood / cyclone) and drought Source: (WFP, 2021)

To make an example in concrete terms, let's consider a possible flood that might hit:

- a municipality that is located along a watercourse that drains a big catchment area (M1);
- a municipality that is located along a watercourse that drains a small catchment area (M2).

Both municipalities are characterised by the same context elements in terms of capacity, exposure and vulnerability and by the same agreed early warning system of thresholds.

When an Early Warning is given the window of opportunity for M1 is larger (e.g. 12-24 hours), while the window of opportunity for M2 is shorter (e.g. less than 1 hour). This aspect has a strong influence in determining the Early Warning System implementation and the actions that the early warning might trigger. This will be discussed later in the text in respect of the different steps considered.

5.1.2. Design and planning of the early action

This handbook does not aim to delve into the definition of early action, as this is beyond the scope of our work. There are other works and studies that adequately cover this topic (for example, the Early Action database of the Anticipation Hub). However, certain elements concerning the design and planning of early actions are closely related to the process we are describing.

Key considerations include:

- Actions must align with the reference scenario outlined in Process 0. Specifically, the scenario should identify targets for action, including their vulnerabilities, from a spatial perspective. With this information, users can define the necessary actions or interventions.

- Users must assess whether the required actions align with available resources and capacities. For instance, consider two communities: one that has undergone information campaigns and simulation exercises during peacetime, and another that has not. For the former, a warning message prompting residents to move to safe areas when a hazard is forecasted may suffice if they are already familiar with these locations. However, for the latter community, such action may not be feasible, as they may need assistance in locating safe areas when the message is issued.
- Users must ensure that the proposed action can be executed within the window of opportunity. This assessment may involve evaluating available resources and capacities. For example, in a municipality with a large catchment area (M1), decision-makers may be able to evacuate at-risk individuals safely. However, in another municipality (M2), evacuation may not be feasible. In this case, sending messages to at-risk individuals and advising them to seek shelter on higher floors may serve as an early action, this based on the knowledge that high rise buildings (i.e., more than 2 floors) exist in the area.

5.1.3. Activation mechanism

Decision-makers need to strategically plan the timing of early actions by considering both the impact scenario developed in Process 0 and the most relevant forecasts and early warnings associated with that specific hazard, which provide sufficient lead time for action (refer to Processes 1, 2, and 3). Transitioning to an operational approach, the concept of "windows of opportunity" can be operationalized through activation mechanisms and phases, serving as a cornerstone of early action implementation.

As a fundamental requirement, early warnings should serve as the initial trigger for initiating early actions 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 early actions 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 early actions, 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 early actions do not always necessitate a specific threshold. For instance, upon receiving an early warning, disaster risk management officials may convene various stakeholders to evaluate the situation and determine whether anticipatory action is warranted, relying on expert judgement and considering the specific circumstances in the area. Importantly, there should be a protocol in place outlining how decisions are made based on forecasts, early warnings, 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 progressive and updated early warnings 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 early actions, especially when the safety of at-risk individuals is at stake. The following simulations of EA protocols can be take and concrete examples: Optimising protocols for early action in Ethiopia, Flood Early action protocol (EAP) Simulation Exercise (SIMEX) scoping visit in Busia, Kenya[54].

This approach enhances the opportunities for early actions 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 early warnings and their associated anticipatory actions and coordination arrangements (Giambelli et al., 2023).

Understanding these activation phases is aided by examining the various terminologies used in different contexts, such as "Attention," "Pre-alarm," and "Alarm" in Italy, and "Monitor," "Prepare," and "Act" for the Emergency Response and Coordination Centre (ERCC), or "Stand by" and "Alert" in Australia (Australian Disaster Resilience Knowledge Hub, 2020).

For example, Figure 14 illustrates increasing activation phases—Light, Reinforced, and Full activation phases—linked to the severity of the warning (level of alert) associated with flood impact scenarios. A brief description of each activation level is provided in the bottom part of the figure.

Each activation phase delineates the level of activation required by actors to execute planned measures and actions. With this activation 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 early warnings 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 predicated 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 (see Process 0).
- Prioritising and progressively activating early actions 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 early action, plays a pivotal role in the operational functioning of such an activation mechanism.

[54] https://www.climatecentre.org/3962/optimizing-protocols-for-early-action-in-ethiopia/

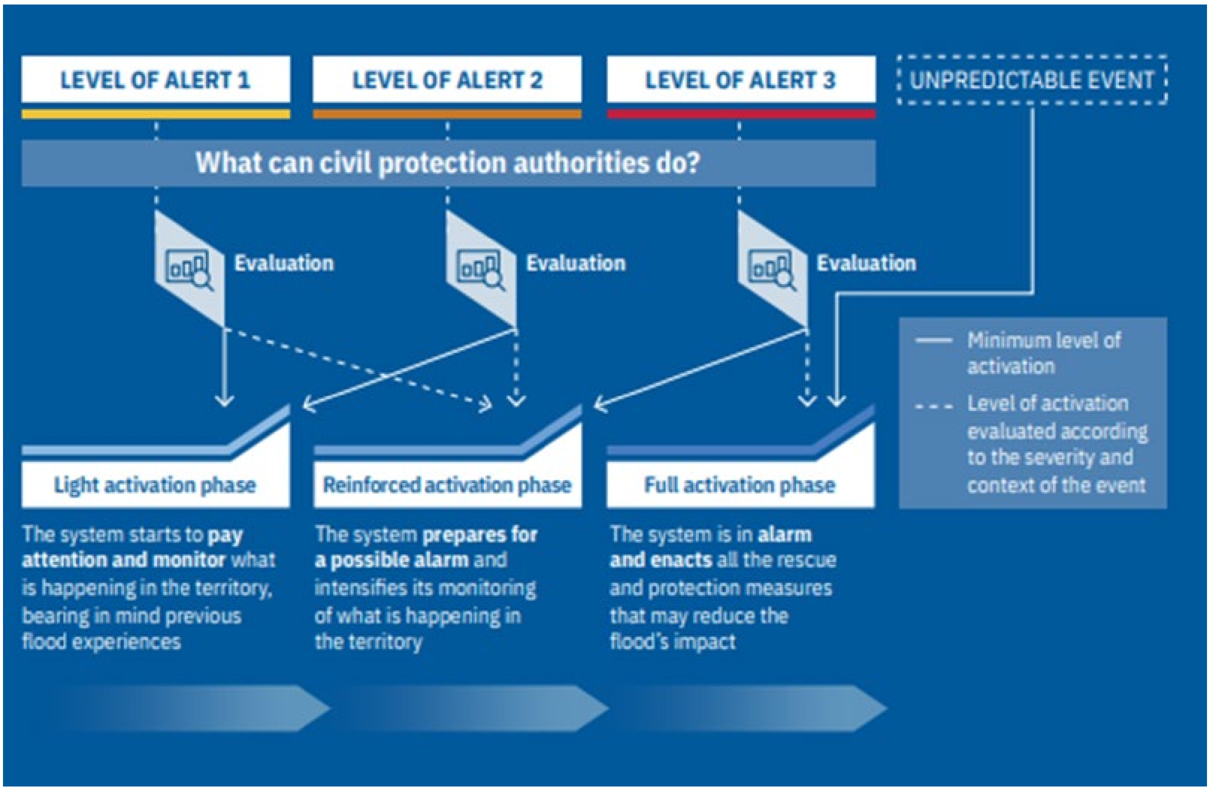

Figure 14 : *Increasing activation phases of the civil protection system and related early actions for floods. Source:* (Giambelli et al., 2023)

Some general notes for Process 7:

- While planning for preparedness and response 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 early actions that aim to provide no-regrets interventions benefiting exposed groups, even if the hazard does not materialise.
- Assessing capacities within communities at risk not only supports preparedness and response 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-EAA System, please see:

- Giambelli M., Meninno S., Deda M., Masi R., Gioia A., Ponte E., Massabò M., Vio R., Paniccia C., Renzulli S., 2023. "Establishing effective links between early warnings and early action: general criteria for floods": an output of the programme "EU support to flood prevention and forest fires risk management in the Western Balkans and Turkey – IPA Floods and Fires". Available at:
- Forecast-based Financing Practitioners Manual. Available at https://manual.forecast-based-financing.org
- https://www.anticipation-hub.org/Documents/Briefing_Sheets_and_Fact_Sheets/Flood_EAP_-_Final.pdf
- UNICEF's Today and Tomorrow Initiative. Available at: https://unfccc.int/sites/default/files/resource/casestudy_today_tomorrow_initiative_unicef.pdf

- Early action database of Anticipation hub. Available at: https://www.anticipation-hub.org/experience/early-action/early-action-database/ea-list

Example of good practice

Risk Information for Forecast-based Financing

The Forecast-based Financing (FbF) is a funding mechanism of the Red Cross and Red Crescent (RCRC) movement to release money to national societies in advance of a disaster, based on hydro-meteorological forecasts and risk analysis (IFRC, 2023). This enables them to take early action to prevent or mitigate the impact of the disaster, such as by providing 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 it can help save lives. The Anticipation Hub[55] displays an overview on anticipatory action initiatives around the world.

Risk information is essential for setting up a Forecast-Based Financing (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 early warning 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 assessments, is essential for accurately assessing the level of risk a community faces. This assessment guides the design of the FbF scheme determining the payout levels and the thresholds for the activation of the mechanism similar to what happens in case of a parametric insurance.

Risk information is also essential to better target the finance dissemination on the territory, to prioritise interventions by knowing the location of vulnerable groups and their expected number. A good representation of the risk scenario would also allow the understanding of when to scale up or scale down operations based on changing risk levels.

in addition, risk information can also direct beneficiaries to spend the distributed resources in the most effective direction (e.g. food or clean water or other essential service that the risk scenario is highlighting 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 early action, 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.

[55] https://www.anticipation-hub.org/

In conclusion, risk information is the cornerstone of a successful Forecast-Based Financing 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. Available at https://manual.forecast-based-financing.org
- https://www.anticipation-hub.org/learn/methodology

How to include ILK into Preparedness and response planning ?

Local and indigenous people are generating considerable knowledge and practices on disaster preparedness over time (Dekens, 2007). Based on a example from a case study in Kenya, the inclusion of such risk knowledge in disaster preparedness and response 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 preparedness and response activities become more equitable and socially just, from in particular a procedural and distributive justice principle ((Van Den Homberg and Sadik Trogrlic, Robert, 2023)). While many actors are responsible for preparedness and response actions, the involvement of communities most affected by hazards is critical as they are the source of the locally contextualised information that can be used to develop tailored and targeted anticipatory actions (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 an increased knowledge and capacity to respond to early warning messages; this can be achieved through assessing the barriers and opportunities in the use of early warning information among the affected communities (Mitheu et al., 2022). The following community engagement processes have been identified to ensure the inclusion of ILK into preparedness and response planning.

INVOLVE

- Involvement in the assessment of the underlying cause of changing risks (e.g. deforestation, demographic trends, agriculture practices…)
- Involvement in using local knowledge to identify early actions 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 context, as well as differentiated needs and coping capacity of vulnerable populations, an example from a case study in Ethiopia (Mitheu et al., 2023c).

COLLABORATE

Collaborate in designing adapted Early Action solutions, ensuring that they address local needs and priorities (e.g. defining the best evacuation route, temporary shelters types, …). Designs on Early Action should include ILK on context-specific factors that could entrave the implementation of the action, as well as on 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[56], by ensuring these communities at risk are effectively prepared for and better able to respond to cyclones associated risks through strengthening knowledge and coping capacities, community involvement and collaboration to include anthropogenic and cultural perspectives in disaster preparedness activities.

Figure 15*: Villagers discussing dyke design with consultants in GVH Nafafa in Malawi and dike construction (Van Den Homberg and Sadik Trogrlic, Robert, 2023)*

EMPOWER

Empower the community in the implementation of the preparedness, Early Action or response plan, and allow communities to give feedback from the actions implementation in a timely manner.

- For instance, the **participation in preparedness and responses exercises** and activities can empower the communities in training others on the use of local knowledge during search and rescue exercises. As an example, the Nepal Red Cross Society has organised community-based risk management training in 20 districts, including the traditional knowledge to builts rafts from banana trees to evacuate people. This has saved lifes in Jhapa district during the 2017 Flooding (IFRC, 2021).
- Experts and community sharing experiences and knowledge in stocking food and basic life supports

Such knowledge inclusion processes, combined with disaster awareness and management campaigns, facilitate the engagement of the community to better prepare for response to emergency conditions.

56 https://globalcompactrefugees.org/good-practices/expanding-early-warning-refugee-settlements-coxs-bazar

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

Here is a non-exhaustive list of risk-related free and open-source dataset, that are commonly used for producing risk information that can feed EWS. the Review of Lindersson et al., 2020 provide additional references specific to flood and drought

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