Knowing what the weather will do: A guide for practitioners on impact-based early warning

Practical examples for floods and droughts in Eastern Africa

May 2026

UNU EHS

Knowing what the weather will do: A guide for practitioners on impact-based early warning

Practical examples for floods and droughts in Eastern Africa

May 2026

Authors

Samira Pfeiffer, Davide Cotti, Nkemakonam Naomi Ukatu, Maria Dewi, Augustin Kiptum, Judith Kawikya Musa, Lorenzo Alfieri, Andrea Libertino, Tatiana Ghizzoni, Daria Ottonelli, Eva Trasforini, Paul Mwangi, Frankline Rono, James Nyaga, Vincent Okoth, Mark Lelaono, Ezra Limo, Jully Ouma, Ahmed Amdihun, Saskia E. Werners, Michael Hagenlocher

UNU EHS

UNDRR UN Office for Disaster Risk Reduction

IGAD ICPAC

cima RESEARCH FOUNDATION

Regional Centre for Mapping of Resources for Development RCMRD

Contents

List of tables

List of figures

Abbreviations

CDI	combined drought indicator
DRM	disaster risk management
EADW	East Africa Drought Watch
EAFW	East Africa Flood Watch
EWS	early warning system
FAO	Food and Agriculture Organization
IbEW	impact-based early warning
IbEWS	impact-based early warning system
ICPAC	IGAD Climate Prediction and Applications Centre
IGAD	Intergovernmental Authority for Development
KMD	Kenya Meteorological Department
NDMA	National Drought Management Authority

Foreword

The Early Warnings for All Initiative (EW4All) represents a collective commitment to ensure every person on Earth is protected by effective early warning systems, with priority given to those most at risk. The United Nations Office for Disaster Risk Reduction (UNDRR), alongside the World Meteorological Organization (WMO), have an unwavering commitment to ensuring that early warning systems can protect every person on Earth, and have strived to invest in risk knowledge and foster collaboration and coordination among all stakeholders.

Eastern Africa is one of the regions most exposed to climate-related hazards, including droughts and floods, affecting millions each year. Despite advancements made in the past, large segments of the population are still not adequately covered by effective early warning systems. This situation propelled UNDRR to partner with the Intergovernmental Authority on Development Disaster Operation Centre (IGAD-DOC), United Nations University Institute for Environment and Human Security, CIMA Foundation and the Regional Centre for Mapping of Resources for Development. Together, these partners worked to develop and implement a novel impact-based early warning (IbEW) approach and methodology, which was consequently applied successfully to two pilot countries in the IGAD region: Ethiopia and Kenya.

The launch of this new technical guide on impact-based early warnings marks a pivotal moment in our collective efforts to shield communities from the escalating volatility of our climate. It provides practical examples on the use of risk information, exposure and vulnerability analysis for transforming hazard forecasts into expected impacts. IbEW shifts the focus from forecasting hazards to anticipating their impacts on people, livelihoods, infrastructure and critical services. This also translates forecasts into risk and information data for relevant sectors, ultimately strengthening decision-making and ensuring that early warnings lead to timely, proportionate action.

The novel IbEW approach has been applied to floods and droughts and is now embedded within the services provided by the IGAD-DOC to its Member States. It complements existing forecasting systems and risk information services delivered by IGAD-DOC to Member States, thereby supporting informed decision-making and timely early action across the region. This innovative approach confirms the centre's leading role in providing climate and risk information services for the East African region.

Effective early warning systems, and successful disaster risk reduction in general, are more important now than ever before. Even as national budgets continue to tighten, and funding often flows toward the aftermath of disasters rather than toward their prevention, hazards continue to become more severe, more common and more destructive. But studies and pilot programmes such as this one can seriously strengthen early warnings and early actions in the IGAD region.

Amjad Abbashar, Chief, Regional Office for Africa, United Nations Office for Disaster Risk Reduction (UNDRR).

We are grateful for our partners at the United Nations University's Institute for Environment and Human Security (UNU-EHS), the IGAD Climate Prediction & Applications Centre, the CIMA Research Foundation, the Regional Centre for Mapping of Resources for Development (RCMRD), the European Union Commission, the Organization of African, Caribbean and Pacific States, and National Disaster Risk Management authorities, hydro-meteorological services and many stakeholders who have participated in this project. Without any of these partners, this pivotal work would not have been possible. The work we do together is about more than generating new data. It is about ensuring that scientific and technological tools provide relevant and reliable risk information for transforming early warnings into early actions, and above all else, it is about ensuring the communities we serve have the information they need to protect what they have built and what they care about.


© NASA / Unsplash

1. How to use this guide

Scope

As climate-related hazards intensify, the need to anticipate not only what the weather will be, but what it will do, has never been more urgent. Traditional hazard-based forecasts, such as those that predict an upcoming flood or drought, describe the likelihood and severity of hazardous events; however, they often fall short of guiding timely, targeted action. Impact-based early warning (IbEW) bridges this gap by linking weather and climate information with an understanding of exposure and vulnerabilities, to predict the potential impacts of hazards on people, livelihoods and assets.

This guidebook introduces a novel conceptual framework and methodology to support practitioners in developing and applying IbEW systems. It offers step-by-step guidance on integrating vulnerability and exposure with hazard-based forecasts to provide actionable warnings. The approach is illustrated through an application example, demonstrating how the methodology has been implemented for floods and droughts in Kenya.

Target audience

This guidebook is aimed at governmental and non-governmental organizations mandated with or engaged in early warning, disaster risk management (DRM), humanitarian response or early action. It aims to support these processes by providing a novel framework and methodology for designing and implementing IbEWs. Of particular interest to technical experts working at national, regional or continental levels, this guidebook:

- Offers insights into what IbEW is, and how integrating risk knowledge with hazard-based forecasts enables more effective and targeted early actions
- Presents a novel framework, standardized methodology and step-by-step guidance for designing and implementing IbEW
- Uses a concrete application example to showcase how the put the framework and methodology into practice

Guidance for the reader

This guidebook is designed to be a stand-alone document. Following the Introduction (**chapter 1**), **chapter 2** introduces the conceptual framework for including risk knowledge into IbEW that is used in this guidebook. It builds on the risk framework of the Intergovernmental Panel on Climate Change, where risk is understood as the outcome of the dynamic interaction of hazards, exposure(s) and vulnerabilities, and where impacts are the manifestation of risks, in the form of adverse consequences. This chapter also clarifies important key concepts and terms, such as “risk”, “hazard”, “exposure”, “vulnerability”, “impact”, “impact-based early warning” and “early action”. The conceptual framework, and the definitions provided, are particularly targeted at readers seeking a more profound understanding of the concepts of IbEW warning and early action. Building on the conceptual framework, **chapter 3** provides detailed practical instructions for the design and implementation of IbEW systems, structured as four different modules. The four modules provide clear, step-by-step instructions for co-constructing an IbEW system; from conducting a needs assessment (**module 1**), to building risk knowledge (**module 2**), to translating concepts into data (**module 3**) and finally to visualizing and communicating outputs and outcomes (**module 4**).

Each module in chapter 3 offers concrete and practical steps, as well as guiding questions for each step. At the end of each module, a description of each step is offered based on a concrete application example, focusing on floods and droughts in Kenya. The same application example is used throughout each of the four modules, allowing for an integrated understanding of all stages throughout the process; from conducting a needs assessment to operationalizing IbEWs in a target platform and/or existing system.

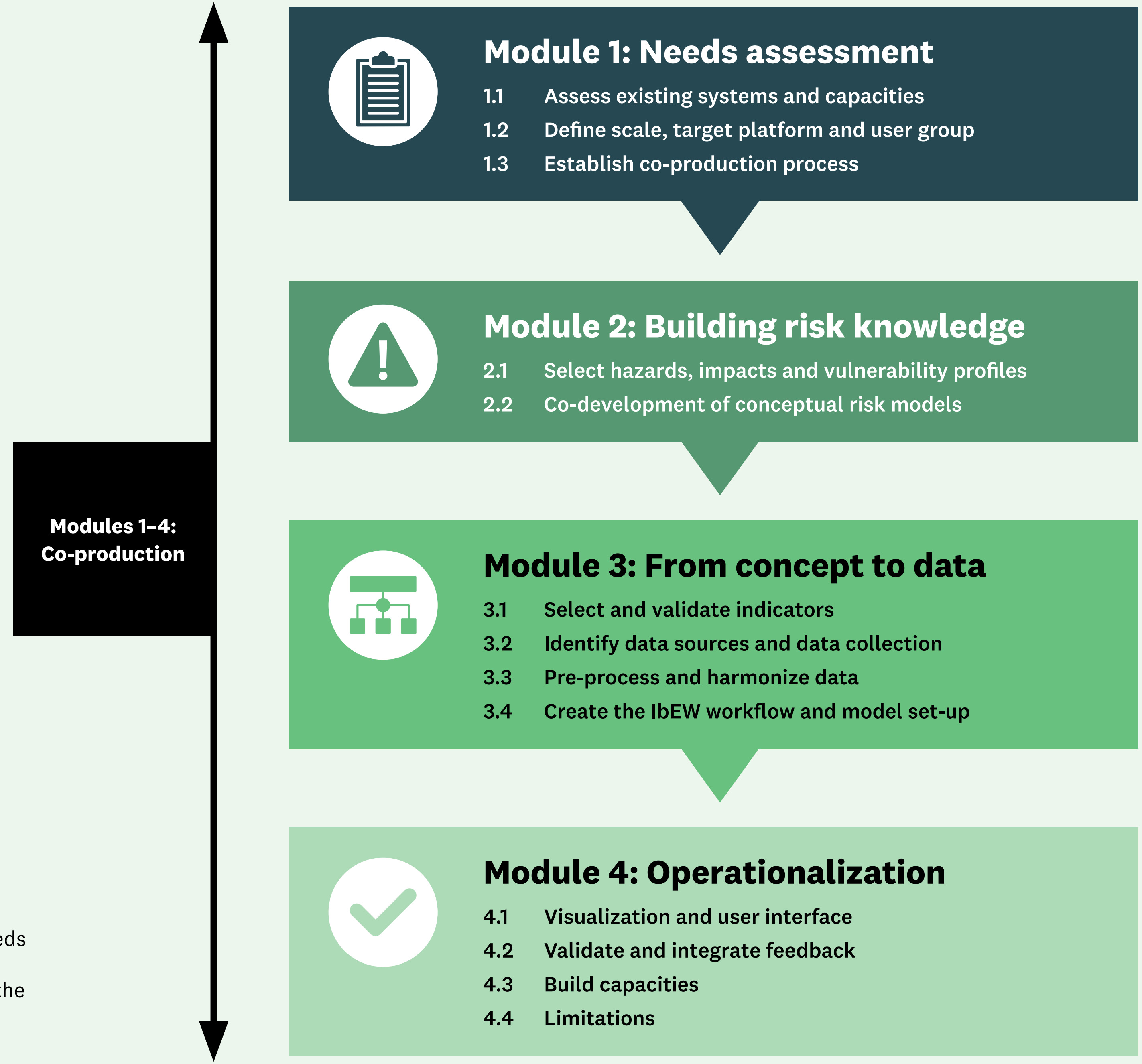

Figure 1: Novel methodology for IbEW, including needs assessment and scoping, building risk knowledge, data-driven component and the implementation in the target platform

Source: Authors.

© Samira Pfeiffer / UNU-EHS

© Ajeet Panesar / Unsplash

© Saskia Werners / UNU-EHS

Introduction to the application example

The application example complements the generic step-by-step instructions in the guidebook, by illustrating these steps and associated guiding questions, using Kenya as a case study. It illustrates how the step-by-step methodology can be applied to develop IbEWs. Kenya provides a representative context due to its dual exposure to prolonged droughts and seasonal floods, both of which have significant socioeconomic impacts on lives, livelihoods and development outcomes. Here, we introduce the country's context; highlight existing EWSs, prevailing challenges, and the rationale for transitioning from hazard-based to impact-based early warnings.

Description of the case study area

Kenya's geography spans arid lowlands, humid highlands and extensive river basins that support both agriculture and dense urban populations. The arid and semiarid lands, which cover nearly 80 per cent of the national territory, experience recurrent droughts that threaten food security and rural livelihoods (ACAPS 2022; The World Bank Group 2021). Most households in the country rely on rain-fed subsistence farming, cultivating maize, beans and pigeon peas (KNBS 2025). When seasonal rains fail or end prematurely, farmers experience widespread crop loss, reduced yield and loss of household income. This particularly affects women-headed households and vulnerable farming groups with limited access to irrigation, credit and agricultural extension services (Pfeiffer and others, 2025). For example, during the 2022–2023 drought, maize and bean yields declined by more than 40 per cent in parts of eastern Kenya, with cascading effects on household food access and market prices (UNOCHA, 2023).

In contrast, urban and peri-urban areas – such as Nairobi, Machakos and parts of Kajiado County – experience recurrent flash floods during the March–May and October–December rainy seasons. The Athi River Basin, which drains a large part of central Kenya, includes both forested uplands and low-lying floodplains heavily modified by settlements, roads and industrial development. In areas such as Mukuru and Mathare, poor drainage infrastructure and informal housing increase the population's exposure to floods that can damage property, disrupt transport and contaminate water supplies (Greibe Andersen and others, 2023; Kiptum and others, 2023; Oduor, 2025). Each year, thousands of households are displaced, and livelihoods are disrupted.

Existing early warning systems and key challenges

Kenya has a strong foundation for early warning, supported by several national and regional institutions that monitor and forecast hazards. The Kenya Meteorological Department (KMD) provides regular weather and seasonal forecasts, while the National Drought Management Authority (NDMA) tracks drought conditions across the country through monthly bulletins that report rainfall levels, vegetation health and water availability. The National Disaster Operations Center plays a coordinating role in sharing alerts and guiding emergency responses, and the Ministry of Water, Sanitation and Irrigation contributes important hydrological information for flood management. At the regional level, the East Africa Drought Watch (EADW) and East Africa Hazard Watch platforms, hosted by the Intergovernmental Authority for Development (IGAD) Climate Prediction and Applications Centre (ICPAC), provide real-time monitoring and climate information that support these national efforts.

Despite these foundations, Kenya's early warning mechanisms remain largely hazard-based, describing what the weather will be, rather than what it will do. For example, drought bulletins may indicate expected rainfall amounts, but rarely explain what this means for farmers; whether crops are likely to fail or when planting should be delayed. Similarly, flood alerts may show rainfall intensity or rising river levels but omit information on the anticipated impacts on people and livelihoods. As such, current warnings are primarily hazard-based, providing insufficient insight into who and what will be affected. This limits the ability of institutions and communities to act early.

These challenges highlight the need to shift toward an impact-based approach that connects weather and climate information with risk knowledge, showing not only when a hazard may occur, but also who and what will be affected and what can be done in advance to reduce its impact.

© Raychel Sanner / Unsplash

2. A framework for impact-based early warning

What is impact-based early warning?

IbEW is a novel approach that aims to enhance hazard-based early warning by including information on potential impacts and risks connected to one or more hazard events (UNDRR and WMO 2024; Harrowsmith and others, 2020). This stems from the realization that early warnings become more understandable and actionable (and, therefore, effective) if they contain information not solely about "what the weather will be", but also about "what the weather will do"; that is, what impacts hazards will have on specific elements at risk, such as lives, properties, infrastructures and so on. For instance, while hazard-based early warning may include information on the amount of precipitation (weather-based) or the extent of a flood (hazard-based) prior to its occurrence, IbEW may include information such as the number of people potentially affected by a flood, and further information about who is vulnerable to the possible impacts of a flood. To achieve this, risk knowledge – that is, information about exposure and vulnerability of who and/or what is at risk – needs to be captured and processed to inform IbEW.

However, given its relative recency, IbEW still comes with multiple conceptual and methodological gaps and challenges, which need to be explored through new applications and testing grounds (Potter and others, 2025; UNDRR and WMO, 2024). In particular, it is crucial to ensure that risk knowledge is captured and co-produced to inform IbEW; from its design, to its implementation and communication (UNDRR and CIMA, 2024).

Risk knowledge for IbEW involves not only identifying the most relevant hazards, risks and impacts that can be tackled through early warnings, but also who and what is exposed and vulnerable to them, and why. Its importance, therefore, extends throughout the full early warning chain, from understanding drivers of risks to designing warning narratives that can be turned into effective early actions. Knowledge of risk can help tailor warnings to the needs and abilities of groups that are most vulnerable, increasing the likelihood that early actions will be effective.[1]

1 For further information on the use of risk knowledge for multi-hazards 2024, see: United Nations Office for Disaster Risk Reduction (2024). Handbook on the use of risk knowledge for multi-hazard early warning systems 2024. Available at https://www.undrr.org/publication/handbook-use-risk-knowledge-multi-hazard-early-warning-systems-2024.

A novel framework for impact-based early warning

To showcase the relevance and role of risk knowledge for IbEW and early action, this report introduces a novel framework, shown in **figure 1**. This framework builds on the understanding of risk – established by the Intergovernmental Panel on Climate Change – in which risk is, generically, the outcome of the dynamic interaction of hazards, exposure(s) and vulnerabilities, resulting in direct and indirect risks and impacts (i.e. manifested risks) (IPCC, 2014).

Risks are, however, heavily influenced by the characteristics of the various groups of people that experience them; not everyone is equally vulnerable to adverse consequences. This means that drivers of risk, and particularly of vulnerability, are often specific to vulnerable groups, and should be identified accordingly. This is especially relevant for IbEW; not only does it allow for better representation of potential impacts, but it can also support the design of dissemination strategies and the identification of capacities to take risk-reducing measures, such as early actions.

When all these components are considered, impact-based early warning can more effectively inform early actions for vulnerable groups, contributing to reducing risks and impacts.

Table 1 provides further information about key concepts and definitions used in this guidebook.

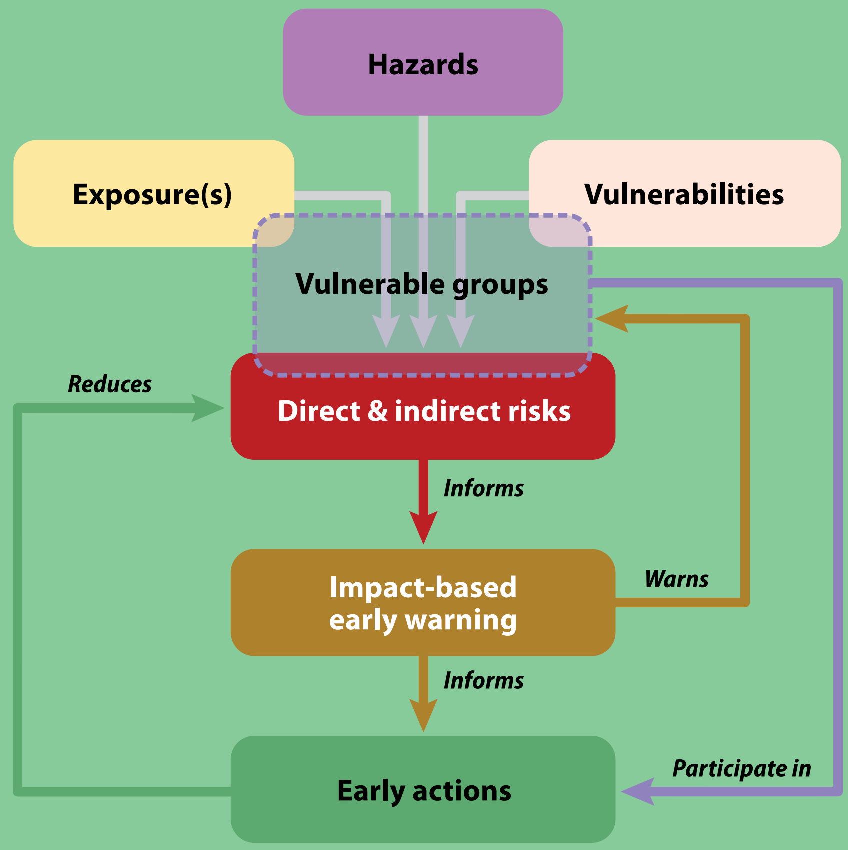

Figure 2: Approach to risk-informed IbEW and early action

Source: Authors.

Table 1: Key concepts, their definition and relevance for IbEW

Concept	Definition	Relevance for IbEW
Risks/impacts	The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk results from the interaction of vulnerability, exposure and hazard (IPCC 2014, p.40).	Understanding risk helps in shifting EWS from simply predicting a hazard to anticipating its potential impacts on people, assets and systems; for example, instead of only warning about heavy rainfall, IbEW indicates whether this rainfall is likely to cause flash floods that could damage homes or disrupt transport.
Hazard	The potential occurrence of a natural- or human-induced physical event or trend; or physical impact that may cause loss of life, injury, or other impacts or damage (IPCC 2014).	Hazard monitoring and forecasting are integral for analysis of any EWS; for example, a forecast of "50 mm of rainfall in 24 hours."
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014).	IbEW integrates vulnerability information to determine who or what will be most affected and why; for example, communities with poor drainage and limited access to emergency shelters are identified as highly vulnerable, prompting targeted warnings and preparedness support before heavy rainfall events.
Exposure	The presence of: people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected and are subject to potential future harm, loss or damage (IPCC 2014).	IbEW integrates exposure data (e.g. on population density, critical infrastructure and timing of activities); for example, a windstorm warning might emphasize impacts on exposed ferry routes or coastal infrastructure, leading to proactive closure of ports or cancellation of services.
Impact-based early warning system	Convey warning about what the weather will do (impact), instead of what the weather will be (hazard) by integrating vulnerability and exposure with hazard monitoring, forecasting and prediction. There is no single definition of impact-based early warning and for the purpose of this guidebook we adhere to the conceptualization provided.	EWS that combine hazard forecasts with exposure and vulnerability information to issue impact-based warning with instructions for early action; for example, instead of "strong winds expected tonight," IbEW communicates: "Strong winds expected tonight may cause power outages and falling trees – avoid travel and secure loose objects," this helps communities take preventive action based on likely impacts, rather than just weather conditions.

3. Methodology for impact-based early warning

This chapter provides practical, step-by-step guidance on how to develop and apply an IbEWS. It comprises four modules: **module 1**, needs assessment; **module 2**, building risk knowledge; **module 3**, from concepts to data; and **module 4**, operationalization.

Each module consists of multiple steps that aim to integrate vulnerability and exposure of information with hazard-centric forecasting. Guidance on how to consider specific vulnerable groups in IbEW, and guiding questions for each step are given. Each module is complemented by an application example that demonstrates how the steps have been applied in a real-world case.

Table 2: What you will learn in the modules

Module	What you will learn in this module	Methods, tools and activities
Module 1: needs assessment	How to identify gaps, needs and capacities in existing EWSs; how to define the scale, users and type of EWS platform; how to establish an inclusive co-production process.	Desk study, review of institutional structures, stakeholder mapping, scoping workshops, engagement focus group discussions.
Module 2: building risk knowledge	How to define what impacts to warn for and who is most at risk; how to identify priority hazards and vulnerability profiles; and how to develop conceptual risk models (i.e. impact chains) linking hazards, exposure and vulnerability.	Organize ecodevelopments sessions with stakeholders; use participatory mapping and the "impact chains" approach; validate models through expert consultations and available data.
Module 3: from concept to data	How to turn risk knowledge into measurable information for IbEW; how to select, validate and process indicators for exposure and vulnerability; and how to build a workflow that connects data to early warning outputs.	Identify and validate data sources; harmonize and clean datasets; design and test an IbEW workflow or model in collaboration with technical partners; document and automate processes.
Module 4: operationalization and communication	How to bring IbEW into practice; how to visualize and communicate warnings; how to validate, train and plan for scaling.	Develop and test visualization formats and user interfaces; organize feedback sessions and validation workshops; build capacity across agencies; and design replication strategies.

Module 1: Needs assessment

Purpose of this module: To identify gaps, needs and capacities in the of concern and the right entry points for integrating risk knowledge, to develop IbEW.

Step 1.1. Assess existing systems and capacities

While EWSs are widely known to effectively save lives, and protect livelihoods, sectors and systems, they remain absent from many countries (WMO and UNDRR, 2022). Moreover, existing EWSs still largely focus on weather-only or hazard-only forecasts (UNDRR and WMO 2025). Understanding gaps and needs in the target area ensures that EWSs, and their transition towards IbEW, build on existing services and capacities.

This step entails an assessment of the presence, functionality and performance of existing EWSs within the target region, to determine the baseline for the development or integration of an IbEWS. The assessment can identify whether an EWS is operational, the scope of hazards it addresses (i.e. single- or multi-hazard), and the institutional and technical frameworks that support it.

The usefulness of hazard-based warning may be assessed, and the potential to transition towards risk-informed early warning and early action, integrating vulnerability and exposure. For example, how effectively these systems generate, disseminate and translate warning information into actionable responses across sectors and communities (e.g. how systems performed during recent incidents and whether they effectively triggered early actions).

Stakeholders' needs and the capacity of different actors to act on them will also be assessed; including national and local authorities, humanitarian organizations, DRM agencies and at-risk communities.

This is a critical step in ensuring that IbEW initiatives are evidence-based, context-specific, and aligned with existing institutional and operational structures of warning, thereby enhancing the transition towards IbEW. This can be done by desk review of relevant studies (including scientific papers, reports, projects and programme documents, online resources and policies), expert workshops, focus group discussions or surveys with relevant institutions.

Zoom into vulnerability profile:
To make IbEW actionable for specific vulnerable groups (e.g. women and girls disproportionately affected by drought risk and food insecurity), you can analyse how existing EWSs consider the specific needs of vulnerable groups. It is critical to consider the vulnerabilities and capacities of vulnerable groups as integral to all the steps involved in developing an IbEW, to ensure actionability.[2]

GUIDING QUESTIONS:

- What are the existing EWSs in the target region?
- What are the gaps in the existing systems?
- What are the needs of stakeholders?
- Are multi-hazard IbEWs already in place?

2 For more information about baseline assessment for vulnerability profiles, see Pfeiffer and others, "Bridging the gaps: Vulnerability profiles to strengthen impact-based early warning and early action for floods and droughts in Kenya", Bonn, Germany: United Nations University Institute for Environment and Human Security (2025).

Step 1.2. Define the scale, target platform and user groups

This step focuses on determining the spatial and temporal scale, the key stakeholders involved and the primary users of IbEW. Understanding the geographic coverage (such as national, subnational or community level) and the temporal scales (such as lead times of existing EWS for different hazards) is essential for transitioning towards IbEW. It is also essential to assess the relevant stakeholders (such as meteorological agencies, water and agriculture ministries, DRM authorities and humanitarian organizations). In parallel, the needs and capacities of users (ranging from national planners and sectoral decision makers to local authorities, first responders and at-risk communities) must be analysed to ensure that the IbEWS delivers actionable information.

This step can be facilitated with the stakeholders (e.g. national authorities, community working groups) depending on your selected target group. It is crucial to consider the IbEWS as an integrated system with various feedback loops (e.g. risk knowledge to response preparedness) and the interrelatedness of different scales (e.g. local information versus national forecasting processes). The aim is to map out the precise purpose of operation for the IbEWS and confirm its function with all relevant stakeholders.

Zoom into vulnerability profile: When you define the spatial and temporal scales for the IbEWS, it is important to think about how vulnerability shifts across different regions and among various population groups. Vulnerability varies extensively across rural and urban areas, livelihood zones and within sociodemographic groups such as women, persons with disabilities, the elderly or marginalized communities. Mapping out these variabilities makes it easier to select geographic coverage, from national to subnational, to community level. It also helps decide the level of detail needed to back up targeted early actions.

GUIDING QUESTIONS:

- At what spatial and temporal scales are the IbEWSs supposed to operate?
- How are scales of EWSs (e.g. local, national and regional) interacting?
- How do these scales align with decision-making needs and early action protocols?
- Who are the key stakeholders involved?

Step 1.3. Establish a co-production process

A co-production approach is essential to ensure relevance, acceptance, usability and uptake of an IbEWS. Co-production can foster collaboration between technical experts, decision makers, and other potential users. By engaging diverse stakeholders – such as national meteorological and hydrological services, DRM authorities, humanitarian actors and community representatives –throughout the process, you can ensure that the system can be tailored to meet their needs. Engaging relevant stakeholders in all steps of the implementation and development can strengthen trust, ownership and uptake of IbEW outputs. Co-production ultimately ensures that warnings are not only technically robust but also accepted and actionable, thus enhancing the platform's capacity to support anticipatory action and risk reduction.

In this step, diverse perspectives can be brought together. For example, co-production should include those who have direct mandates to act (e.g. DRM authorities), as well as those who are at risk (e.g. community representatives). Further, it is critical to establish a clear and accessible co-production design throughout the entire development phase. The key guiding principles for any co-production may be: "Who is missing? Whose perspectives are represented? What are the blind spots of the co-production?" Ensuring different participation activities (e.g. focus groups, participatory mapping, workshops, surveys, transect walks) can help to increase inclusivity. Finally, establishing independent advisory committees with experts, diversity representatives and individuals with backgrounds in the topics of concern can be an additional mechanism to guide co-production, with external feedback on the product under development.

Zoom into vulnerability profile: Vulnerable groups are often left behind in decision-making, or underrepresented in the co-production processes. Hence, it is critical to ensure equal representation and an inclusive format of the co-production. For example, investing in tools that can grant access for people with special needs to co-production. It is equally important to discuss and acknowledge who is missing is as it is to consider who is represented.

GUIDING QUESTIONS:

- What are the relevant perspectives for ensuring inclusivity and equity in co-production?
- Who should be involved and consulted?
- Who is missing?
- What are effective and inclusive mechanisms for co-production before, during and after product development?

Module 1: Application example

Step 1.1. Assess existing systems and capacities

- What are the existing EWSs in the target region? What are the gaps in the existing systems? What are the needs of stakeholders?

A combination of desk review, expert input and focus group discussions to assess existing tools, capacities and actors on county, national, regional and global levels was conducted. For example, key institutions – such as the KMD, the NDMA, the Ministry of Water, Sanitation and Irrigation, and the National Disaster Operations Center – were examined to understand their mandates, tools and coordination mechanisms. The assessment found that, while KMD provides hazard-specific forecasts and NDMA issues drought bulletins, both systems lack integration of vulnerability and exposure information, particularly for women-headed households, smallholder farmers and persons with disabilities. Existing systems also do not fully account for communities in camp settings, who often face multiple barriers to receiving and acting on early warnings. Spatial coverage remains limited due to sparse weather-station networks, and warning products are still largely hazard-driven, providing little insight into who is most at risk or how different groups can act early.

Step 1.2. Define the scale, target platform and user groups

- At what spatial and temporal scales is the IbEWS supposed to operate? How are scales of EWSs (e.g. local, national and regional) interacting?
- How do these scales align with decision-making needs and early action protocols? Who are the key stakeholders involved?

The target platforms for implementing and operationalizing IbEW are the EADW and East Africa Flood Watch (EAFW) platforms, developed and hosted by ICPAC. These portals operate on the regional scale, serving 11 countries in the Horn of Africa. To date, these portals provide dynamic, near-real-time data and forecasts for environmental hazards, including weekly rainfall projections and climate variability indicators; and continuously monitor climate change-related indicators. hence served as an ideal entry point for transitioning from hazard-based to impact-based forecasts and warnings.

The target users include national meteorological and hydrological services, DRM authorities, and humanitarian organizations that depend on these platforms for planning, preparedness and anticipatory action.

However, while the platforms offered data on population density, land use and infrastructure alongside hazard forecasts, they lacked integrated information on vulnerability and exposure. Without these layers, early warnings could not fully explain who and what would be affected or *where* and *when* the impacts might occur, limiting their use for anticipatory decision-making.

Step 1.3. Apply inclusive co-production and knowledge sharing

- What perspectives ensure inclusivity and equity in co-production? Who should be involved and consulted? Who is missing? What mechanisms enable co-production before, during and after product development?

In Kenya, the development of an IbEWS followed a co-production approach that emphasized collaboration between scientists, institutions and users. The process brought together experts, decision makers, and community representatives to jointly design, test and refine early warnings, ensuring they were not only scientifically sound but also practical and usable.

A multiformat engagement process supported this collaboration. During a dedicated stakeholder workshop, participants jointly identified and prioritized drought and flood risks to be included in the early warnings. These discussions directly informed the design of the IbEW prototypes. Follow-up focus group discussions and key informant interviews captured in-depth insights from government agencies, humanitarian actors, academics and grassroots organizations, enriching understanding of local vulnerabilities and user needs. To ensure inclusivity, special attention was given to groups disproportionately affected by floods and droughts; for example, women and girls, persons with disabilities and people in camp settings. Their participation helped identify barriers to receiving, understanding and acting on early warnings; including gendered access to information, physical mobility constraints and unequal decision-making power. This collaborative approach created a shared understanding of existing gaps and led to co-produced vulnerability and exposure data.

To broaden participation, preliminary products were later presented at regional forums such as the Greater Horn of Africa Climate Outlook Forum. These sessions provided an avenue for feedback from practitioners across Kenya and neighbouring countries, helping validate the approach and improve usability.

This inclusive process created a shared foundation of knowledge that guided the next module: translating co-produced insights into concrete risk indicators and conceptual models to define what impacts to warn for and who is most at risk.

© Dieuvain Musaghi / Unsplash

Module 1: Practitioners' self-assessment checklist

Key reflection areas	Yes	Partly	No
Understanding the system			
Existing EWSs, their coverage and performance have been mapped and analysed	☐	☐	☐
Institutional, technical and community capacities have been reviewed to define a baseline	☐	☐	☐
The distinction between hazard-based and impact-based systems is clearly understood by all stakeholders	☐	☐	☐
Defining the scope and users			
The spatial and temporal scales of the IbEW are defined and aligned with decision-making processes.	☐	☐	☐
Primary user groups and institutions have been identified, including those responsible for early action protocols and standard operating procedures	☐	☐	☐
Interactions between local, national and regional levels are reflected in the design	☐	☐	☐
Co-production process			
A balanced mix of technical agencies, decision makers and at-risk communities is engaged	☐	☐	☐
Participation mechanisms ensure gender, disability and social inclusion	☐	☐	☐
A structured co-production and feedback process has been established	☐	☐	☐
Advisory or steering groups are in place to guide the process	☐	☐	☐
Reflection			
Stakeholders demonstrate ownership and trust in the IbEW design process	☐	☐	☐
Key needs, capacities and entry points for IbEW transition are clearly documented	☐	☐	☐

© Dibakar Roy / Unsplash

Module 2: Building risk knowledge

Purpose of this module: In this module, you will develop a shared understanding of what to warn for and who is at risk. You will also engage with analytical tools (i.e. impact chains) to map the interconnectedness of risk factors.

Step 2.1. Select hazards, impacts and vulnerability profiles

Each IbEW takes place in a unique setting, which requires dedicated exploration. As a starting point, you can identify and prioritize the hazards that most affect the region, such as droughts, floods, storms or extreme heat. This process should be carried out jointly with local stakeholders to ensure that the system reflects local experiences, knowledge and needs (e.g. group discussions, participatory mapping; see step 1.3.).

Once you have identified the key hazards, analyse the potential impacts of these events. These can include both direct impacts (e.g. crop loss, livestock deaths, damage to infrastructure) and indirect impacts (e.g. reduced income, food insecurity, migration or health crises). Understanding these links helps translate hazard forecasts into meaningful impact warnings.

It is also essential to map exposure and vulnerability. Exposure refers to who or what is in harm's way; for example, settlements, farmlands or critical infrastructure located in flood-prone or drought-affected areas. Vulnerability, on the other hand, explains why certain people or systems are more likely to be affected and are less able to recover. Groups such as smallholder farmers, pastoralists, women-headed households or people living in arid and semiarid regions may be particularly at risk due to limited resources, access to information or coping capacity.

Finally, understanding when and why certain groups are most vulnerable and what coping mechanisms or strengths they already possess can help you later on to tailor warning messages and preparedness actions with your IbEW.

This step works best through participatory processes that bring together scientists, government agencies, community representatives and local organizations. This inclusive approach ensures that the selected hazards and impacts are context-specific and locally relevant. It is important to document the outcome of this exercise in order to perform the analytical assessment in **step 2.2**.

Zoom into Vulnerability profile: To make IbEW actionable for different vulnerable groups, drivers and root causes of risk need to be uncovered. This means to discuss not only what impacts are relevant for IbEW, but also what are the social, political, economic and cultural mechanisms that generate them in the first place and make them disproportionate for specific vulnerable groups. In this step it is vital to include experts from different at-risk populations (e.g. camp management representatives, organizations working with persons with disabilities) to ensure that these deeply rooted determinants of risks are captured.

GUIDING QUESTIONS:

- What are the main hazards in the region?
- What are the main direct and indirect impacts?
- Who is most vulnerable, when and why?
- How are risk drivers and root causes interconnected?

Step 2.2. Co-development of conceptual risk models

Risk knowledge is an important component of IbEW and is at the centre of the proposed approach and methodology described in this guidebook.

One of the key features of risks is their complexity. Scientifically, this means that risks are rarely determined by single factors, but instead emerge as the result of interaction between a multitude of different factors, or drivers, of risk. The kernel of this complexity is already evident in the widespread understanding of risk as not just a function of hazard, but also of exposure and vulnerability. Each of these subcomponents, however, is the results of many diverse and interacting drivers, which require further unpacking. Capturing this complexity is crucial to assess, monitor and address risk. However, it is also challenging, as complexity is by definition elusive and therefore requires a guiding approach and the support of dedicated tools.

Conceptual risk models, which are widely used in climate and DRM and adaptation (Menk and others, 2022), can offer an important first step in describing this complexity and concurrently in building risk knowledge for IbEW. They do so by identifying some of the most important drivers of risk across all subcomponents (hazard, exposure and vulnerability), and then highlighting their interactions in a visual model through cause–effect relationships. The resulting model, especially if co-produced in partnership with stakeholders, can guide understanding and communication of how risks are generated. This can be done by designing an assessment and monitoring methodology, and discussing entry points for different risk reductions solutions (including early warning and IbEW).

The drivers of impacts, hazards, vulnerabilities and exposures identified in **step 2.1**. can now be mapped using the impact chain methodology or similar conceptual model approaches. This step can help you understand the hazards, vulnerability and exposure factors that matter for your assessment.

Zoom into vulnerability profile: The novel framework proposed in this guidebook highlights how vulnerable groups intersect with the interaction of hazard, exposure and vulnerability. Hence, specific conceptual models can be developed to identify risk drivers and root causes that are particularly associated with the impacts on the selected vulnerable group. You can follow the analytical guidance for building conceptual risk models, however, with a strong focus on the risk factors relevant for the selected group.

GUIDING QUESTIONS:

- Which impacts and risks affect your region of concern?
- Which climate-related hazards pose a risk to your system?
- What are the direct and indirect impacts?
- What are the main drivers of vulnerabilities for the particular risks identified?

Impact chains for IbEW: What are they? How to build them and how to use them

Of all different approaches and methodologies for conceptual risk models, "impact chains" (Fritzsche and others, 2014; Hagenlocher and others, 2018; Menk and others, 2022; Zebisch and others, 2021; Zebisch and others, 2023) have gained particular attention in recent years. Impact chains are designed to explore the interrelationships of risk drivers in the subcomponents of hazard, exposure and vulnerability, and are particularly suited to identifying entry points and actions for comprehensive risk management.

Impact chains, as an analytical tool, is particularly adapted to explore in-depth how single risks are generated. In particular, the impact chain methodology prompts the user to first identify and select a specific impact and/or risk of concern; and from there to trace back its drivers of hazard, exposure and vulnerability; and finally to identify the distant but consequential root causes of risks.

The first step in building impact chains is to elicit and construct case-specific risk knowledge with a set of representative stakeholders. This step – which can involve dedicated workshops, focus group discussions or other participatory methods – not only ensures that local risk knowledge emerges and is represented, but also provides an important opportunity for stakeholders, as potential future users of IbEW, to steer the focus and the design of the IbEW system. An example of the risk knowledge generated in this step is the identification of risk(s) of interest, including connected hazards and vulnerable groups to be prioritized.

Secondly, the development of impact chains needs to ground local risk knowledge within the available science. This can be done through in-depth review of the scientific and grey literature, so that additional relevant information can be uncovered and integrated. For example, the literature might report experiences from groups other than those present during the stakeholders' consultations, or provide new findings on how socioecological processes contribute to specific impacts in the area of interest.

When all the information is collected and processed (either qualitatively, quantitatively or both), it can be used to create a visual representation of drivers' interactions. In this phase, it will become apparent that a "sweet spot" lies between being fully comprehensive in capturing all drivers and interactions and keeping the model's visual complexity manageable. Below this balance point, the impact chain result may be too generic to be useful; and, above it, it might be too overwhelming for anyone who was not involved in its production, limiting its communication potential. Consequently, it is best to regard this as a highly iterative process, where the producers aim to identify crucial elements, and leave out or cluster redundancies or less applicable information (e.g. relevant to only a minor subset of the case study).

As a final step, stakeholders' validation is necessary to ensure that the representation of risk in the impact chain aligns with the lived experience of people on the ground. This can be achieved through detailed feedback gathered during dedicated interactions, providing insight to guide constructive changes to the model's content and design. Such a step can also provide a capacity-building component, whereby stakeholders understand how to construct conceptual risk models and use them to identify entry points for risk reduction measures.

Ultimately, developing impact chains for risk knowledge in IbEW clarifies what it can provide in terms of risk reduction (e.g. which drivers are addressed) and what remains to be managed through long-term, comprehensive risk management.

Module 2: Application example

Step 2.1. Identify hazards, impacts and vulnerability profiles

- What are the main hazards in the region?
- What are the direct and indirect impacts?
- Who is most vulnerable, when and why?

The identification of key hazards and impacts began through a co-production process that brought together government agencies, DRM authorities and humanitarian actors. Representatives from the KMD, the NDMA, humanitarian organizations and disaster management agencies came together to discuss which impacts most urgently required early warning. Through these discussions, participants prioritized two key risks: (1) crop loss in rain-fed agricultural systems due to drought, and (2) physical harm caused to people by floods.

Building on these priorities, expert inputs and desk-based research helped to identify three key vulnerability profiles: women and girls, persons with disabilities and people in camp or displacement settings – as being disproportionately affected by both droughts and floods. Women and girls often experience increased livelihood insecurity, caregiving burdens and reduced access to timely warning information. Persons with disabilities face physical and communication barriers that limit mobility and access to evacuation or shelter facilities. People in camp settings are very vulnerable to cascading hazards due to overcrowding, poor infrastructure and dependence on external support.

These intersecting vulnerabilities mean that hazards such as droughts or floods have compounding effects across social groups, amplifying risks to safety, food security and livelihoods. Combining participatory discussions with literature review made it possible to capture both scientific and local knowledge, providing a basis for developing the conceptual risk models in **step 2.2**.

Step 2.2. Develop conceptual risk models

- Which impacts and risks affect your region of concern?
- Which climate-related hazards pose a risk to your system?
- What are direct and indirect impacts? What are the main drivers of vulnerabilities for these risks?

Developing the conceptual risk models began by translating the priority risks from **step 2.1** into visual “impact chains” that show how hazards, exposure and vulnerability interact to create impacts. During stakeholder discussions, participants mapped the main drivers of each component, identifying where risks begin, how they cascade and who is most affected. These insights were then expanded and cross-checked through a literature review.

Two core impact chain models were produced for Kenya: “Risk of physical harm to people due to floods” and “Risk of crop loss and impacts on subsistence farmers in rain-fed agricultural systems due to drought”. Each model was refined in collaboration with stakeholders and enriched with information about vulnerable groups and corresponding risk-management options. The finalized models were validated with stakeholders during focused consultation sessions to ensure that they reflected on-the-ground realities and user needs. In addition, “risk knowledge” deep dives into specific vulnerable groups were also created, in accordance with the conceptual framework (see **Figure 2**). **Figure 3** and **Figure 4** show examples of conceptual models.

Together, these conceptual models form the analytical foundation for the next module, where the identified drivers are translated into spatial indicators and data workflows for operational IbEW.

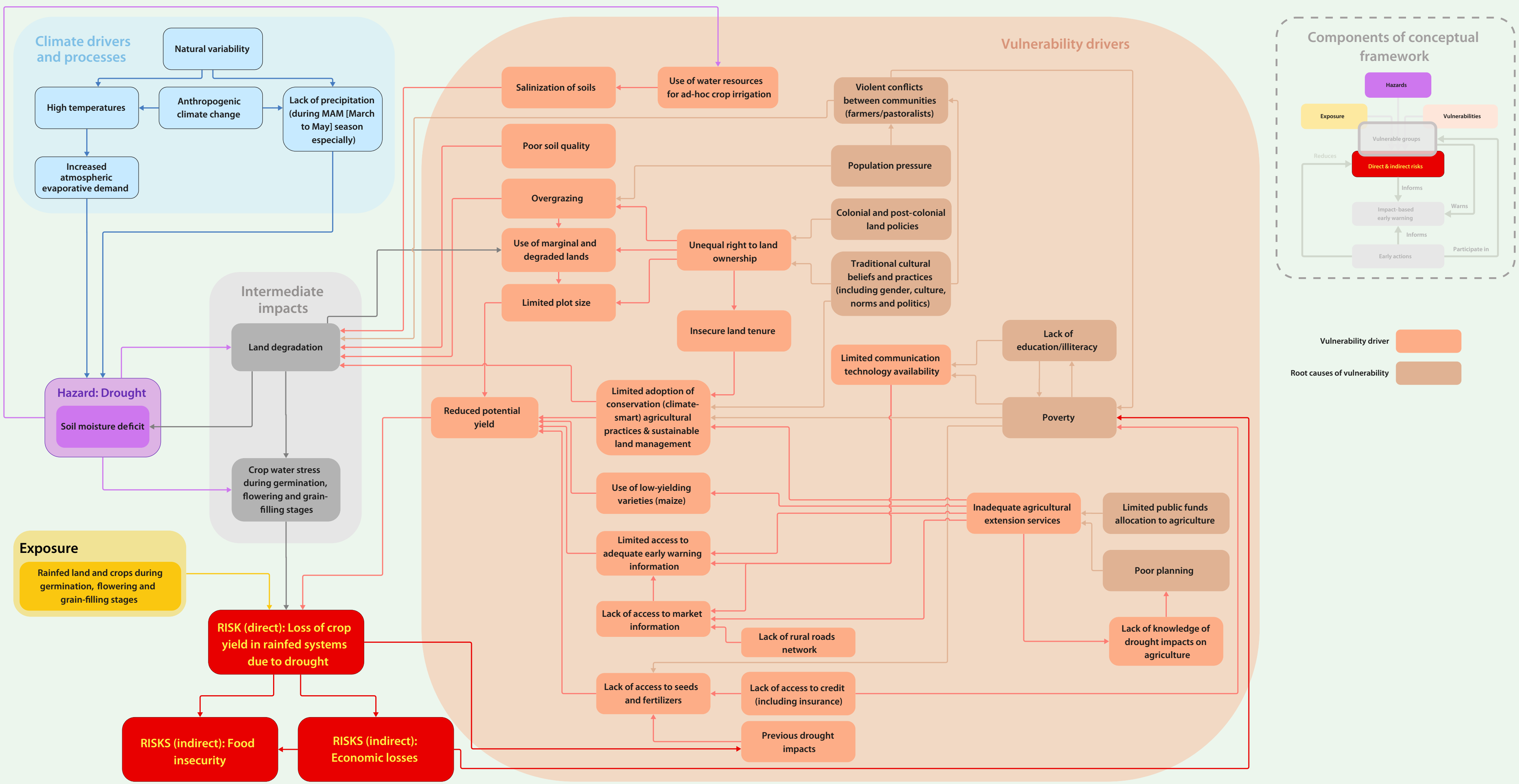

Figure 3: Impact chain conceptual model for risk of crop loss and impacts on subsistence farmers in rain-fed agricultural systems due to drought in Kenya

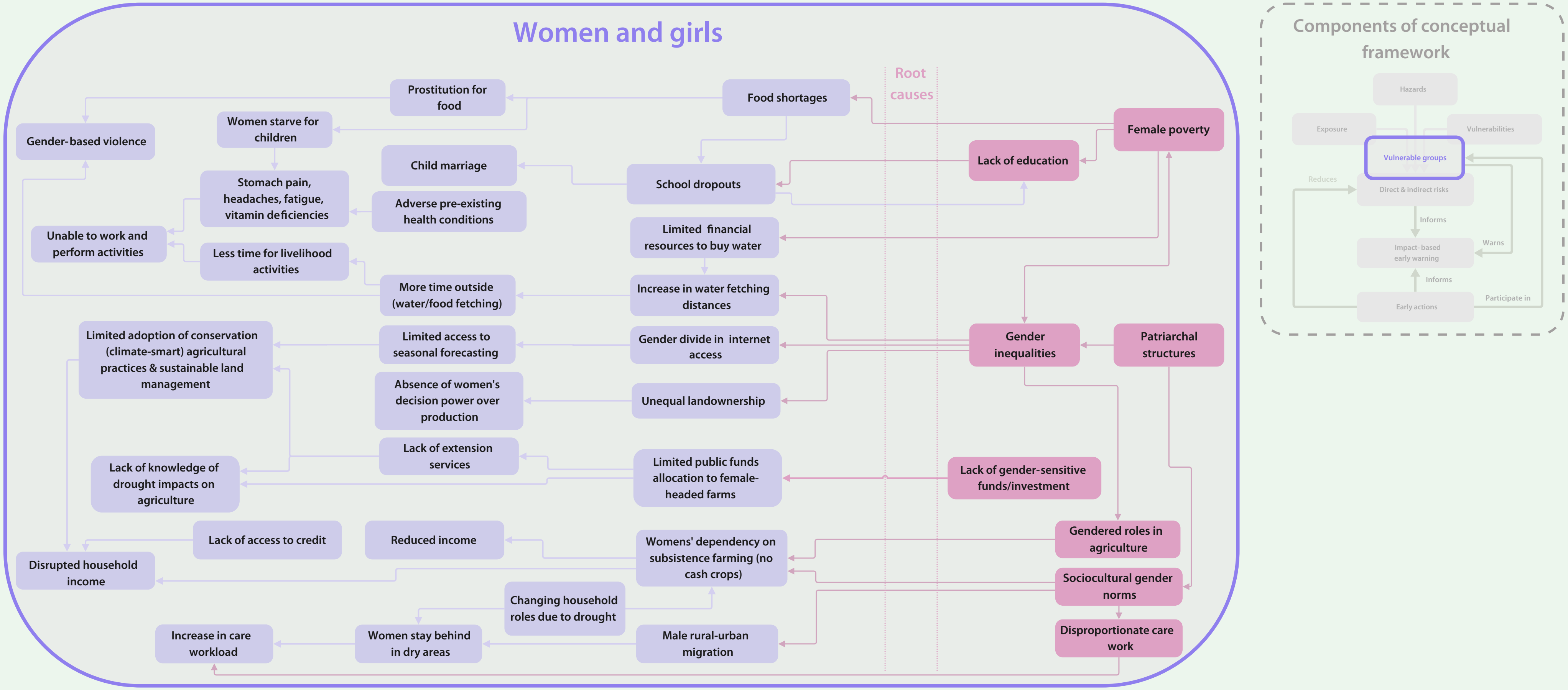

Figure 4: Conceptual model of risk knowledge on women and girls in Kenya in the context of drought-related risks

Module 2: Practitioners' self-assessment checklist

Key reflection areas	Yes	Partly	No
Defining risks and impacts			
Hazards and their impacts have been jointly identified and prioritized	☐	☐	☐
Both direct and indirect impacts (e.g. livelihoods, health, infrastructure)	☐	☐	☐
Groups, assets and systems most at risk are mapped and described	☐	☐	☐
Developing conceptual models			
Impact chains or other causal models have been codeveloped with stakeholders	☐	☐	☐
The models reflect drivers of vulnerability and interlinkages among factors	☐	☐	☐
Conceptual models have been validated through expert or stakeholder review	☐	☐	☐
Participatory methods			
Participatory mapping, focus groups or similar tools have been used to integrate local knowledge	☐	☐	☐
Literature has been considered to triangulate and complement results	☐	☐	☐
Key assumptions and uncertainties in the models are acknowledged	☐	☐	☐
Reflection			
The risk knowledge developed is context-specific and decision-relevant	☐	☐	☐
Vulnerability and exposure factors are evidence-based and traceable to data	☐	☐	☐
Knowledge or data gaps are identified and documented for follow-up	☐	☐	☐


© FORTYTWO / Unsplash

Module 3: From concepts to data

Purpose of this module: This module is about how you can translate the risk knowledge that you have built into measurable, operational components for an IbEWS.

Step 3.1. Select and validate indicators

Indicators are variables that identify the state or the performance of a desired phenomenon of interest. Selecting indicators is particularly important, as they will inform the data collection and the nature of the information delivered by the IbEWS.

Indicators should in general be chosen so that they: (1) ensure validity and relevance (i.e. represent the risk driver from the conceptual risk model well); (3) convey precise meaning (i.e. stakeholders agree on what the indicator is "measuring") and clarity in their direction (i.e. an increase in value is unambiguously positive or negative with relation to exposure or vulnerability); and (3) provide reliability, allowing for the acquisition of data. You can begin by selecting a set of exposure and vulnerability indicators that best describe the key drivers of risk identified in your conceptual model. It is recommended to choose indicators that are specific, measurable and relevant to the local context. Indicators can be direct (e.g. percentage of households located in flood-prone areas) or proxy-based (e.g. access to irrigation as a proxy for drought resilience). When using proxies, it is important to test their validity through stakeholder consultations and expert discussions (e.g. agriculture ministries) to confirm that they accurately represent the underlying condition.

For each indicator, it is important to consider the most appropriate spatial and temporal scales. Some indicators are best measured at the community level (e.g. access to safe water), while others are more meaningful at district or regional scales (e.g. average rainfall variability). Ensure that your indicators align with the intended scale of the IbEWS and the available data sources.

To strengthen ownership and relevance, you can codevelop and validate indicators with stakeholders through participatory workshops or data review sessions. Ultimately, a clear, jointly validated set of indicators allows you to produce consistent, credible and actionable risk assessments that support the design of IbEW messages and early actions.

Zoom into vulnerability profile: To apply a differential vulnerability lens when selecting and validating indicators, ensure that differences in exposure, vulnerability and risk knowledge are explicitly captured (e.g. gender). Wherever possible, choose indicators that can be disaggregated by sex and age, and other relevant factors; and that they include gender-sensitive measures that reflect women's and girls' access to resources, decision-making and risk information (e.g. access to land, credit or early warning messages). When interpreting and using indicators, consider systemic inequalities that may not be captured in the indicators used for measuring and tracking. For example, caregiving burdens, mobility constraints or unequal access to communication channels. Where gaps exist, clearly identify limitations and communicate them to inform future research. Ultimately, integrating these aspects ensures that IbEW indicators are inclusive, contextually grounded and support gender-responsive interventions.

GUIDING QUESTIONS:

- What are suitable indicators to characterize risk knowledge for IbEWC?

Step 3.2. Identify data sources and data collection

You can start this step by reviewing available data sources that provide information on the selected vulnerability and exposure indicators. You can look for both national and global datasets to ensure your IbEWS is built on robust, multilevel evidence, depending on the scale.

At the national level, data may come from government agencies such as national statistical offices; meteorological and hydrological services; ministries of agriculture or environment; or DRM authorities. At the global level, you can use open and recognized datasets from organizations such as the Food and Agriculture Organization (FAO), World Bank, United Nations Environment Programme or the National Aeronautics and Space Administration, which often offer standardized and comparable data.

It is important to apply clear quality criteria when selecting data. Reliable data are typically:

- Produced by credible national or international institutions.
- Updated regularly and available in accessible formats.
- Transparent about their methods and sources.
- Suitable in terms of spatial (level of geographic detail) and temporal (frequency of update) resolution.

As with any risk assessments, verified, recent and spatially detailed data influence the accuracy of your analysis. For example, using high-resolution population or land-use data allows you to better understand who and what is exposed to hazards at the local level.

You can also codevelop data inventory with relevant stakeholders. This helps clarify who holds which data, reveal gaps or overlaps and establish data-sharing arrangements. Where data gaps exist, you can explore complementary methods such as field surveys, remote sensing, participatory mapping or citizen-generated data.

Finally, ensure that data collection and management practices follow clear documentation and storage protocols. This supports transparency, reproducibility and the continuous improvement of your IbEWS over time.

Zoom into vulnerability profile: Where existing data are limited, and conditions allow for it, consider complementing them with participatory or community-based methods such as focus group discussions or participatory mapping with women and girls to fill knowledge gaps. When assessing data quality, also consider whether collection processes capture the realities and voices of women and girls, especially those in marginalized or rural settings. Codeveloping data inventories with gender focal points or women's organizations can help identify gaps, improve inclusiveness and strengthen ownership.

GUIDING QUESTIONS:

- What are the data sources and providers for vulnerability and exposure indicators?
- How are the quality and resolution of the data?
- What are the possible gaps and limitations of the data?

Step 3.3. Preprocess and harmonize data

The data preprocessing phase is a crucial step to ensure that the information used for IbEW is reliable, consistent and ready for analysis. You can think of this step as "getting your data in shape" before it is used to generate indicators or risk maps.

Start by cleaning the data to ensure internal consistency and completeness. This means checking for missing or duplicate values, correcting errors and flagging unusual or unrealistic entries (for example, rainfall values that are physically impossible or population figures that are inconsistent with census data). Clear documentation of any changes made during this step helps maintain data transparency and traceability.

Furthermore, you can harmonize the data so that information from different sources can be combined and compared. Harmonization means imposing the same format, reference system and level of detail on all datasets. For spatial data, this involves processes such as converting datasets to a common coordinate reference system, unifying spatial resolution (e.g. ensuring all gridded data have the same cell size) and standardizing administrative boundaries or units of analysis (e.g. districts or provinces).

These actions ensure that datasets are interoperable and can be layered accurately in spatial or statistical analyses.

Whenever you use global datasets to fill data gaps at national or local levels, they should be validated with stakeholders or local experts to confirm their relevance and accuracy. For instance, rainfall anomaly data from global sources can be compared with local meteorological records or community observations. Reviewing the data for update frequency, level of detail and access restrictions is also important, since these factors influence how effectively the data can support early warning analysis and decision-making.

Engaging stakeholders – such as data providers, local institutions and technical experts – during this step helps verify data quality and build shared ownership of the information used in the IbEWS.

GUIDING QUESTIONS:

- Are the data cleaned, harmonized and quality assessed?
- Is the spatial resolution aligned and suitable for transfer and operationalization in the models and target platforms?

Step 3.4. Create the IbEW workflow and model set-up

Establishing a workflow is a critical step in operationalizing your IbEW. Workflows provide a visual representation of how all the components of a process interact to produce a defined output. They usually include inputs (such as data), processing steps (e.g. preprocessing and modelling) and output generation. A well-designed workflow facilitates interdisciplinary collaboration between producers by delineating responsibilities and ensuring methodological consistency, testing and replicability. Moreover, it enhances transparency for users.

In the context of IbEW, a workflow clarifies and communicates how the vulnerability and exposure data interact with the hazard modelling component to produce an impact assessment and generate all the remaining relevant information that will be featured in the warning message or bulletin. Importantly, an IbEW workflow can also cover and include the thresholds considered for the analysis. Examples of thresholds can be (but are not limited to): the minimum size of the hydrological basins considered, the minimum hazard return period or other metrics of hazard severity (e.g. water height for floods), the number of assets exposed and so on. While many threshold considerations are possible, it is crucial for IbEW to implement them so that they will not affect the actionability and credibility of the warning, or induce ethical doubts. For example, an impact threshold to trigger a warning (e.g. "at least 50 people affected by the flood") needs to be carefully evaluated before being implemented, as it might imply that a certain amount of loss is acceptable. This would undermine the principle of an early warning for all.

In this guidebook, we do not suggest one specific workflow; a variety of approaches to combine vulnerability, exposure and hazard data for impact-based early warning exist, and each case might warrant its own tailored implementation.

For IbEW, this step also includes important technical decisions about the frequency of the model runs (e.g. hourly, daily or weekly), which depend on the availability of updates to the input data (including but not limited to the hazard forecast). The model should be optimized for efficiency, minimizing processing time while maintaining the analytical depth and reliability of outputs.

The model set-up may need to combine multiple environments and integrate external APIs or real-time data feeds for hazard and impact monitoring. Modular design is recommended to enable future adjustments, incorporation of new data sources and methodological enhancements. Intermediate products (such as exposure maps, vulnerability indices or hazard layers) should be stored alongside the final outputs: this enables diagnostic review and advanced analysis by expert users, but also increases transparency in the overall system.

A database management and version control framework can help ensure traceability and reproducibility. This facilitates systematic archiving of input data, intermediate results and final products, enabling historical comparison and evaluation of the performance of the IbEWS.

GUIDING QUESTIONS:

- How is the workflow transformed into an automated system?
- What model do you use to combine risk knowledge for an operational system?

Zoom into vulnerability profile: While creating the workflow and implementing the model, it is essential to keep in mind considerations about the vulnerable groups that are both targets and recipients of the IbEW information produced. The workflow can provide the transparency needed for them to understand exactly how the information and data that is used to represent them will be transformed and elaborated during the analysis. The model implementation, on the other hand, should be set up to also cater for the needs of each group considered (e.g. receiving information in a specific format, or at specific scales).

Module 3: Application example

Step 3.1. Select and validate indicators

- What are suitable indicators to characterize risk knowledge for IbEW?

Building on the conceptual risk models from step 2.2, the key drivers of risk were translated into measurable indicators that describe how floods and droughts affect people and livelihoods. This process involved identifying a practical set of direct and proxy indicators for each hazard: floods, focusing on people at risk or affected; and droughts, focusing on crop yield loss in rain-fed systems.

Table 3: Overview of indicators for impact-based flood early warnings

No	Category	Data name	Description
1	Hazard	Inundation maps	Hydrodynamic inundation maps.
2	Exposure	Gridded population distribution	Spatially distributed population dataset (gridded), reporting absolute number of people per pixel.
3	Vulnerability	People with mobility disability	Percentage of people with disabilities connected to mobility (walking and climbing domain) at the county level.
4	Vulnerability	Age groups	Number of people below 5 or above 65 years of age.
5	Exposure	People in buildings facing potential structural collapse	Number of people affected by damage to their homes and workplaces, in different sectors.

Table 4: Overview of indicators for impact-based drought early warnings

No	Category	Data name	Description
1	Hazard	Combined drought indicator (CDI)	Three drought indicators produced operationally in the EDO framework, comprising the standardized precipitation index, the soil moisture anomaly and the fraction of absorbed photosynthetically active radiation (fAPAR) anomaly to allow areas to be classified according to three primary drought categories.
2	Vulnerability	Crop calendars for the three main crops: maize, wheat and sorghum	Calendar showing monthly information for planting/sowing, harvesting and growing, available at each Agro-Ecological Zone.
3	Exposure	Crop production quantity for maize, wheat and sorghum in rain-fed agricultural systems	Estimations of crop distribution within disaggregated units.
4A	Vulnerability	Number of subsistence farmers	Farmers who grow crops only for home/family consumption; number of farmers doing subsistence farming based in national statistics.
5A	Vulnerability	Contribution of agriculture, forestry and fishing sectors to gross county product (GCP)	Contribution of agriculture, forestry and fishing sectors to GCP, an overall economic output of Kenya, and the county-level equivalent of the national gross domestic product (GDP).
6A	Vulnerability	Food poverty	All individuals (or households, if estimated at household level) whose food consumption per adult equivalent was less than the food poverty line of KS h 2,668 per month in rural areas and KS h 3,520 per month in urban areas were considered to be food poor or live in "food poverty."

Step 3.2. Identify data sources and data collection

- What are the data sources and providers for vulnerability and exposure indicators?
- How are the quality and resolution of the data?
- What are the possible gaps and limitations of the data?

To support the selection of indicators, available datasets were reviewed and mapped through both online research and direct engagement with national data providers. This process helped identify what information already exists, who manages it, and how it can be accessed. The review focused on key aspects such as data format, spatial and temporal resolution, coverage, update frequency and accessibility. It also helped highlight gaps, such as missing local data or inconsistent updates that may limit the precision of impact-based analyses.

Step 3.3. Preprocess and harmonize data

- Are the data cleaned, harmonized and quality assessed? Is the spatial resolution aligned and suitable for operationalization in the target platform?

This step ensures that all datasets are consistent, comparable and ready for use in the IbEW workflows. Harmonization allows different types of data, from population statistics to hydrological maps, to work together seamlessly within the same analytical environment.

All geospatial layers were standardized to the 1984 World Geodetic System to ensure interoperability. Statistical data were aligned to Administrative Level 1 (counties in Kenya), providing the best balance between data detail and model efficiency (e.g. the size of sub-basins considered for the hydrological model).

Data preprocessing for drought: Data for three locally important crops – maize, wheat and sorghum – were checked and harmonized for completeness and interoperability. FAO crop calendar data were reviewed to correct inconsistencies in phenological stages and validated against local sources. Because Kenya has two cropping seasons per year, annual production values were evenly split between them as an interim measure.

Data preprocessing for flood: Input datasets for FloodPROOFS (satellite rainfall, reanalysis and forecasts) were downscaled from ~10–28 km to the model's ~1–3 km grid, and resampled to hourly time steps. Inundation outputs at 90 m resolution were harmonized with exposure and vulnerability rasters. Age- and disability-disaggregated population data were recreated from Kenya's national census and WorldPop, converted into ratios at county level and spatialized across the population grid. Quality assurance included prerun checks (projection, grid alignment, null values, timestamps) and postrun spot checks for sample counties before publishing results.

Step 3.4. Create the IbEW workflow and model set-up

- How is the workflow transformed into an automated system? What model do you use for combining risk knowledge for an operational system?

This step translates the risk knowledge developed in previous modules into operational workflows that can generate real-time impact-based early warnings. Two IbEW workflows were developed for Kenya, one focusing on drought-related crop loss and another on flood-related harm to people (see **step 2.2** conceptual risk models) and the IbEW framework (**Figure 2**). Each workflow follows three steps:

- Hazard-exposure analysis: combine hazard forecasts with spatial information on exposed assets and populations.
- Contextual warning information: add vulnerability layers to identify who may be most at risk and why.

- Impact-based warning: integrate all components into a single, user-oriented output such as a warning map or bulletin.

Drought workflow: Crop yield loss in rain-fed systems

Hazard component: The CDI was selected as the main metric. Originally developed by the Joint Research Centre of the European Commission and adapted by ICPAC for the EADW platform, CDI offers a robust and well-known multi-indicator framework for monitoring drought hazards across three key dimensions: precipitation, soil moisture and vegetation anomaly.

Exposure component: To translate CDI information into actionable risk insights, spatially and temporally differentiated crop data were integrated. The first step was to distinguish cropland areas from other land uses using the FAO Spatial Production Allocation Model (MAPSPAM), which provides crop-specific annual production maps (in metric tonnes) disaggregated by production systems: rain-fed, irrigated or mixed. To capture seasonal dynamics, crop calendars were added. These show the typical growth stages (phenology) of each crop by month and by county. Combining CDI outputs with crop calendars made it possible to assess how drought conditions coincide with different growth stages, revealing how much

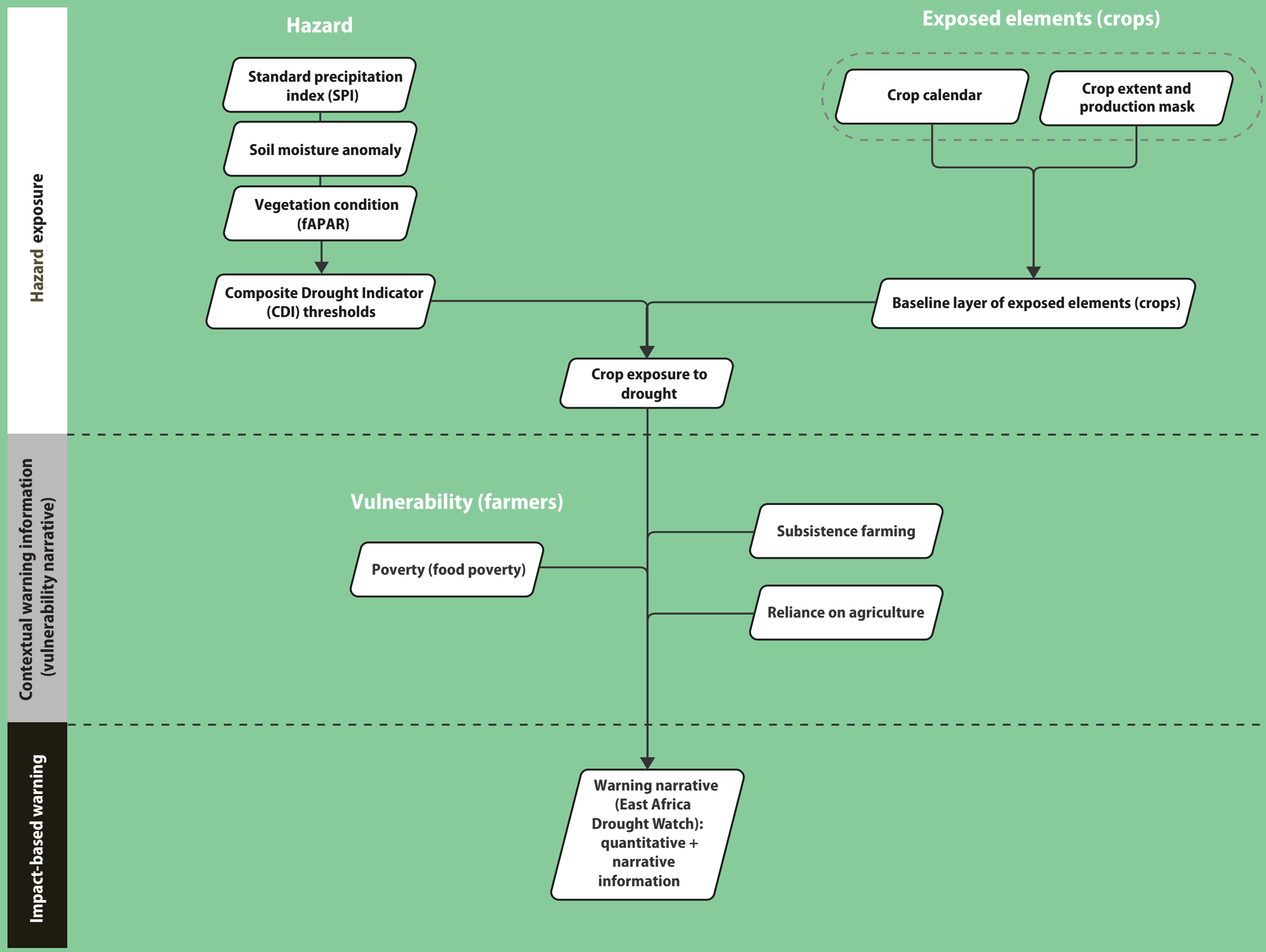

Figure 5: Simplified workflow for IbEW for risk of crop loss and impacts on subsistence farmers in rain-fed agricultural systems due to drought

Source: Authors.

potential production is at risk at any given time and location. By matching drought intensity with crop type, stage and location, the workflow generated dynamic hazard-exposure maps showing where and when drought stress could cause yield loss.

Vulnerability (contextual) component: The workflow also integrates vulnerability data as "contextual warning information" on who is most at risk and why. This component represents selected vulnerability drivers in the conceptual models and is meant to offer an overview of pre-existing challenges for subsistence farmers, providing additional context for early action decisions and guidelines.

Figure 5 shows the resulting IbEW workflow for risk of crop loss and impacts on subsistence farmers in rain-fed agricultural systems due to drought.

Flood workflow: Risk of physical harm to people (Kenya)

This workflow demonstrates how to generate an IbEW for floods by combining hydrological forecasts with population and vulnerability information. The approach focuses on riverine floods, simulated using the FloodPROOFS model, developed by the Centro Internazionale in Monitoraggio Ambientale Research Foundation and applied within the Greater Horn of Africa EWS.

Hazard and exposure: FloodPROOFS integrates data on inundation extent, depth and flood magnitude with spatial population data to generate high-resolution hazard-exposure maps. These maps help identify areas where people and assets are most likely to be affected under different flood scenarios.

Vulnerability component: To better reflect how impacts vary across groups, two flood depth thresholds, 25 cm and 100 cm, are applied to assess exposure among elderly people, children and individuals with mobility disabilities. This distinction acknowledges that certain groups are more sensitive to flooding than others, moving beyond the "average adult" assumption often used in impact modelling.

To improve accuracy in identifying affected populations, an additional exposure layer was developed. This layer estimates the population living in buildings likely to experience significant damage by combining information on building materials and flood-depth-specific collapse thresholds derived from existing vulnerability curves, to which population data are downscaled. In addition, health facilities are mapped as critical infrastructure layers, to inform preparedness and response planning. Together, these components create a dynamic workflow that visualizes not just where floods will occur, but who and what will be affected.

Figure 6 (below) shows the resulting IbEW workflow for risk of physical harm to people due to flood.

Model set-up and automation

The drought IbEW workflow was implemented as an ArcGIS toolbox and a stand-alone R script. The model ingests CDI maps, county boundaries and crop baseline layers (production and phenology). It overlays CDI × crop stage × production to estimate the volume of crop yield under drought stress; aggregates result to counties, and appends vulnerability information (e.g. food poverty, number of subsistence farmers). Outputs – tables and shapefiles – feed directly into the EADW platform, allowing users to filter by CDI class and crop stage.

For floods, the daily five-day forecasting pipeline runs three automated steps: hydrological simulation and threshold detection; inundation depth and extent mapping; and impact and warning-level generation.

The system integrates hazard, exposure and vulnerability to estimate affected populations. Two flood-depth thresholds (25 cm and 100 cm) represent different risk levels for children, elderly persons and people with mobility disabilities. Warning levels are derived using relative and absolute thresholds, co-produced with regional partners and aggregated to county level. Additional impact layers such as covering crops, grazing land, built-up areas, livestock and road networks, are also generated and published on the EAFW platform.

Each model run is logged and time-stamped to ensure transparency and version control. Dashboards display the last update time, helping users verify data freshness and reliability.

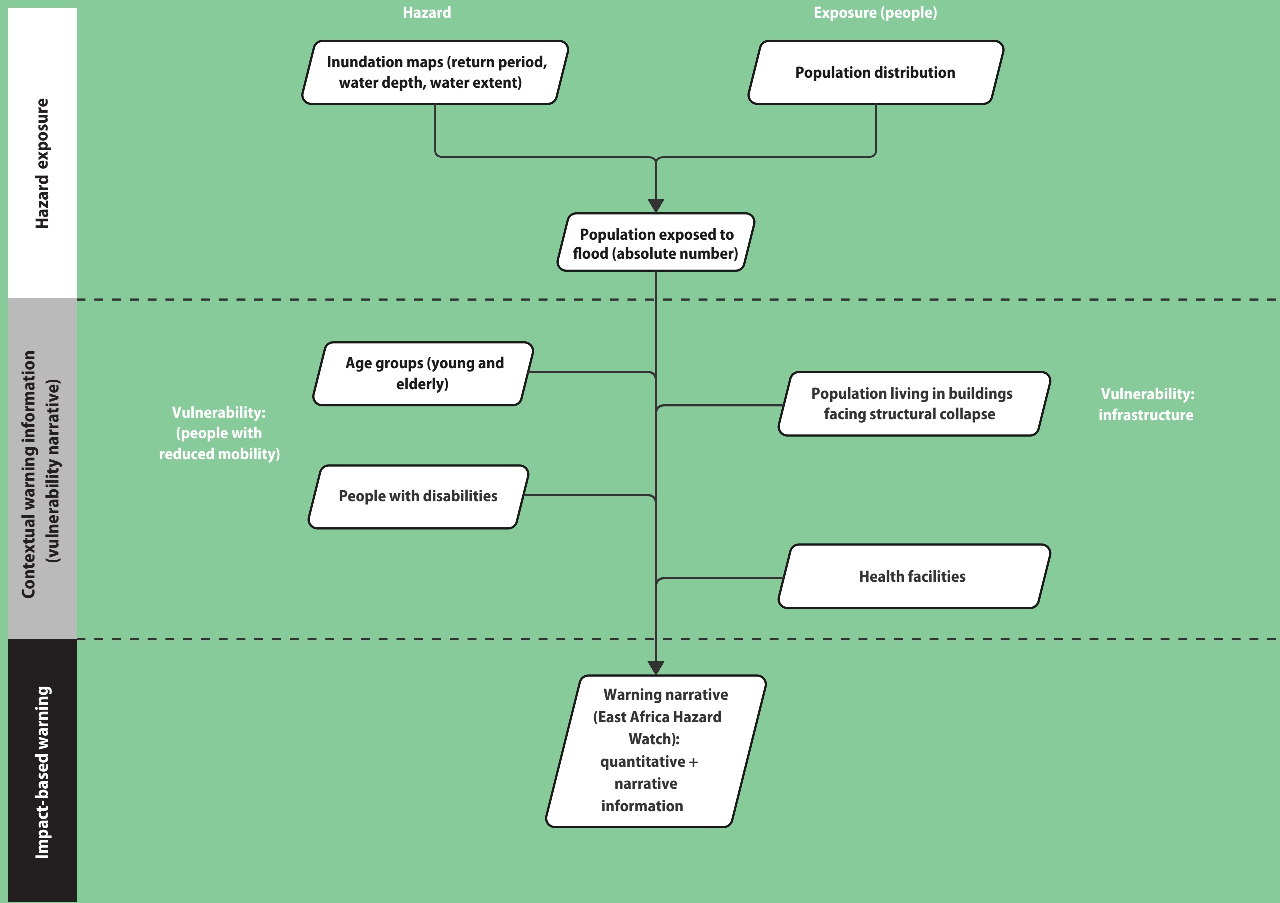

Figure 6: Simplified workflow for IbEW for Risk of physical harm to people due to flood

Source: Authors.

Module 3: Practitioners' self-assessment checklist

Key reflection areas	Yes	Partly	No
Indicator selection			
Indicators accurately represent key vulnerability and exposure factors	☐	☐	☐
Indicators are measurable, relevant and context-appropriate	☐	☐	☐
Indicator selection has been validated with technical and local experts	☐	☐	☐
Data sources and quality			
National, local and global data sources have been identified and reviewed	☐	☐	☐
Data quality criteria (credibility, timeliness, resolution, transparency) are applied	☐	☐	☐
Data gaps and limitations are documented and addressed	☐	☐	☐
Data harmonization and processing			
Datasets are cleaned, harmonized and quality-checked	☐	☐	☐
Spatial and temporal resolutions are compatible for integration	☐	☐	☐
Data processing steps are documented for transparency and reproducibility	☐	☐	☐
Workflow and model design			
A clear workflow connects data inputs, analysis and warning outputs	☐	☐	☐
Roles and responsibilities for workflow operation are defined among partners	☐	☐	☐
The workflow supports automation, regular updates and scalability	☐	☐	☐
Reflection			
Stakeholders and data providers have validated the workflow and outputs	☐	☐	☐
Uncertainties and limitations of data and models are communicated	☐	☐	☐

Module 4: Operationalization and communication

Purpose of this module: This module is about how you can translate the risk knowledge that you have built into measurable, operational components for an IbEWS.

Step 4.1. Visualization and user interface

Designing effective visualizations and a user interface to deliver IbEW requires careful consideration of how risk information is communicated to diverse users.

You can utilize various formats to visualize IbEW effectively in the target outlet (e.g. platform, bulletins). This can include various formats (e.g. interactive maps showing predicted impacts overlaid with population or infrastructure data; impact summary dashboards providing key statistics, thresholds and alert levels; scenario narratives that describe potential outcomes in plain language; and alert bulletins that combine visual and textual information to support early actions decision-making).

Integrating vulnerability and exposure information into the selected interface can add significant value, allowing users to understand what the potential impacts could be. Another opportunity afforded by a dedicated user interface is the display of high-risk areas with clear colour coding (e.g., red for severe, orange for moderate), together with icons that indicate exposed assets such as schools, health centres or farms. Short text summaries or pop-up messages can explain the expected impacts in plain language; such as, “Flooding may affect up to 1,200 households and two health centres in the lower basin.”

While there is no one-size-fits-all approach, codesign different options that are suitable for the product of concern can help ensure that risk knowledge is integrated in a clear, actionable and accessible manner.

Zoom into vulnerability profile: While creating the users’ interface, consideration of accessibility from different groups are paramount. It is critical to acknowledge that different end users have different needs in terms of access and communication. For example, disability-inclusive interfaces should be considered to allow universal access to information.

GUIDING QUESTIONS:

- How can risk-informed early warning information be visualized effectively in the target outlet?
- What are the key dissemination formats and channels for different user groups to include IbEW?
- How can vulnerability and exposure information be integrated into a user-centric interface?

Step 4.2. Validate results and integrate feedback

Validation and evaluation of implementation are essential to assess its technical performance, practical usability and integration with existing early action mechanisms.

From a technical perspective, validation means testing the system's performance, including the accuracy, lead time and consistency of IbEW. For example, testing against past disaster events to verify that the IbEW system accurately predicts observed impacts and reflects the actual vulnerability and exposure of people, sectors and assets of concern.

Validation must also assess how well the system operates under pressure, such as during cascading or compound hazards. In terms of inclusivity, the validation process often includes technical and institutional actors, while the perspectives of at-risk groups (such as communities, women and girls, persons with disabilities or subsistence farmers) are frequently overlooked.

While IbEW is often developed to inform humanitarian actors and DRM agencies, it is critical to consider the validation and actionability of IbEW with those who are most affected. Finally, evaluating the actionability of IbEW products depends on the targeted user group, which is why a robust validation strategy must not only test technical performance, but also assess whether the system delivers timely, understandable and actionable warnings to all users.

Zoom into vulnerability profile: In the validation process, it is important to check if the IbEW response is effective for the differential vulnerabilities of the selected vulnerable groups. For example, whether the impacts that are included in the warning reflect the realities of women and girls. An in-depth evaluation and validation process should consider these factors.

GUIDING QUESTIONS:

- Has the IbEW methodology been validated against historical impact data and past events?
- What specific metrics are used to evaluate the performance of the methodology?
- Which key stakeholders or user groups have not yet been consulted?
- How relevant and usable is the IbEW for different target user groups?
- Does the IbEW align with existing early action mechanisms in the country?

Step 4.3. Build capacities

Capacity-building for different DRM and humanitarian actors, as well as national members, is essential for establishing uptake and leverage capacities for IbEW. Strengthening the skills and knowledge of these stakeholders ensures that they can use, interpret, communicate and act on early warning information in a timely and coordinated manner, which is crucial for minimizing disaster risks and protecting lives and livelihoods.

For example, engaging decision makers to utilize IbEW tools, understand vulnerability and exposure data, and translate warnings into early, targeted actions. By investing in capacity-building, countries enhance their preparedness and response capabilities, ensuring that EWSs are not only technically sound but also actionable and trusted by the people, sectors and systems they serve.

Zoom into vulnerability profile: Building capacities to understand risks to vulnerable groups is crucial to effective use of IbEW by stakeholders, that is tailored to the needs of these groups. Furthermore, empowerment and building resources amongst representatives of the vulnerable groups can further enrich the actionability of IbEW over the long term.

GUIDING QUESTIONS:

- What specific skills and knowledge do DRM and humanitarian actors, as well as national members, need to effectively interpret, communicate and act on IbEWs?
- How can training and capacity-building activities be designed to foster collaboration and information sharing among different stakeholders involved in the EWS?

Step 4.4. Limitations

This step involves a critical reflection on the assumptions and limitations that shape the design, performance and interpretation of the IbEW system. Recognizing limitations is not a weakness, but it is an essential part of ensuring transparency, credibility and continuous improvement.

An important first step is to examine conceptual limitations, such as simplifying assumptions made within the risk framework or modelling approach. For example, hazard-impact relationships may rely on linear assumptions that do not fully capture complex interactions or cascading effects. Similarly, vulnerability and exposure are often treated as static variables, even though they evolve over time due to social, economic or environmental changes.

Next, assess data-related constraints that may affect analytical accuracy and generalizability. These can include incomplete or outdated datasets, inconsistent spatial or temporal resolution, reliance on proxy indicators, or the use of global datasets that do not fully represent local conditions. Acknowledging such limitations helps clarify the uncertainty range associated with impact forecasts, and strengthens the interpretation of results.

It is also important, in this phase, to consider operational limitations to implementation; such as computational capacity, automation reliability, institutional coordination gaps or limited engagement with specific user groups. These factors can influence the timeliness, inclusivity or sustainability of IbEW operations.

Finally, this step provides an opportunity to identify pathways for methodological refinement and system enhancement.

Zoom into vulnerability profile: For this step, it is important to think about biases, positionality and specific limitations that might impact the actionability of the product for specific vulnerable groups. Identifying and documenting the shortcomings of the IbEW for specific vulnerable groups can help in recommending improvements and evaluating performance in terms of inclusivity and actionability over the longer term.

GUIDING QUESTIONS:

- What are the key assumptions and limitations of the chosen methodology, and how might they affect the quality or generalizability of the findings?
- How do specific aspects of the conceptual framework, data selection or implementation process constrain the scope or interpretation of results?
- What opportunities for methodological refinement or expansion of warning products can be identified for future improvement?

Module 4: Application example

Step 4.1. Visualize and design user interface

- How can risk-informed early warning information be visualized effectively in the target outlet?
- What are the key dissemination formats and channels for different user groups to include IbEW?
- How can vulnerability and exposure information be integrated into a user-centric interface?

Flood IbEW visualization: New impact forecast layers were developed using the FloodPROOFS model, which runs automatically on a cloud platform. Each time new weather data become available, the system generates daily forecasts of inundation depth, extent and population affected. These layers are transferred to the EAFW platform, providing near real-time insights into who and what may be impacted. By combining hazard data with exposure and vulnerability information, the platform moves beyond simply predicting “where it will rain” to illustrating how floods will affect people and assets. This enables targeted preparedness and response planning at both national and subnational levels.

Drought IbEW implementation: A complementary data pipeline was developed to assess drought exposure of maize, wheat and sorghum using the CDI, crop calendars, and vulnerability layers. The pipeline produces monthly and decadal risk maps showing potential yield losses and counties most affected.

These visual outputs are published on the EADW platform, shifting early warnings from purely hazard-based forecasts to impact-oriented tools that inform agricultural planning, food security analysis and anticipatory action.

Step 4.2. Validate results and integrate user feedback

- Has the IbEW methodology been validated against historical impact data and past events? What specific metrics are used to evaluate the performance of the methodology?
- Which key stakeholders or user groups have not yet been consulted? How relevant and usable is the IbEW for different target user groups?
- Does the IbEW align with existing early action mechanisms in the country?

Validation combined technical testing with stakeholder engagement to ensure that IbEW products are both reliable and user-friendly. Feedback was gathered through the Greater Horn of Africa Climate Outlook Forum, bilateral consultations and a dedicated validation workshop in Kenya.

Participants from government agencies, humanitarian organizations and technical institutions emphasized three main priorities: localized insights at county or ward level to better guide local decision-making; integration of national datasets from the Ministry of Agriculture, NDMA and other agencies to improve contextual accuracy; and simplified visualizations using colour codes and symbols consistent with existing national warning systems. These recommendations guided improvements to visualization and message clarity, ensuring that IbEW outputs are both technically sound and operationally relevant.

Step 4.3. Build capacities

- What specific skills and knowledge do DRM and humanitarian actors, as well as national members, need to effectively interpret,

communicate and act on impact-based early warnings?
- How can training and capacity building activities be designed to foster collaboration and information sharing among different stakeholders involved in EWS?

A national capacity training workshop in Kenya brought together over 40 participants from disaster management authorities, humanitarian partners and technical agencies. The two-day event combined short conceptual overviews with hands-on exercises, where participants used IbEW tools, analysed exposure and vulnerability maps, and practiced linking forecast results to potential early actions. The training helped participants understand how to interpret and communicate risk-informed warnings, enhancing their confidence to use IbEW products in real-world operations.

Step 4.4. Reflect on limitations and opportunities for improvement

- What are the key assumptions and limitations of the chosen methodology, and how might they affect the quality or generalizability of the findings?
- How do specific aspects of the conceptual framework, data selection or implementation process constrain the scope or interpretation of results?
- What opportunities for methodological refinement or expansion of warning products can be identified for future improvement?

This step focuses on identifying key assumptions, data constraints and operational challenges that may influence the reliability and use of IbEW results. Every IbEW process faces hurdles, such as limited data availability, coarse spatial resolution or insufficient local validation, that can influence the precision and timeliness of forecasts. To strengthen system reliability over time, it is essential to: document identified limitations clearly and transparently; engage data providers and technical partners to close gaps in data quality or coverage; integrate local and indigenous knowledge to enhance contextual understanding; and continuously test and validate outputs against real events to refine model performance.

By viewing these challenges as part of an iterative learning process, institutions can progressively improve the accuracy, trust and usability of IbEWSs.

Module 4: Practitioners' self-assessment checklist

Key reflection areas	Yes	Partly	No
Visualization and communication			
Visualization formats and interfaces are codesigned with target users	☐	☐	☐
Hazard forecasts are clearly linked to expected impacts on people, sectors and assets	☐	☐	☐
Products are accessible and inclusive (e.g. disability-friendly, plain language)	☐	☐	☐
Multiple dissemination channels (e.g. dashboards, bulletins, alerts) are used	☐	☐	☐
Validation and feedback			
The IbEW has been tested against historical data or real-world events	☐	☐	☐
Metrics for accuracy, timeliness and usability are defined and applied	☐	☐	☐
Feedback from all user groups, including at-risk communities, is integrated	☐	☐	☐
The IbEW aligns with existing early action and response protocols	☐	☐	☐
Capacity strengthening			
Capacity needs of institutions and practitioners have been assessed	☐	☐	☐
Training and knowledge-sharing plans are developed and implemented	☐	☐	☐
Mechanisms for cross-agency collaboration and data exchange are established	☐	☐	☐
Limitations and learning			
Value addition to hazard-centric forecasts are documented	☐	☐	☐
Methodological assumptions and limitations are clearly assessed	☐	☐	☐
Areas for refinement, scaling or replication are identified	☐	☐	☐
Mechanisms for continuous learning and improvement are in place	☐	☐	☐
Reflection			
The IbEW effectively supports anticipatory action and risk-informed decision-making	☐	☐	☐
Users demonstrate confidence and capacity to interpret and act on warnings	☐	☐	☐


© RoonZ nl / Unsplash

About the EarlyWarning4IGAD project

The United Nation's Early Warnings for All initiative aims to ensure that EWSs protect everyone on Earth by 2027 (WMO and UNDRR, 2022). In the Horn of Africa, a region particularly affected by disasters connected with hydrological extremes, multiple EWSs tools and initiatives that provide hazard-based warnings exist, but an established methodology and application for IbEW is currently absent. Information about expected impacts, and not just upcoming weather or hazard conditions, can enhance early warning and ensure more effective early action.

Addressing this need, the EarlyWarning4IGAD project supports the transition from hazard-based EWSs towards actionable impact-based EWSs focusing on the IGAD region in Eastern Africa, with Ethiopia and Kenya as pilot countries. The focus of the project is on floods and droughts and the risks associated with these hazards (i.e. harm to people due to floods and drought risks for small-scale farmers in rain-fed subsistence agriculture) with the aim to codevelop an approach and methodology that can be extended to other climate-related extremes and natural hazards.

This project was executed by United Nations University Institute for Environment and Human Security (UNU-EHS, Germany) in close collaboration with ICPAC (Kenya), the Regional Centre for Mapping of Resources for Development (RCMRD, Kenya) and Centro Internazionale in Monitoraggio Ambientale (Italy). The project is funded by the United Nations Office for Disaster Risk Reduction under the "Strengthening Disaster Risk Governance and Recovery Capacities Action", within the Intra-ACP Natural Disaster Risk Reduction Programme funded under the 11th European Development Fund.

References

Assessment Capacities Project (2022). Kenya - Impact of Drought on the Arid and Semi-Arid Regions. Thematic report. Available at www.acaps.org/fileadmin/Data_Product/Main_media/20220331_acaps_thematic_report_kenyaimpact_of_drought.pdf. Accessed on 19 January 2026.

Fritzsche, Kerstin, and others (2014). The Vulnerability Sourcebook: Concept and guidelines for standardised vulnerability assessments. Obrigheim, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit, Adelphi and European Academy of Bolzano.

Greibe Andersen, Johanne, and others (2023). Climate change and health risks in Mukuru informal settlement in Nairobi, Kenya – knowledge, attitudes and practices among residents. *BMC Public Health*, vol. 23, No. 393.

Hagenlocher, Michael, and others (2018). Climate Risk Assessment for Ecosystem-Based Adaptation: A Guidebook for Planners and Practitioners. Bonn. Deutsche Gesellschaft für Internationale Zusammenarbeit, European Academy of Bolzano and United Nations University – Institute for Environment and Human Security. Available at www.adaptationcommunity.net/wp-content/uploads/2018/06/giz-eurac-unu-2018-en-guidebook-climate-risk-asessment-eba.pdf. Accessed on 19 January 2026.

Harrowsmith, Melanie, and others (2020). The Future of Forecasts: Impact-Based Forecasting for Early Action. International Federation of the Red Cross; UK MET Office. Available at www.forecast-based-financing.org/wp-content/uploads/2020/09/Impact-based-forecasting-guide-2020.pdf. Accessed on 19 January 2026.

Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Kenya National Bureau of Statistics (2025). National Agriculture Production Report. Available at https://www.knbs.or.ke/wp-content/uploads/2025/10/National-Agriculture-Production-Report-2025.pdf. Accessed on 19 January 2026.

Kiptum, Augustine, and others (2023). Advancing operational flood forecasting, early warning and risk management with new emerging science: Gaps, opportunities and barriers in Kenya. *Journal of Flood Risk Management*, vol. 18, No. 1, e12884.

Menk, Linda and others (2022). Climate change impact chains: A review of applications, challenges, and opportunities for climate risk and vulnerability assessments. *Weather, Climate, and Society,* vol. 14, No. 2, pp. 619–636.

Oduor, Frankline (2025). Floods displace over 500 families in Nairobi slums as Mathare wall collapse kills three. Kenyans.co.ke. Available at https://www.kenyans.co.ke/news/111317-floods-displace-over-500-families-nairobi-slums-mathare-wall-collapse-kills-three. Accessed on 19 January 2026.

Pfeiffer, Samira and others (2025). Bridging the gaps: Vulnerability profiles to strengthen impact-based early warning and early action for floods and droughts in Kenya. Bonn, Germany: United Nations University Institute for Environment and Human Security. Available at https://doi.org/10.53324/BBZL1019. Accessed on 19 January 2026.

Potter, Sally H., and others (2025). Research Gaps and Challenges for Impact-Based Forecasts and Warnings: Results of International Workshops for High Impact Weather in 2022. *International Journal of Disaster Risk Reduction*, vol. 118, p. 105234. DOI: 10.1016/j.ijdrr.2025.105234.

United Nations Office for the Coordination of Humanitarian affairs (2023). Kenya Drought Response Plan, January–December 2023 (Issued January 2023). Available at https://www.unocha.org/publications/report/kenya/kenya-drought-response-plan-january-december-2023. Accessed on 19 January 2026.

United Nations Office for Disaster Risk Reduction, and Centro Internazionale in Monitoraggio Ambientale Research Foundation (2024). Handbook on the Use of Risk Knowledge for Multi-Hazard Early Warning Systems. Geneva, Switzerland. United Nations Office for Disaster Risk Reduction; Centro Internazionale in Monitoraggio Ambientale Research Foundation. Available at https://www.undrr.org/media/101628. Accessed on 19 January 2026.

United Nations Office for Disaster Risk Reduction, and World Meteorological Organization (2024). Global Status of Multi-Hazard Early Warning Systems. Geneva, Switzerland. United Nations Office for Disaster Risk Reduction; World Meteorological Organization. Available at: https://www.undrr.org/media/91954. Accessed on 19 January 2026.

United Nations Office for Disaster Risk Reduction and World Meteorological Organization (WMO) (2025). Global Status of Multi-Hazard Early Warning Systems. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction and World Meteorological Organization. Available at https://www.undrr.org/reports/global-status-mhews-2025. Accessed on 19 January 2026.

World Bank Group (2021). Climate Risk Country Profile: Kenya. World Bank Group. Available at https://afri-res.uneca.org/sites/default/files/2023-07/15724-wb_kenya_country_profile-web.pdf. Accessed on 19 January 2026.

World Meteorological Organization, and United Nations Office for Disaster Risk Reduction (2022). Executive Action Plan: Early Warnings for All. World Meteorological Organization and United Nations Office for Disaster Risk Reduction. Available at https://earlywarningsforall.org. Accessed on 19 January 2026.

Zebisch, Marc, and others (2023). Climate Risk Sourcebook. Bonn and Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH. Available at https://collections.unu.edu/eserv/UNU:9270/Zebisch_etal_2023_Climate_Risk_Sourcebook.pdf. Accessed on 19 January 2026.

Zebisch, Marc, and others (2021). The vulnerability sourcebook and climate impact chains – a standardised framework for a climate vulnerability and risk assessment. *International Journal of Climate Change Strategies and Management,* vol. 13, No. 1.

Imprint

Bonn, Germany
May 2026

Authors
Samira Pfeiffer[1], Davide Cotti[1], Nkemakonam Naomi Ukatu[1], Maria Dewi[1], Augustin Kiptum[1], Judith Kawikya Musa[1], Lorenzo Alfieri[2], Andrea Libertino[2], Tatiana Ghizzoni[2], Daria Ottonelli[2], Eva Trasforini[2], Paul Mwangi[3], Frankline Rono[3], James Nyaga[3], Vincent Okoth[4], Mark Lelaono[4], Ezra Limo[4], Jully Ouma[4], Ahmed Amdihun[4], Saskia E. Werners[1], Michael Hagenlocher[1]

[1] United Nations University Institute for Environment and Human Security (UNU-EHS), Germany
[2] Centro Internazionale in Monitoraggio Ambientale Research Foundation, Italy
[3] Regional Center for Mapping of Resources for Development (RCMRD), Kenya
[4] Regional Climate and Prediction Center (IGAD ICPAC), Kenya

Suggested citation
Pfeiffer, Samira and others (2026). Knowing what the weather will do: A guide for practitioners on impact-based early warning. Practical examples for floods and droughts in Eastern Africa. Bonn: United Nations University Institute for Environment and Human Security.

Acknowledgements
The authors would like to thank the participants of the stakeholder workshops and expert consultations for useful insights, comments and feedback. We would also like to thank United Nations Office for Disaster Risk Reduction colleagues for reviewing and supporting the development of this report.

Funding source
This work has been conducted as part of the EarlyWarning4IGAD project. The project is funded by the United Nations Office for Disaster Risk Reduction; grant agreement: UNDRR/GR/2023/027) under the "Strengthening Disaster Risk Governance and Recovery Capacities Action", within the Intra-ACP Natural Disaster Risk Reduction Programme funded under the 11th European Development Fund. United Nations Office for Disaster Risk Reduction would like to acknowledge its major core donors for their support: Sweden, Norway, Japan, Switzerland and Finland; as well as other core contributors, including the Republic of Korea, Luxembourg, China, Philippines, Israel and France. This report was further supported by the German Federal Foreign Office. The views expressed in this publication do not necessarily reflect the views of the donors.

Editing, design, layout and proofreading
Green Ink