International Journal of Disaster Risk Science (2025) 16:103–116
https://doi.org/10.1007/s13753-025-00622-9

www.ijdrs.com
www.springer.com/13753

ARTICLE

Multi-Hazard Early Warning Systems in the Sendai Framework for Disaster Risk Reduction: Achievements, Gaps, and Future Directions

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Accepted: 30 December 2024 / Published online: 4 February 2025

Abstract
Bringing together global efforts to enhance the implementation of warnings in managing vulnerabilities, hazards, risks, and disasters is essential to saving lives and for long-term vulnerability reduction. Ten years into the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), there has been a renewed focus on warnings following the 2022 announcement by the United Nations Secretary-General of the five-year goal of Early Warnings for All. Delivering on Target G of the SFDRR has subsequently generated significant outcomes, however substantial gaps remain with implementing effective early warning systems (EWS). This article charts the policy evolution of warnings within the UN context and outlines the progress and remaining gaps of EWS in the SFDRR to date. Three key gaps that hinder the effective delivery of SFDRR and beyond are identified: (1) the need for common understanding of warning processes and terminology, such as multi-hazard EWS, and further elucidation of indicators used to measure and chart progress; (2) the need to mobilize and strengthen existing EWS, many of which are not formally recognized yet do the work of warnings across actors and entities, especially in fragile or resource-poor contexts; and (3) the need to foster collaboration between the multitude of actors and approaches involved in all forms of warnings, including people-centered warnings to address diversity and inclusivity, and integrate top-down and bottom-up approaches across sectors. Significant barriers to working across the numerous silos (institutional, geographical, political, and scientific) must be overcome to generate effective people-centered multi-hazard EWS to support disaster risk reduction in the future. Recommendations on how to fill these gaps in future frameworks are provided, to support people-centered, integrated warnings for all.

Keywords Alerts · Early warning systems · Policy · Preparedness · Sendai framework · Warnings

1 Warnings in the Sendai Framework

Warning systems have consistently been identified as a key tool within disaster risk reduction (DRR) to coordinate and implement numerous activities to provide people with relevant and timely warnings (UNISDR 2006b; Kelman and Glantz 2014). Early warning systems (EWS) are defined as "an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events" (UN 2016, p. 17). In recent decades, global institutions have increasingly recognized the role of warnings in DRR, particularly through United Nations (UN) commitments and policy agendas, including the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR). In this article, a brief review of evolution of warnings within the context of the UN and the SFDRR is presented and significant gaps in the implementation and assessment of warnings 10 years into the SFDRR implementation are explored, followed by recommendations of next steps needed to address warnings in the remaining years of the SFDRR and beyond.

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1.1 The Rising Role of Warnings in Disaster Risk Reduction

Despite several UN conferences dedicated to advancing DRR measures and EWS throughout the 1990s and 2000s, research on warning systems only significantly expanded after the catastrophic Indian Ocean Tsunami of 2004 (Zschau and Kuppers 2003; UNISDR 2006a; UNISDR 2006b). Had an EWS had been established prior to the event, tens of thousands of lives could have been saved during the disaster that killed over 230000 people in at least 12 countries (Thieren 2005). Following this tragedy, numerous actions were initiated; EWS conferences were launched in over 23 countries with 20 international agencies with a focus on "people-centered" (that is, community-based) EWS that require systematic approaches and diverse activities spanning four key elements of an EWS, according to the UN: Risk knowledge, monitoring and warning service, dissemination and communication, and response capability. A global survey on EWS was produced (UNISDR 2006b), and the Hyogo Framework for Action 2005–2015 (UNISDR 2005, p. 7–8) established Target 2 to "identify, assess and monitor disaster risks and enhance early warning."

In 2015, the SFDRR continued to prioritize warnings with Target G, aiming to "substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030" (UNISDR 2015, p. 12). The SFDRR's first decade of implementation has generated global progress towards achieving Target G and highlighted the importance of warnings, yet as this article outlines, a number of gaps and issues remain to be addressed.

1.2 Warnings in and Beyond the Sendai Framework for Disaster Risk Reduction: International Cooperation towards Common Goals

Major policy initiatives in 2015 were developed to address the common objective of "reducing vulnerability and enhancing resilience" (WMO 2024, p. 6), including the SFDRR, the Sustainable Development Goals (SDGs), and the Paris Agreement. Global commitment to sustainability and resilience goals led to a coherent *UN Plan of Action on DRR for Resilience* to help support Member States implementing the SFDRR and other international agreements. So far, 19 out of 50 UN organizations reporting on the UN Plan of Action have disaster or climate risk and resilience indicators in their monitoring and evaluation systems (UNDRR 2018). At the country level, progress towards attaining the goals and targets of these major initiatives has been mixed. While it is widely accepted that the key to understanding disaster risk is by recognizing that disasters are indicators of underlying vulnerability factors and development failures, there are still significant gaps in addressing vulnerability to disasters (Gaillard 2023; UNDRR 2023c). Consequently, the SFDRR has spurred additional efforts to implement its targets, specifically with regards to Target G on warnings.

The 2022 *Global Status of Multi-Hazard Early Warning Systems* reported that only half of countries globally had multi-hazard early warning systems (MHEWS) (WMO 2022). Subsequently, the Early Warnings for All (EW4All) initiative launched on World Meteorological Day 2022 by UN Secretary-General António Guterres, called for initial targeted investments of USD 3.1 billion to be put into strengthening MHEWS locally, nationally, and globally. EW4All is a "groundbreaking effort to ensure everyone on Earth is protected from hazardous weather, water, or climate events through life-saving early warning systems by the end of 2027" (WMO 2022, p. 52). The initiative is built on four pillars that replicate the prior four elements of EWS, according to the UN (see Fig. 1).

The heightened focus and investments on EWS spearheaded by the EW4All initiative have reaffirmed the value of warning systems as integral elements of DRR and in building sustainability and resilience (UN 2023). Yet, fundamental issues remain.

First, it is not clear how MHEWS are defined, measured, and reported on by individual countries and across agencies (Rokhideh 2025). Within the SFDRR, there are insufficient indicators to measure the effectiveness of warning systems, making monitoring progress towards targets challenging. Second, much of the focus has been on hydrometeorological and climate-related hazards, excluding links and interactions with other hazards and risks. Pressure is mounting to expand warnings for the full scope of the hazards in the SFDRR and to consider the complex nature of crisis as being cascading, compounding, or concurrent hazards within a systemic risk context (UNDRR and ISC 2020). Third, the SFDRR and the EW4All initiative do not adequately capture the wide range of warning systems that are not formally recognized by UN structures (perhaps mainly by the World Meteorological Organization (WMO)). Lastly, despite the importance of an approach to warnings that requires multi-directional communication, collaboration, and coordination between all actors and organizations within a warning system (that is, government, scientific, community, and so on), the SFDRR has not focused on interactions between decision makers, communicators, and users (Fearnley and Beaven 2018; Golding 2022).

Ten years into the SFDRR implementation, there have been some remarkable achievements, particularly in

Fig 1. Overview of the four pillars of the Early Warnings for All Initiative. Acronyms are GPC: Global Producing Centre; RSMC: Regional Specialized Meteorological Centre; NMHS: National Meteorological and Hydrological Services; NDMO: National Disaster Management Office. *Source* UNDRR (2024a)

increasing interest, investment, and integration of warnings into international legislation, national policies, and humanitarian agencies. Increased cooperation and global partnerships have helped foster progress towards Target G. One key example is the Risk-informed and Early Action Partnership (REAP) that brings together more than 70 partners with the aim of making one billion people safer from disasters by 2025. The REAP has focused extensively on the role of warnings, including a dedicated working group on people-centered approaches to EWS, which has facilitated discussions, key outputs, and activities, and is part of the EW4All interpillar coordination group and multi-stakeholder forum. Several REAP publications such as *The Roles of State and Non-State Actors in Early Warning and Early Action* (REAP 2023) have presented an interdisciplinary perspective to warnings to help bring research, practice, and policy together (see also Marchezini 2020).

1.3 Implementation and Progress towards the Sendai Framework for Disaster Risk Reduction Targets

The SFDRR midterm review (UNDRR 2023c) found that progress towards reducing disaster impact has been slow and that countries are not on track to realize some expected outcomes. However, several other achievements have been realized, demonstrating significant progress. The review highlighted that of the 187 countries participating in the SFDRR, 95 reported the existence of MHEWS, which is a twofold increase from 2015, but still less than half the countries in the world (UNDRR 2023c).

Global progress in the implementation of the SFDRR has been addressed via a set of 38 custom indicators that measure progress in achieving the seven established targets. Much of the focus of the indicators are on global trends in the reduction of risk and losses. Six of these are specific to Target G (see Table 1).

Table 1. Indicators for the Sendai Framework for Disaster Risk Reduction Target G

G-1	Number of countries that have multi-hazard early warning systems
G-2	Number of countries that have multi-hazard monitoring and forecasting systems.
G-3	Number of people per 100000 that are covered by early warning information through local governments or through national dissemination mechanisms.
G-4	Percentage of local governments having a plan to act on early warnings.
G-5	Number of countries that have accessible, understandable, usable and relevant disaster risk information and assessment available to the people at the national and local levels.
G-6	Percentage of population exposed to or at risk from disasters protected through pre-emptive evacuation following early warning. Member States in a position to do so are encouraged to provide information on the number of evacuated people.

Source UNDRR (2024b)

Reporting of the targets indicates that to date warning dissemination and communication are the most reported pillars of MHEWS (as per indicator G-3 at 42%), while the least reported pillar is risk knowledge (G-5 at 20%). Under indicator G-2, only 31% of WMO Members have the necessary monitoring and forecasting systems for multiple hazards occurring simultaneously or cumulatively over time (UNDRR 2023a). Of the 30 selected countries in the EW4All initiative, only a few have comprehensive MHEWS that cover more than one hazard type, and often not of sufficient quality (UNDRR 2023a). Many of these statistics depend on what is meant by a MHEWS, and while plans for a multi-hazard approach may be in place, they may not be operational in practice.

Indicators in UNDRR (2023c) also demonstrate that countries affected by disasters are spending limited funds on responding to recurring crises. This may indicate that nations are stuck in a cycle of response, and unable to move towards more preparedness and anticipatory actions due to limited resources or corruption (Tupper 2023). Additionally, the existence or coverage of warnings does not necessarily equate to their effectiveness, as seen in the 2020 tsunami warnings in Chile (Soulé 2014). In summary, while many statistics look promising, the value of the indicators presented can be questioned given that they are unable to capture whether a warning has been "successful" or not.

2 Identifying and Filling the Gaps

While evidence indicates significant progress in the development of warnings both within, and peripherally to the SFDRR implementation, there are several gaps that need to be addressed to help ensure that warnings are effective and adapted to all scales, peoples, and needs. Three key gaps are identified: (1) the need for common and well-defined understanding of warning processes and terminology; (2) the need to mobilize and strengthen existing systems; and (3) the need to foster collaboration between the multitude of actors and approaches involved in all forms of MHEWS.

2.1 Gap 1: Common Understanding of Warning Processes and Terminology

Currently there does not exist a single common framework of MHEWS and its core components, leading to critical gaps, inconsistencies, and incoherence due to varying definitions and interpretations of terms. To achieve this requires standardization of MHEWS terminology and approaches as well as clear indicators by which to measure and compare progress of MHEWS across countries. A MHEWS also requires coordination and collaboration across agencies such as weather agencies, geophysical hazard specialists, health agencies, emergency response, municipalities and government agencies, service providers, insurance companies, and aid agencies as well as collaboration with other forms of warning systems, including indigenous and local warnings. A multitude of actors must work together to gather observational data, monitor hazards, communicate and deliver multi-hazard warnings, and respond to and manage multiple, cascading, cumulative, or compounding hazards. More collaboration across sectors and levels of society, including with researchers and civil society organizations is needed in order to strengthen and improve both tools related to forecasting and monitoring risks, and strategies to respond effectively to multi-hazard risks.

2.1.1 Insufficient Indicators

Indicators specific to Target G offer a starting point to MHEWS, but major gaps related to how they are understood, measured, and self-reported by countries remain, making implementation of the SFDRR challenging. Target G indicators are broad and lack guidance and definition of key MHEWS terms and processes, that is, specific explanation and details on what constitutes a "multi-hazard monitoring and forecasting system" (G-2) and "early warning information" (G-3) is currently lacking. Some indicators are also confusing; it is unclear whether G-6 refers to an evacuation plan or a post-disaster evacuation. There is an urgent need for complementary indicators that go beyond vague numeric

indicators and assess the degree of achievement of elements of MHEWS. Target G largely focuses on coverage, overlooking other important dynamics of warnings. Receiving a warning is not enough—further data are needed on whether warnings issued are effective, useful, actionable, accessible, and user-friendly for all users, taking into consideration diverse needs, backgrounds, abilities, genders, and so on. Further elaboration of the indicators and how they are measured and reported on by self-reporting bodies is critical to improving the implementation of MHEWS in practice.

Not only do current indicators fail to measure the effectiveness of warnings and the systems in which they operate but they also imply a top-down approach to warnings, where people are passive recipients rather than active participants in warning systems and even sources of warnings themselves. More data are needed on how warnings are used by all actors: Are design and messaging dynamic and interactive; to what extent are MHEWS proactively adopted by people; do warnings elicit decision making and actions that minimize impacts; do people know what to do prior, during, and after a warning; to what extent do people have trust in sources and communication channels; how reliable are sources of information; how are emergency action plans evaluated and assessed for usability, preparedness, and effectiveness; are roles and responsibilities clearly outlined within and between authorities/agencies; do entities at each level have the necessary capacities to carry out their remits? Many of these questions point to the important complexities that remain unanswered within the current iteration of indicators. These issues also highlight the different ways success is defined and reported on and underlines the need for discussions to determine collective understanding of an effective MHEWS.

There are significant gaps in the scope of hazards that countries report warnings for, as well as the tracking of hazards that are covered within a MHEWS. Many hazards have their own siloed knowledge, expertise, policies, and practices. For example, volcano observatory networks often have separate warning systems disconnected from national weather services and warning systems. Landslide EWS are also challenging to implement despite new advances like the LandAware Network (Guzzetti et al. 2020). In some countries, government and scientific organizations tasked with monitoring and observation of hazards have limited authority and collaborations with communication and response processes, including with National Disaster Management Offices (NDMOs).

Another factor lies in inconsistencies and confusion over the roles and responsibilities within MHEWS, creating issues on how indicators are reported. National Meteorological and Hydrological Services (NMHS) that are mandated with issuing warnings are generally focused on forecasting, monitoring, and issuing alerts (for example, putting a bulletin on their website). Anything beyond this that involves risk knowledge, outreach/education, communication and dissemination, media interaction, and early action plans (EAPs) are not in their remit nor budget. National Meteorological and Hydrological Services call the "monitoring and warning" element of an EWS a MHEWS in and of itself, while it is only one element of a MHEWS covering one type of hazard profile. Information and decision making about what to put in warnings, what actions and measures are recommended, and who makes those decisions and at what levels, require different agencies to work together and decide upon; it is a multi-expert process (Fearnley 2013). There can often be confusion as to whose responsibility it is to carry out different aspects of warning (Fearnley and Beaven 2018; REAP 2023).

2.1.2 Multi-Hazard Early Warning System Inconsistencies

There are inconsistencies with regards to how MHEWS are defined and interpreted across countries and agencies, which creates challenges in reporting on Target G indicators (see Table 1.). Within the UN system and agencies, definitions of MHEWS vary. Much of the WMO work on warnings has strictly focused on hydrometeorological and climatic hazards in the 2018 *Checklist for MHEWS* (WMO 2018, p. 3):

> Multi-hazard means (1) the selection of multiple major hazards that the country faces, and (2) the specific contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. Hazards include (as mentioned in the Sendai Framework for Disaster Risk Reduction 2015–2030, and listed in alphabetical order) biological, environmental, geological, hydrometeorological and technological processes and phenomena.

Due to a lack of clearly defined terminology as to what constitutes MHEWS, it is unclear the extent to which a country's warning system is truly multi-hazard, and how they define it. Countries currently self-assess whether they have a MHEWS, creating vastly different interpretations of what a MHEWS is, resulting in a lack of coherence in reporting. Without a common framework and clear indicators of MHEWS that all countries can use, it is difficult to operationalize warnings across sectors and countries (Rokhideh 2025). In the most recent reporting of the Sendai Framework Monitor (UNDRR 2023a), countries self-report MHEWS for single hazards. That is, when a country has a warning system for hydrometeorological hazards, this is self-reported as having a MHEWS (indicator G-1). However, what makes a warning system multi-hazard is a number of factors, including integration of warning systems for multiple hazards

and risks across various scales (local, municipal, regional, national, transnational) and users as well as cross-sectoral and multidisciplinary coordination and collaboration.

Another major challenge with monitoring and reporting on the 38 SFDRR indicators is related to the data capacities of countries, especially at different scales. The collection, management, assessment, standardization, and review of data quality, among other methodological aspects, have hindered the reliability and robustness of the indicators (Chmutina et al. 2021; UN 2022). While each country defines its own institutional arrangements, the institutional and statistical capacities of member states vary greatly, especially at regional and local levels, making reporting in practice quite challenging. In many countries, data used for monitoring the SFDRR indicators are drawn from alternative information sources, such as administrative records maintained by various sectors or territorial actors, which make data quality and reliability difficult to assess (Kohler et al. 2020; UN 2022). A critical first step for effective monitoring and measuring progress of indicators should focus on improving data systems across member states (Winters et al. 2022). While monitoring and evaluation can be exceptional, if the fundamentals of the data used for an indicator are flawed, then the resulting evaluation will have less value.

In countries with extensive resources, forecasts usually require high levels of data, monitoring systems, and forecasting centers across hazard types. In countries with limited resources, there are known monitoring data gaps and much smaller capacity within government NDMOs to cover different hazard types, although traditional knowledge may help address these gaps (see Gaps 2 and 3).

Finally, there are several challenges that arise with self-assessment and self-reporting. For example, without a common framework of what constitutes a MHEWS, countries may "stretch" the definition of a MHEWS and therefore some of the results could suggest that they are achieving more than they actually are. Without verification and triangulation of data, achievements of indicators cannot be reliable and comparable. Indicators are used to generate policies and decisions by institutions for financial and insurance purposes (either for sovereign risk or for insurance pricing), and thus require transparent systems of measuring, tracking, monitoring, and evaluation. There is subsequently a concern that people may invest too heavily into indicators of EWS without fully understanding the quality and limitations of the data.

2.2 Gap 2: Mobilizing and Strengthening Existing Systems

The SFDRR midterm review (UNDRR 2023c) indicates that only 95 countries have reported having MHEWS. In many countries reporting that they do not have MHEWS, hazards like floods and tsunamis can be predicted at a global or regional level and could be used to generate warnings (Jaime et al. 2022). A potential solution is to develop more robust warnings by using existing global resources, whether that be existing satellite monitoring capabilities, or building community-based warnings working with traditional and indigenous knowledge systems that are low cost, utilize existing resources, and enhance existing infrastructure (Khan et al. 2020). In many places, implementing an EWS requires the remobilization and use of existing (albeit limited) resources to help achieve Target G. It is crucial to join the dots between the different silos and stakeholders to enhance the resources available and prevent confusion, and support reinforcing warnings using existing knowledge and infrastructure.

2.2.1 Mobile Telecommunications

Technology such as cell broadcasting (widely distributed since 2008) can help notify millions of people instantly of a significant event, via the rapid transmission of messages to all wireless devices connected to cellular networks, enabling instant ability to reach the masses with no subscription required, while preventing network congestion and building network resilience. Additional benefits include that the message can be translated to the language of the handset, provide links to further information, and offer updates. Global System for Mobile Communications Association (GSMA) (Shanahan and Bahia 2023) stated that 95% of the world's population has access to mobile broadband networks and 78% of the population owns a mobile phone.

Mobile technologies have played a significant role in the EW4All initiative, with International Telecoms Union (ITU) taking the lead to help increase access and provide technical infrastructure to support cell-based warnings. However, it is important to consider that mobile solutions are one of many, and a comprehensive warning system requires multiple modes and channels of communication as well as integration and harmonization from the local to national level (Taylor and Rokhideh 2024). The Common Alerting Protocol (CAP)[1] provides a standard international format for emergency alerting and public warning, that sends the same alerting message over multiple platforms to increase coverage and impact, enhance trust in alerting services, enable redundancy, and also help warnings to be more inclusive. It is critical to note that over 22% of the global population do not own a mobile phone (GSMA 2023), that technology regularly fails at the time it is most needed, and that receiving a message does not automatically lead to action (Bean 2019).

[1] https://www.itu.int/en/ITU-D/Emergency-Telecommunications/Pages/Common-Alerting-Protocol-and-Call-to-Action.aspx

2.2.2 Including Diverse Knowledge Systems in Disaster Risk Reduction

Integrating and investing in the perspectives of local, indigenous, and traditional knowledge (LITK) is crucial to designing effective people-centered MHEWS (Balay-As et al. 2018) and enabling the risk knowledge base of populations (UNDRR and WMO 2023). Local, indigenous, and traditional knowledge lies in the accumulated experience that comes with the close relationship of these communities to their environment, formed through successive trials and errors over generations. The UNDRR (2022) guide *Words into Action: Using Traditional and Indigenous Knowledges for Disaster Risk Reduction* argues that space for traditional and scientific knowledge to co-exist is needed and can help fulfill the SFDRR. Masinde (2015) described an innovative drought EWS that integrates indigenous and scientific drought forecasting approaches. The work builds on a novel integration framework called Information Technology and Indigenous Knowledge with Intelligence. Many cultures globally have been working alongside scientific institutions to help foster relationships around hazards information for warnings and warning signs—a good example is in New Zealand between the government hazard monitoring agencies and the Māori (Harrison et al. 2021). The UNDRR report *Local, Indigenous and Traditional Knowledge for Disaster Risk Reduction in the Pacific* highlights how some successful partnerships have helped enhance warnings in areas, a well-known example is that of the Fiji Women's Weather Watch (Singhand and Naidu 2018), which has enabled communities to obtain warning information much quicker, and help prepare and respond to warnings throughout their community (UNDRR 2022). However, aside from some key case studies, many LITK-based warning systems remain informal, unrecorded, and often unrecognized by national governments. Yet, there is also a danger that increasing use of cell-broadcasting and other mobile related technologies may result in the weakening of traditional warning systems, with the potential of leading to ineffective, non-integrated, and non-contextual warnings over time.

2.2.3 Resource Gaps, Particularly for Low-Income, at-Risk, and Fragile Communities

Despite major investments and initiatives to support warning initiatives globally, significant gaps remain in country capacities of MHEWS, especially in fragile and conflict-affected situations (FCAS). Disaster risk reduction investments have been insufficient to cover increasing needs and costs. It is currently estimated that lower income countries need an estimated USD 70 billion annually for risk reduction measures that include warning systems, a figure that is expected to rise exponentially by 2030 (UNDRR 2021a). Even in countries where risk prevention is earmarked as a primary objective, the allocation is less than 1% of national budgets (UNDRR 2021b). Addressing corruption and issues related to poor infrastructure and ineffective prevention measures could be a key solution (Lewis 2011).

Effective MHEWS require significant, reliable, and long-term funding/investment from national actors and the global community to enhance provision worldwide. Funding is needed across all four pillars of the SFDRR, including improving technologies and data systems, stretching community outreach and engagement, and resourcing emergency responders. Currently no single entity is tracking the following to understand the current status:

- How much is invested into MHEWS?
- Who/where is it going to—where (geographically), state or non-state (which organizations), and what level (national or local)?
- What is it being spent on (technology versus soft approaches, what components of EWS, which hazards)?
- Evaluating effectiveness—and guidance on the most effective way of spending money to see results.

2.3 Gap 3: Integrating Actors and Approaches of Multi-Hazard Early Warning Systems

There are significant gaps within MHEWS, most notably on how to integrate top-down with bottom-up approaches. Some of the key tools that can be used include focusing on the first mile, early action plans and forecast-based financing, being more inclusive, and considering FCAS, many of which have received significant focus but still lack progress in implementation. Working across the many silos remains challenging and the standardization of warnings present the need for flexibility while also providing consistency, and quality control.

2.3.1 Greater Emphasis on Early Action

The SFDRR reaffirms the understanding that decisions that create or prevent, amplify or reduce risk before the risk becomes a disaster, are of critical importance. Often classed under the term "Early Warning, Early Action" (EWEA) (but also known as anticipatory action or forecast-based action), requires taking steps to protect people before a disaster strikes. To be effective, it must involve meaningful engagement with at-risk communities (IFRC 2024). Subsequently, EWEA-based financial products have been created to provide financial support before disasters or crises occur, and so reducing the impact of disasters. Forecast-based financing (FbF) finances communities to prepare for, respond to, and recover from hazards by establishing triggers, based on when a forecast exceeds a defined threshold, that indicates

a probability of humanitarian impact. Predefined actions include evacuating to a safe place, providing cash advances, and prepositioning resources and supplies.

These types of financial tools are better for more frequent smaller-scale crises (Scott 2022; Flaherty et al. 2023). The START Network and International Federation of Red Cross and Red Crescent Societies (IFRC) have championed access to FbF for humanitarian organizations to enable early action. In 2023, REAP launched *Getting Ahead of Disasters: Launch of a Charter on Finance for Managing Risks* that sets out principles for collaborative action to ensure better use of finance to manage risks and protect people in the most vulnerable countries (IFRC 2024). After decades of statistics stating that USD 1 invested before a disaster saves over USD 10 of cost post-disaster (Shreve and Kelman 2014), financial products are making this feasible using early warnings. Many countries still lag behind, with gaps in institutionalizing these financial interventions for the long term with government support.

2.3.2 Consideration of Diversity, Inclusivity, and Vulnerability

Building on the SDGs and previous frameworks, the SFDRR explicitly recognizes that inequality and poverty are direct drivers of vulnerability to disasters, highlighting the critical links between disaster risk and development dynamics. In this way, the SFDRR places vulnerability at the center of DRR but this does not materialize in efforts and strategies (Chmutina et al. 2021). Monitoring and measurement within the SFDRR have largely been focused on event/hazard-based DRR rather than capacity approaches that address risk and vulnerability (Chmutina et al. 2021). While the SFDRR references the importance of integrating marginalized people in disaster risk policy, resourcing, and implementation, thus far inclusivity goals have yet to be achieved (Carby et al. 2018; King et al. 2019; Zaidi and Fordham 2021). Future iterations of global DRR frameworks for action could be greatly enhanced by integrating vulnerability drivers and development indicators.

There has been considerable work in the area of inclusivity, accessibility, and intersectionality for warning systems from early discussions by Fordham (2001), to looking at the overlap between gender equality and social inclusion and warnings (Brown et al. 2019) and developing entry points for inclusive and accessible EWS (Yore et al. 2023) (Fig. 2). Checklists and implementation guides systematically integrate and monitor gender and disability inclusivity across all warning actions (UNDRR 2023b). These reflect an increasing trend to move from impact-based warnings towards community-based action-based forecasting. Integrating these findings into practice remains challenging due to limited resources, conflict, and continued marginalization (Yore et al. 2023).

2.3.3 Resource-poor, and Fragile and Conflict-Affected Situations (FCAS)

There have been critiques of the SFDRR and EW4All with regards to the specific vulnerabilities, needs, and challenges that arise in FCAS, for example lacking in "appropriateness in contexts of complexity, uncertainty, informality, fragility, insecurity (including conflict)" (Oxley 2015, p. 6). In challenging governance contexts, capacities and resources to achieve the outcomes and goals of the SFDRR are extremely cumbersome and might not even be a priority. For instance, many African states have faced challenges related to insufficient institutionalization of DRR, political will, lack of funding, and shortages of human resources to carry out DRR activities (Botha and Van Niekerk 2013; Hagelsteen and Becker 2013; Malalgoda et al. 2014). Van Niekerk et al. (2020) found that with regards to Target G, African states face significant challenges in integrating MHEWS across multiple hazards and at various levels and in different sectors, as well as issues with national sovereignty in relation to cross-border EWS.

Noting these urgent concerns, there has been increased attention and new reports to address some of the gaps in FCAS. Wagner and Jaime (2020) highlighted that forecast-based action (FbA) could be expanded to situations of conflict in terms of forecasting hazards, alongside the conflict itself. The World Bank/GFDRR (2024) report provides insights into EWS implementation within FCAS for natural hazards, focusing on enhancing stakeholder coordination, optimizing resource allocation, and fostering community resilience. It builds on recommendations made in the Centre of Excellence for Disaster and Climate Resilience (2023) report. Many challenges lay ahead, but it is important to look at integrating other forms of EWS, such as community and traditional systems, that can be strengthened and that existed long before formal mechanisms.

2.3.4 The First and Last Mile

One of the ongoing EWS challenges for the SFDRR remains ensuring that all levels (local, municipal, sub-regional, national, and regional levels) have an integrated MHEWS. Working across a wide range of scales from international, to national, regional, local levels requires significant work in bringing together bottom-up and top-down approaches. For warning processes to be efficient, collaboration and working across the many organizations and silos that span across hazards, risks, and vulnerability is needed. Figure 3 highlights the various tools and actions suggested to aid coordination across different levels of governance.

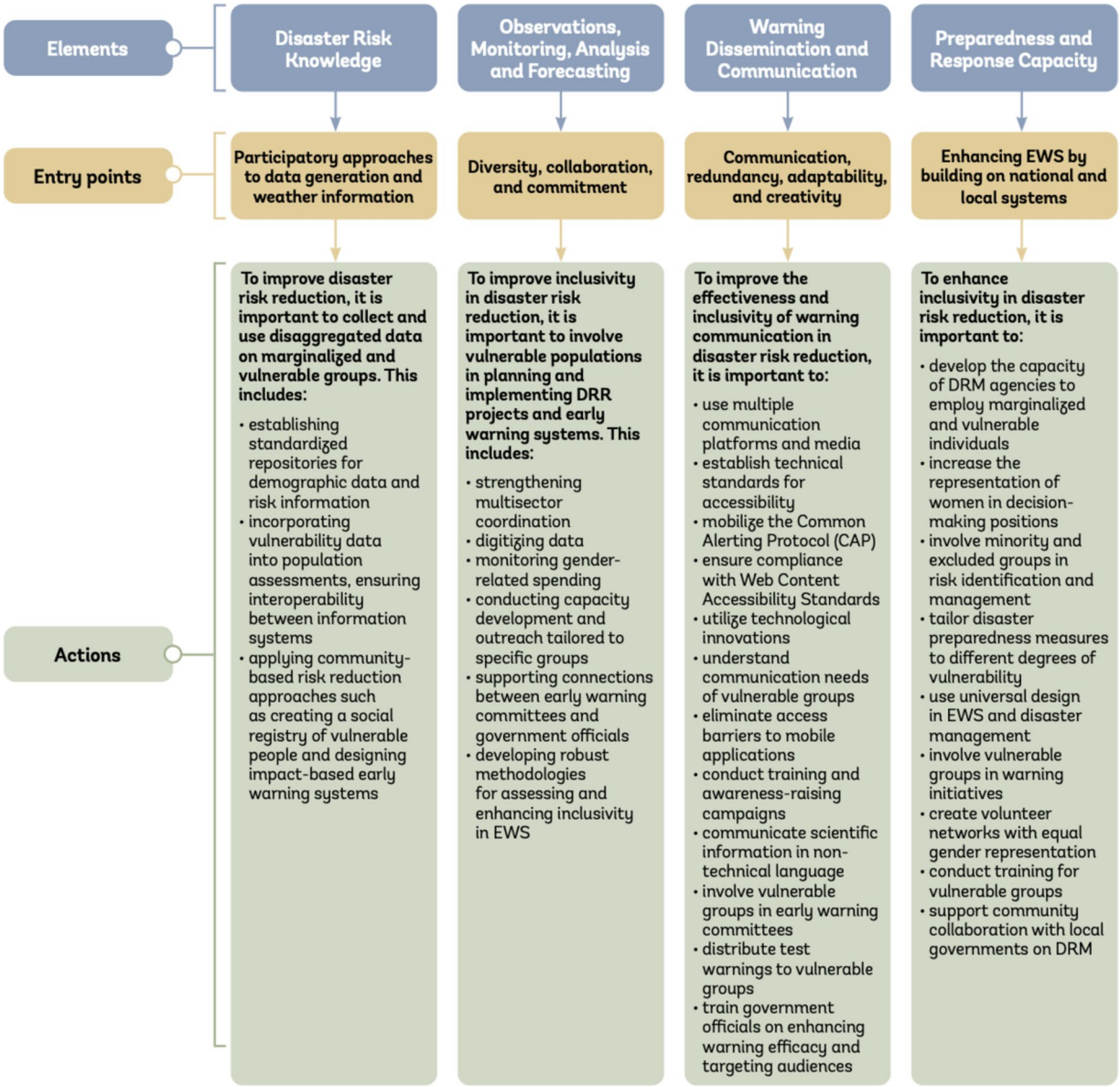

Fig 2. Early warning system (EWS) elements, identified entry points, and potential actions. *Source* UNDRR (2023c, p. 26)

Typically, and historically, warnings have followed a top-down approach with the local community or individuals receiving the information last in the process. The concept of the "last mile" aimed to overcome the challenge of the people most needing warnings often not being reached. Closing the gap between warnings and the people needing them (which includes all of us) is seen as the final step of a complete EWS. The "last mile" paradigm is flawed, because placing individuals as the last or final step overlooks their needs in warnings and actions. Local communities should be included in the warning system from the beginning, that is, "the first mile," to ensure that they know what warnings are and how to act upon them when issued. This requires a significant paradigm shift in the approach to warnings (Kelman and Glantz 2014).

There is an increasing recognition of the importance of inclusive and community-based/driven EWS in disaster response (Tupper 2023). Governments have learned that the effectiveness of emergency alerts depends on individuals' and businesses' ability to act upon them, and there is a growing understanding of the need for two-way communication between early warning institutions and at-risk communities. For effective disaster response, EWS must be tailored to specific contexts and be multi-directional, recognizing communication between certain groups or individuals that may not be privy to all stakeholders (Fearnley and Beaven 2018).

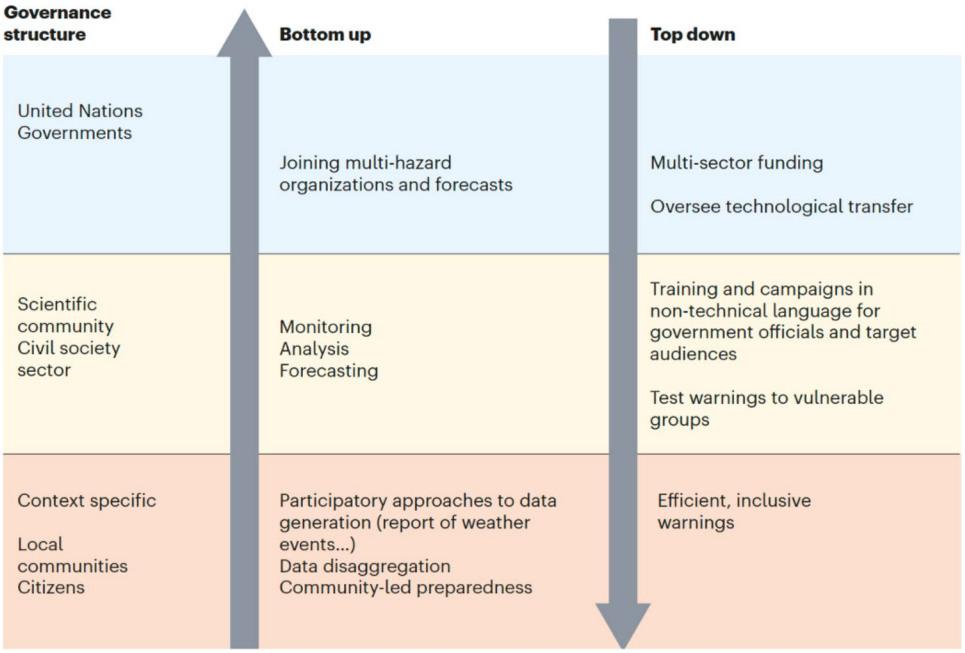

Fig 3. Combining top-down and bottom-up processes (devised by Carina Fearnley and Andrew Tupper)

To achieve this, two key approaches can be taken. First, upstream engagement is the process of including the people affected by a policy or warning at the start of the process, rather than being at the end/last mile. This enables people to provide input into defining what is the problem, how it can be met and managed, and what information or resources they need to be safe, before plans are put into place. Upstream engagement is commonly seen within controversial science and technology, for example in the use of genetically modified crops or in gene editing (Wilsdon 2004). Second, using community-based/driven EWS that empower the populations, the most vulnerable develop capacity to manage warnings, respond to them, and take actions (IFRC 2020). Community-driven EWS, where communities lead the process, also have the ability to provide valuable citizen science and engagement to feed upstream to the national level.

By approaching warnings from multiple starting points, it is possible to avoid designing warning systems as linear, end-to-end processes; there is no single pathway to a single end point, as outlined by Kelman and Fearnley (2024):

> The warning process based on the first mile converges and branches according to our changing needs. It never really finishes, instead being incorporated into our day-to-day lives and livelihoods. The warning threads always intersect, feeding back into each other and ensuring that we connect to learn from and teach each other. Warnings are much more than end-to-end, being end-to-end-to-end-to-end-to-end-to-end-to-end-to-end... or, perhaps, node-to-node-to-node-to-node... emphasizing that the warning process never ends.

First mile approaches also help address a number of the challenges outlined including inclusivity and should be used for people-centered MHEWS, while giving space to accommodate deeply political, cultural, and religious processes.

2.3.5 The Links within an Early Warning System and Standardization

A particular challenge within the EW4All initiative and the SFDRR has been how to include the many diverse organizations involved in warnings, often with extensive expertise and practice, when there are already challenges working within the agencies in the UN to achieve goals (Budimir and Fearnley 2023, p. 4):

> The reality is that significant interagency conflicts on warning system priorities already occur, and Early Warnings for All Initiative needs to incorporate a mechanism to guide solutions to such conflicts (Tupper and [Bear-]Crozier 2022). There are examples of strategies and existing tools that can be used to address these gaps (Fearnley and Beaven 2018), such as establishing effective communication networks, better coordinating practitioners needs to drive scientific research, integrating scientific knowledge into practice, developing effective and context-specific decision-making processes, defining accountability and responsibility, acknowledging the importance of risk perception and trust in the information for effective action, and considering the differences among technocratic and participatory approaches in EWS (Garcia and Fearnley 2012; IFRC 2020).

Budimir and Fearnley (2023) proposed that a core pillar/element should sit in the middle of the four elements/pillars, to facilitate cross-pillar collaboration and integration that includes the engagement of the wider community and most vulnerable. In 2024, the EW4All established a Multi-Stakeholder Forum to provide opportunities to engage across a wide range of stakeholders globally. In some countries, multi-stakeholder EWS advisory teams exist (for example, Nepal and Bangladesh), where state and non-state actors are consulted and work collectively (despite frequent clashes), whereas in other contexts, this does not happen. All of these activities require sustained funding, and ongoing goodwill. The EW4All's pillar 5 focuses on "monitoring and observing" the initiative. It is where the work of groups such as the REAP, Anticipation Hub, and START Network has been critical in bringing in needed voices, including those from communities.

Garcia and Fearnley (2012) demonstrated the importance of flexibility and the consideration of local context in making EWS effective. The standardization of EWS is vital to convey information to a wide range of stakeholders. However, there are pros and cons as outlined in Table 2). The process of standardization is often shaped by social, political, and economic factors, rather than in response to scientific needs specific to a hazard (Fearnley et al. 2012). Yet, standardization is difficult to implement due to the diversity and uncertain nature of hazards at different temporal and spatial scales. Therefore, EWS need to be scalable and sufficiently flexible for use by local stakeholders via standardized communication products designed to accommodate local contingency, while also adhering to national/international policy (Fearnley and Dixon 2020). By doing so, it enables community-based approaches to connect to government level policies and procedures that assist in the management of a crisis.

3 Beyond the Sendai Framework for Disaster Risk Reduction: Next Steps and Future Considerations

This article highlights the focus on warnings within the SFDRR 10 years on, and the significant progress that has been seen, alongside numerous remaining challenges. One foundation of contemporary disaster research is how MHEWS can stop hazards becoming disasters, accepted by the UN for over 30 years (Mileti and Sorenson 1990; Zschau and Küppers 2003; Knight 2009; Garcia and Fearnley 2012). The commitment to warnings via the SFDRR targets (especially G) and EW4All is necessary, bold, and ambitious. Yet, despite significant progress, many member states are not on track to meet the 2030 goals of the SFDRR as per the SFDRR midterm review (UNDRR 2023c), but the UN alone cannot achieve the goals; communities must work together:

> Significant gaps exist in multi-hazard early-warning systems (target G of the framework). Supporting actions must accelerate. Investments need scaling up, with a focus on low-income countries, multi-sector cooperation, risk information and data collection and management (Tupper and Fearnley 2023, p. 478).

The achievements of the SFDRR 10 years on in relation to warnings is impressive, but considerable work is still needed. Key gaps and potential solutions are summarized:

(1) Developing Common Understanding of Key Warning Terminology, Actors Involved, and Processes

- An urgent need for a common framework of MHEWS and its core components to address critical gaps, inconsistencies, and incoherence. This requires standardization of MHEWS terminology and approaches, and clear indicators by which to measure and compare progress. A MHEWS also requires coordination and collaboration across a wide range of agencies, such as weather agencies,

Table 2 The pros and cons of standardizing warnings

Issues	Local (Non-Standardised)	National (Standardised System)
Users' needs	Provides flexibility to local community but global users may be confused	Limits flexibility possible, but provides consistency and clarity to all
Communication Methods	Local interpretation likely to be more effective	Common terminology and understanding, but must be known
Decision Making	Gear decision on local needs, circumstances and knowledge	Descriptions provide guidelines / criteria, but implications may vary
Management	Local stakeholders develop close relationships	Streamlines communication within government agencies reducing confusion

Source Fearnley and Kelman (2021, p. 25)

geophysical hazard specialists, health agencies, emergency response, municipalities and government agencies, service providers, insurance companies, and aid agencies.
- It is challenging to obtain EWS metrics that capture exactly what is going on. Therefore, data collected while useful, should be considered within the relevant constraints.

(2) Mobilizing and Strengthening Existing Systems
- Numerous MHEWS exist but are not captured under official definitions and formally recognized processes. It is critical that these EWS are recognized, are supported, and work with more formal existing EWS. Often, they support more inclusive systems, and enable low-income and FCAS to use EWS.

(3) Integrating Early Warning Systems

- Focusing on the first mile is vital to make sure that MHEWS can deliver to the people who will be using it. Tools like forecast-based action enable many to prepare for events, although for some hazards, longer term mitigation strategies are better (for example, building codes and planning regulations).
- Standardization of warning processes and guidelines could enhance EWS, enabling them to be locally and contextually relevant, while providing enough coherence to enable and integrate top-down and bottom-up approaches in EWS.

To close these key gaps, working with a broader range of experts and more joined-up thinking is urgently needed as initiatives may lag unless supported and implemented from beyond the realms of the UN system. Experts in the first mile, be they peoples with vernacular, local, and indigenous/traditional knowledges, are critical to a more co-productive approach, and academic institutions can bring valuable analysis to aid EWS effectiveness. Ten years into the implementation of the SFDRR, the need to work together to make sure that warnings enhance the people they serve, is needed more than ever.

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