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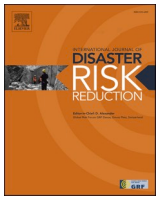

An evaluation of availability and adequacy of Multi-Hazard Early Warning Systems in Asian countries: A baseline study

Ignacio Aguirre-Ayerbe [a,*], María Merino [a], Seinn Lei Aye [b], Ranjith Dissanayake [c], Fathimath Shadiya [d], Crisanto M. Lopez [e]

[a] IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Spain
[b] University of Yangon, Myanmar
[c] University of Peradeniya, Sri Lanka
[d] Maldives National University, Maldives
[e] Ateneo de Manila University, Philippines

A B S T R A C T

Early warning systems are widely considered as one of the more important aspects to reduce the impacts and consequences that hazardous natural events pose to societies. Similar to the other terms related to disaster risk reduction, this concept has evolved over time to eventually result in a comprehensive framework, that includes features from the upstream phase, such as detection and forecasting tools and models, to the downstream phase that considers a people-centred approach.

Based on this holistic conceptual framework, this paper attempts to assess the degree of adequacy and integration of early warning systems with reference to international standards using a multi-hazard perspective. The study is focused on the following Asian countries: the Maldives, Sri Lanka, Myanmar and the Philippines.

Results obtained provide an inventory of existing approaches and systems, showing common backgrounds and consistencies in their conceptualisation. In addition, the findings of this study highlight the strengths and weaknesses of Multi-Hazard Early Warning Systems in each country considering their technical, legal, and socio-economic complexities. These findings are intended to support target countries to improve the availability and effectiveness of their warning systems.

1. Introduction

Early Warning Systems (EWS) are one of the most important elements for effective disaster risk reduction. They should provide, in their more holistic understanding, a comprehensive scheme from the upstream detection and analysis of hazards to the downstream warning communication and response actions.

Over the past few years, international initiatives have focused on a multi-hazard approach, resulting in the so-called Multi-Hazard Early Warning System (MHEWS), to enhance the effectiveness of EWS and strengthen cooperation among the various agencies involved [1]. While much attention has been given to the upstream phase, less emphasis has been placed on the study of the downstream phase [2] and in the significant and delicate linkage between both phases. The importance of these phases is highlighted by the specific objective of EWS, a risk reduction measure mainly focused on reducing the exposure of the population to different hazards, thus contributing to the reduction of the impacts faced by communities and to ensure public safety [3].

The Asian region is highly threatened by multiple hydrometeorological and geological hazards, including tropical cyclones, severe storms, coastal and inland floods, droughts, earthquakes and tsunamis, causing two million fatalities and $1.5 trillion economic loss between 1970 and 2018 [4]. The efforts needed to reduce these impacts unquestionably involve the development of effective people-centred early warnings [24,25].

Considering these hazardous events, this study aims to (i) develop a baseline study of available MHEWS covering four Asian countries (Maldives, Sri-Lanka, Myanmar, and the Philippines) and, (ii) analyse their adequacy according to international recommendations, with attention to the interface and downstream phases.

In order to contextualize the study, the etymology and evolution of the concept of early warning in the context of disaster risk management were first addressed. Then, a compilation of existing regional and national MHEWS frameworks was conducted. Finally, an assessment framework was designed and applied by means of a questionnaire to determine the scope, complexity and quality of the systems according to guiding principles of global initiatives on MHEWS.

* Corresponding author.
E-mail address: aguirrei@unican.es (I. Aguirre-Ayerbe).

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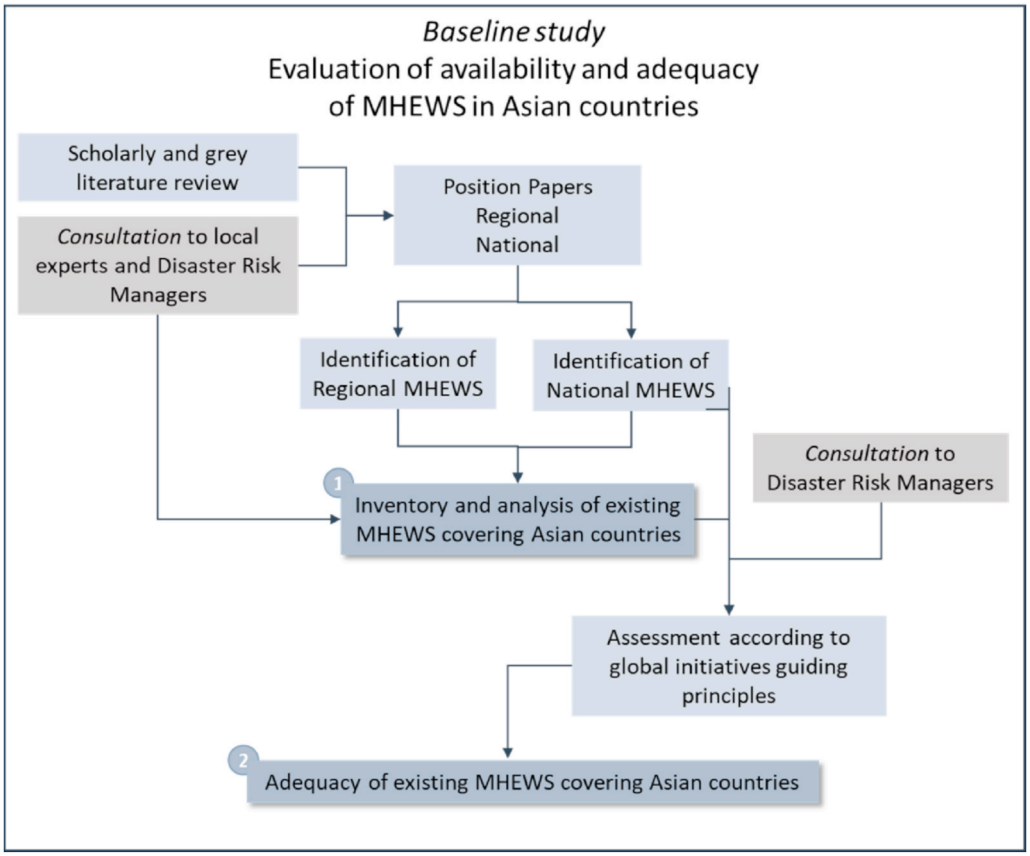

Fig. 1. Schematic Methodology workflow.

2. Conceptual framework. Evolution of the concept of early warning systems

The concepts of EWS and MHEWS have significantly evolved over time and addressed by various authors and intergovernmental institutions, especially the World Meteorological Organization (WMO) and the United Nations Office for Disaster Risk Reduction, UNDRR (formerly UN-IDNDR and UNISDR).

Since the first reference to EWS as related to disaster risk reduction by a consolidated international institution at the Yokohama First World Conference on Natural Disaster Reduction (1994) was made, the concept has been identified as a key factor to successful disaster prevention and preparedness [5]. UNISDR-WMO International conferences in Early Warning, EWC I (1998, Postdam), EWC II (2003, Bonn) and EWC III (2006, Bonn), provided further efforts by establishing the principles, guidelines and set the goals and priorities for an International Early Warning Programme (IEWP). It established the Platform for Promotion of Early Warning (PPEW), which remained operational until 2008 [6]. An important further step was done with the outcome of ECW III, wherein the document *Developing Early Warning Systems: A Checklist* was released "to both inform and draw upon the discussions and practical examples raised during the conference, and to support the implementation of the early warning components of the Hyogo Framework for Action" [7].

However, the concept of EWS was formally defined for the first time in 2004, in the UNISDR document *Living at Risk*, within its glossary on disaster risk reduction [8]. This document also mentions the new concept of "chain of concerns", which has evolved into the concept of the "four interrelated key elements" of a MHEWS, as defined in UN (2016, approved in 2017), which will be explained later. Since 2004, the evolution of the concept has begun to focus towards a people-centred approach, emphasizing the real need for understandable warnings. This was stated at the Second World Conference on Disaster Risk Reduction, held in Kobe in 2005, which defined the Hyogo Framework for Action.

The evolution of early warning systems towards the multi-hazard approach was first addressed at the First Symposium on MHEWS for Integrated Disaster Risk Management [9]. The concept evolved borrowing the previously addressed "people-centred" approach, and included the "end-to-end" and "impact-based warnings" approaches while considering that MHEWS are compounded by "four interrelated key elements". Accordingly, it was defined in UNISDR [10] and recognized in the Sendai Third World Conference on Disaster Risk Reduction [11,12], where the International Network for Multi-Hazard Early Warning Systems (IN-MHEWS) was also established.

In 2016, the definition of Early Warning System made by UNISDR in 2009 was updated, including for the first time a specific description of Multi-hazard early warning systems [13]. An EWS is accordingly understood 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" [13].

The annotation to this definition included the effective "end-to-end" and "people-centred" early warning systems that may include four interrelated components, which need to be coordinated for the system to work effectively. Following this approach, the elements are E1 - Disaster Risk Knowledge; E2- Detection, monitoring, analysis and forecasting of the hazards and possible consequences; E3 - Warning, dissemination and communication; and E4 - Preparedness and response capabilities (adapted from [13]).

Regarding the multi-hazard approach, it is stated that a MHEWS addresses several hazards and/or impacts of a similar or different type in contexts that may occur alone, simultaneously, cascadingly or cumulatively over time, considering the potential interrelated effects [13].

These systems, properly developed with well-established

Table 1
Elements and major themes included in the questionnaire adapted from WMO [19]. The final resulting questionnaire with the 14 major themes and 115 questions is provided in "Appendix A. Supplementary material" accessible at: https://doi.org/10.1016/j.ijdrr.2020.101749.

Element		Major themes	Questions
Introduction	T0	- Early warning systems availability	Q1 - Q4
E1 - Disaster Risk Knowledge	T1.1	- Are key hazards and related threats identified?	Q5 - Q6
	T1.2	- Are exposure, vulnerabilities, capacities and risks assessed?	Q7-Q15
	T1.3	- Are the roles and responsibilities of stakeholders identified?	Q16 - Q20
	T1.4	- Is risk information consolidated?	Q21 - Q27
	T1.5	- Is risk information properly incorporated into the EWS?	Q28 - Q31
E2 - Detection, monitoring, analysis and forecasting of the hazards and possible consequences	T2.1	- Are there monitoring systems in place?	Q32 - Q42
	T2.2	- Are there forecasting and warning services in place?	Q43 - Q59
	T2.3	- Are there institutional mechanisms in place?	Q60 - Q67
E3 - Warning dissemination and communication	T3.1	- Are organizational and decision-making processes in place and operational?	Q68 - Q73
	T3.2	- Are there communication systems and equipment in place and operational?	Q74-Q89
	T3.3	- Are early warnings communicated effectively to prompt action by target groups including the general public?	Q90 - Q94
E4 - Preparedness and response capabilities	T4.1	- Are there disaster preparedness measures, including response plans, developed and operational?	Q95-Q108
	T4.2	- Are public awareness and education campaigns conducted?	Q109 - Q113
	T4.3	- Is public awareness tested and evaluated?	Q113-Q115

coordination mechanisms at technical and institutional levels, increase the efficiency and consistency of warnings, thus reducing the negative consequences of hazardous events. The methodology applied in this study relies on the evolved concept of EWS explained above.

3. Methodology

On the basis of the evolved concept of EWS, a methodology was developed to accomplish the two main objectives of the study. These objectives included the development of an inventory and analysis of existing EWS and MHEWS covering the Asian target countries, and the analysis of their adequacy according to the recommendations of international initiatives (see Fig. 1).

For the inventory, a systematic approach was followed supplied by different sources of information. The starting point was the work done on the National and Regional Position Papers on the current context of the MHEWS for each of the target countries [14–17]; and [18]. Local experts and practitioners, most of them from Higher Education Institutions (including the authors of this study) have developed this work. Through literature reviews, interviews, and focus group discussions, these documents allowed to identify key stakeholders related to disaster risk management that may strengthen EWS and understand the existing policies, initiatives, and actions on EWS and coastal resilience in each of the countries. In addition, local experts and practitioners were consulted to identify specific systems and operating initiatives currently in use by means of a short survey. It addressed the following issues: element/s of the MHEWS to which the system is better related with (following the definition applied, explained above); the supporting agency for each system discerning between public or private; the geographical coverage of the system (national, regional, global); and the type and number of hazards that the system addresses, including earthquakes, tsunamis, landslides, riverine, coastal and flash floods, tropical cyclones, severe storms and extreme temperatures.

This allowed to develop the inventory and to analyse the currently available EWS and MHEWS in the target areas. The next analysis, following the second objective of this study, focused on the assessment, at the national level, of the adequacy of these systems according to guiding principles of global initiatives.

To this end, a comprehensive questionnaire has been developed, applied and completed by key stakeholders of the EWS currently operating in the Maldives, Sri Lanka, Sri Lanka, and the Philippines. The main source of information used to develop the questionnaire was the MHEWS Checklist [19,26], which is the outcome of the first Multi-hazard Early Warning Conference and updated checklist on EWS developed in 2006 [7].

The WMO Checklist [19] has 89 questions, covering 14 major themes related to the four interrelated elements. This checklist was adapted considering other relevant documents and initiatives on EWS and MHEWS. This revision included the original checklist developed in 2006 [7], the Asian Disaster Management News journal, in its volume on EWS and communities [1]; the background paper of WMO to the Global Risk Assessment Report 2015 [20]; the Technical Guidance Note on Data and Methodology to Estimate the Availability of and Access to MHEWS, related to the achievement of the Target G of Sendai Framework for Disaster Risk Reduction [12]; the United Nations document on building functional EWS [21]; and the proposed set of metrics for measuring access and effectiveness of EWS developed by the Climate Risk and Early Warning Systems initiative [22].

In this review, some issues to improve the current WMO checklist [19] were detected and incorporated into the questionnaire. These are related to standardization, updating and accessibility of information related to hazard, vulnerability and risk; technical modelling, automation and validation of processes; differentiation between hazard-based and impact-based approaches; the private sector; issues on technologies, on understandable and suitable warning systems and communications; and, on the EWS planning in the preparedness and response capabilities.

Accordingly, the questionnaire developed included 26 additional questions to address these issues. Eventually, the resulting questionnaire had 115 questions, spread across the 14 major themes. An introductory section was also included, containing four questions. The four interrelated elements (E), themes (T) and questions (Q) are related as shown in Table 1.

Based on the questionnaire, face-to-face interviews were held in each Asian target countries, guided by the authors of this study, to receive

Table 2
Stakeholders interviewed who answered the questionnaire.

Country	Stakeholder interviewed	Respondents
Maldives	National Disaster Management Authority (NDMA)	2
	Maldives Meteorological Authority (MMA)	2
Sri Lanka	Disaster Management Centre (DMC)	1
	Department of Meteorology (DoM)	1
	University of Colombo	1
	Open University of Sri Lanka	1
	Dept. Coast Conservation and Coastal Resources Management	1
Myanmar	Department of Disaster Management (DDM)	3
	Department of Meteorology and Hydrology (DMH)	2
Philippines	National Disaster Risk Reduction and Mgmt. Council (NDRRMC)	1

Table 3
Main regional and global EWS and MHEWS covering the Asian target countries of this study and the different MHEWS elements covered.

Acronym	Name	Geographical coverage	Hazard	MHEWS-elements covered[a]
RIMES	Regional Integrated Multi-Hazard Early Warning System for Africa and Asia.	21 member states (including the four target countries of this study) and 27 collaborating countries across Africa and Asia.	Tsunami, and hydro-meteorological, including extreme events.	E1, E2, E3, E4.
RSMC-WMO	Regional Specialized Meteorological Centre (Indian Met. Dep.)	West, Central South and part of South East Asia	Hydro-meteorological, including extreme events	E2, E3
IOTWS	Indian Ocean Tsunami Warning System	Indian Ocean region	Tsunami	E1, E2, E3, E4
PTWS	Pacific Tsunami Warning System	Pacific Ocean region/Global	Tsunami	E2, E3
ESSO-INCOINS	ESSO - Indian National Centre for Ocean Information Services	Indian Ocean region/Global	Tsunami, storm surge	E1, E2, E3
ADPC	Asian Disaster Preparedness Centre	Asia and Pacific	Floods, landslides, earthquake, cyclones, droughts, etc.	E1, E4
GDACS	Global Disaster Alert and Coordination System.	Global	(Real-time alerts on…) Earthquakes, tsunami, tropical cyclones, volcanic eruption, floods	E3, E4

[a] The four elements are E1 Disaster Risk knowledge; E2 Detection, monitoring, analysis and forecasting of the hazards and possible consequences; E3 Warning dissemination and communication, and E4 Preparedness and response capabilities.

responses from the main stakeholders related to EWS currently operating in the countries. Stakeholders interviewed are shown in Table 2.

The questions had four possible answers: 0 -Does not exist; 1- Partially developed (no operational); 2 - Developed but not yet operational; and 3 - Developed and operational. For each country, the data were processed to obtain the average values for each answer, the adequacy of each element and major theme being estimated by the average value for their corresponding questions.

4. Results

The results presented are divided according to the two objectives of the study. The results related to the availability of MHEWS in target countries are based on the analysis of literature review and stakeholders consultation. Results related to the adequacy of MHEWS are based on the answers provided by key stakeholders involved in EWS to the questionnaire.

Analysis of the availability of MHEWS in target countries.

According to the different sources of information, documents and consultations made and analysed in this study, several EWS and/or MHEWS were found at the national, regional (Asia) and global levels. Table 3 summarizes the available regional and global EWS and MHEWS covering the Asian target countries of this study.

Most of the systems included in Table 3, based on international and intergovernmental initiatives, are related to forecasting and hazard detection (related element E2) and the warning and dissemination (related to element E3). However, included in the list is also the Global Disaster Alert and Coordination System (GDACS), an information system not providing forecasts or hazard early warning, but issuing real-time alerts immediately after sudden-onset events, thus covering the dissemination process and enhancing response capabilities (elements E3 and E4). In the same sense, it is also included the Asian Disaster Preparedness Centre (ADPC), an intergovernmental organization focused on the disaster risk knowledge and the preparedness and response capabilities (elements E1, E4) in Asia and the Pacific.

Among these systems, it can be concluded that RIMES is the most comprehensive one, both in terms of MHEWS elements covered and the multiple hazard perspective. This regional MHEWS was established in 2009 in the aftermath of the 2004 Indian Ocean tsunami disaster to provide early warning services and building capacity in the end-to-end early warning of tsunami and hydro-meteorological hazards.

At the national level, the following paragraphs highlight the results obtained regarding available EWS and MHEWS for each of the countries analysed.

Considering that it is essential for any EWS to include the detection, analysis and forecasting of hazards, as well as the warning dissemination and communication (i.e., elements E2 and E3, see Table 1), the inclusion of these two elements within the institutional schema of each country has been considered as the starting point for the analysis. On the other hand, most of the agencies mentioned below also cover, at least theoretically, the disaster risk knowledge and the preparedness and response capabilities elements (i.e., elements E1 and E4; see Table 1).

In the Maldivian context, there are two main agencies related to the MHEWS context, the Maldives Meteorological Service (MMS), and the National Disaster Management Authority (NDMA).

The technical agency responsible for issuing early warnings related to tsunami, tropical cyclone, heavy rainfall, storm surge and floods is the MMS. The agency may receive data from its own facilities to determine the hazard alert, but they may also receive this information from regional and international agencies (for instance for tsunami hazard). In this sense, the possibility of communication and internet failure is currently a challenge [14,23]. MMS will release the alert to the NDMA, responsible for coordinating early warning, along with the relevant technical agencies, for ensuring dissemination to relevant authorities and public [23].

Although there is not a MHEWS as such, the communication framework exists and the work of the NDMA and MMS links the technical agencies and their warnings (upstream phase) to the downstream communication phase.

In Sri Lanka, the main agency related to EWS/MHEWS is the Disaster Management Centre (DMC), under the Ministry of Public Administration and Disaster Management. The DMC is responsible, together with its National Emergency Operations Centre (EOC), for coordinating early warning, dissemination of alerts and ensuring that the dissemination reaches communities. The country has a system established for multi-hazard early warning dissemination.

The technical agency responsible for issuing meteorological and tsunami hazards is the Department of Meteorology, while the Department of Irrigation (DOI) issues drought and flood forecasting and early warning [15]. In addition, the DMC may receive data alerts from regional and global technical agencies, such as INCOIS, IOTWS or RIMES. Once the DMC receives the warning message, a national level message is disseminated by the EOC to several institutions, including the emergency response committees. The message is then disseminated at four different levels: district/divisional/local authority/Grama Niladhari, to finally reach the affected community by different methods (local police, local authority officials, volunteers, etc.), which are, according to the DMC, more or less effective depending on the specific local

Fig. 2. Level of development and operationalization of elements per target country.

characteristics.

Besides the above-mentioned agencies, there are other institutions at the national level which are involved in the EWS framework of Sri Lanka, such as the Coast Conservation Department, the Marine Environment Protection Authority, the Geological Survey and Mines Bureau, the National Council for Disaster Management, the National Disaster Management Committee, and the National Disaster Relief Services Centre.

In Myanmar, the main agencies related to the MHEWS context are the Department of Meteorology and Hydrology (DMH), under the Ministry of Transport; the Department of Disaster Management (DDM), formerly Relief and Resettlement Department, under the Ministry of Social Welfare, Relief and Resettlement; the General Administration Department (GAD), under the Ministry of the Office of the Union Government; and the Myanmar Red Cross (MRC). The DMH, led by the National Committee for the Protection of Natural Disaster, established the National Multi-hazard Early Warning Centre (NMHEWC) in 2006.

The DMH is the focal point responsible for issuing early warnings on meteorological, geological and maritime-related hazards. The agency may provide information based on its own facilities to define the hazard alert (e.g., for cyclone and storm surge), but they may also receive information from regional and international agencies, such as RIMES and IOTWS. In addition, as pointed out during the focus group meetings, despite the establishment of an Emergency Operation Centre (EOC) through cooperation between the DDM and MRC, the DMH remains as the provider of disaster information, especially regarding meteorological and hydrological events [16]. Accordingly, DHM is responsible to disseminate the warning to the decision level, such as the DDM, the MRC and the GAD at both the national and regional levels. These latter agencies are responsible to disseminate the warning message to district, township and village levels in order to reach affected local communities and population.

In addition to these agencies, there are other institutions in Myanmar with different roles on the disaster risk knowledge and the preparedness and response capabilities elements of the EWS (i.e., elements E1 and E4; see Table 1). Among them the Fire Services Department, Myanmar Engineering and Geophysical associations, Myanmar Earthquake Committee, the National Disaster Preparedness Central Committee and the International Organization of Migration.

The existing framework allows for a deeper development of MHEWS, necessary to clearly define the competencies of each agency, avoiding overlaps, and strengthening the role of the EOC in the coordination of warning alerts and the communication process to the downstream phase.

In the Philippines, there are two main agencies involved in the context of MHEWS. The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) is the National Meteorological and Hydrological Services agency of the Philippines mandated

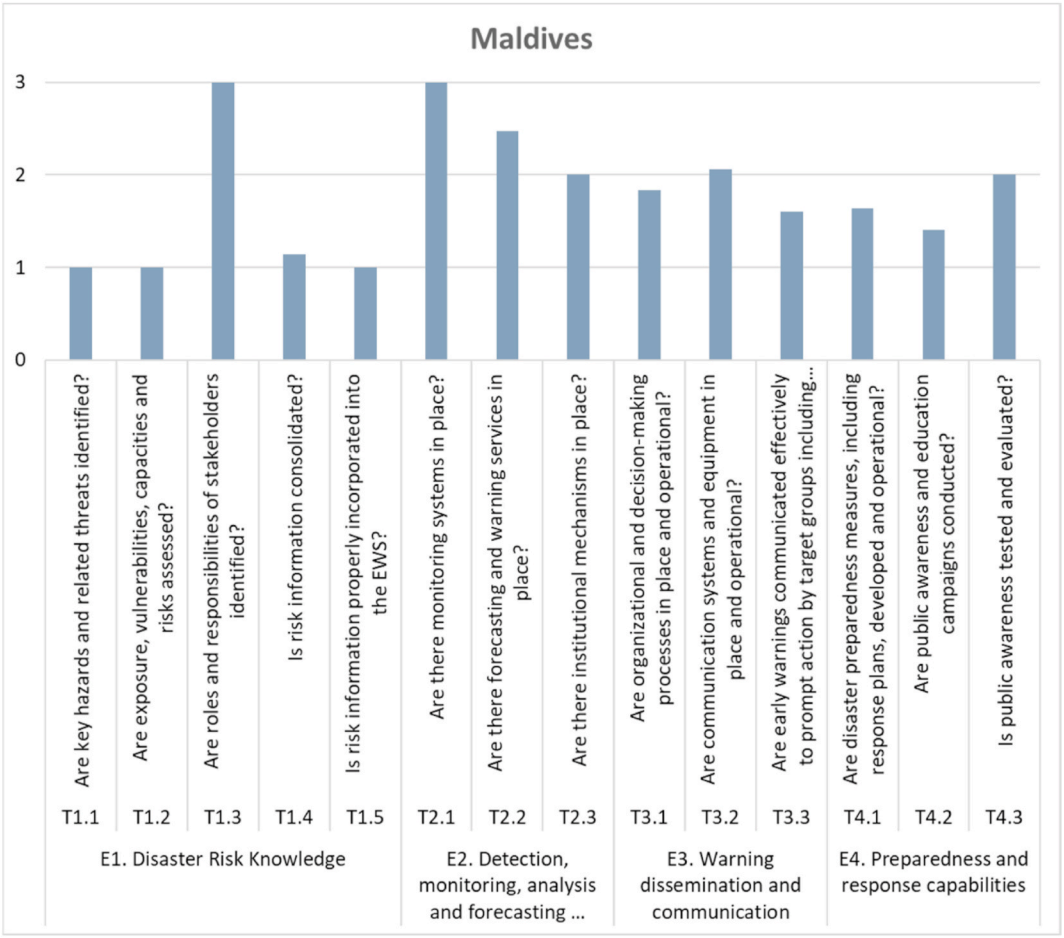

Fig. 3. Level of development and operationalization of major themes in the Maldives.

to provide protection against disasters related to natural events, and the Philippine Institute of Volcanology and Seismology (PHIVOLCS), under the Department of Science and Technology, principally mandated to manage disasters from volcanic eruptions, earthquakes, tsunamis, and other related geotectonic phenomena. The National Disaster Risk Reduction and Management Council (NDRRMC), under the Department of National Defence, is a working group that includes several governmental and non-governmental organizations, which also play an important role in the EWS framework in the country.

PAGASA issues warnings related to hydro-meteorological hazardous events such as tropical cyclones, rainfall-induced flooding or storm surge, while PHIVOLICS issues warnings from volcanic eruptions, earthquakes, tsunamis, and other related geotectonic phenomena. Warnings issued include hazard characteristics and potential impacts and are disseminated both to the public (through TV, radio, social networks and government websites) and to the NDRRMC. The latter agency is responsible to activate the emergency responders at the national level and the local DRRMCs, who is responsible to disseminate warning information to their communities [17].

In addition to these agencies, there are other national institutions in Philippines involved in the EWS context in the country, especially regarding disaster risk knowledge and preparedness and response capabilities, such as the Mines and Geosciences Bureau (MGB), and the University of Philippines Nationwide Operational Assessment of Hazards (UP NOAH).

Although there are different agencies issuing warnings, NDRRMC links the technical agencies to the downstream communication phase, as it happens within the other countries analysed. However, strengthening of the whole MHEWS framework is needed in terms of avoiding overlaps, clarifying competences and reinforcing communication and cooperation mechanisms. In addition, institutional responses need to be adjusted to the actual socio-cultural and economic characteristics of the people at risk, which currently are ignored [17].

Analysis of the adequacy of MHEWS based on international recommendations.

Once the national MHEWS have been identified, their adequacy with respect to international guidelines was assessed through the analysis of the questionnaire completed by the key stakeholders involved in the EWS currently in place.

The questionnaire included (i) an introductory section, with four questions (Q1 to Q4), focusing on the assessment of the availability of EWS and MHEWS in each target country, and (ii) four main sections, with 14 themes and 111 specific questions (Q5 to Q115) to assess the adequacy to international guidelines of each of the four interrelated elements (E1 to E4) of currently operating EWS/MHEWS. Table 1 presents the structure of the questionnaire, divided into elements (E), major themes (T) and questions (Q). To better understand the results presented in this section, see the complete questionnaire presented as supplementary material.

The introductory section examines the perception of respondents about the availability of EWS or MHEWS in each target country. These answers have been compared with the aggregated results obtained from the four main sections to analyse how the perception of stakeholders corresponds to the results obtained in the specific questions.

Answers to the introductory section indicated that there are operational EWS for single hazards in all target countries but only the Maldives has formally established a MHEWS in place. In this introductory section, respondents from the Maldives have scored all elements of

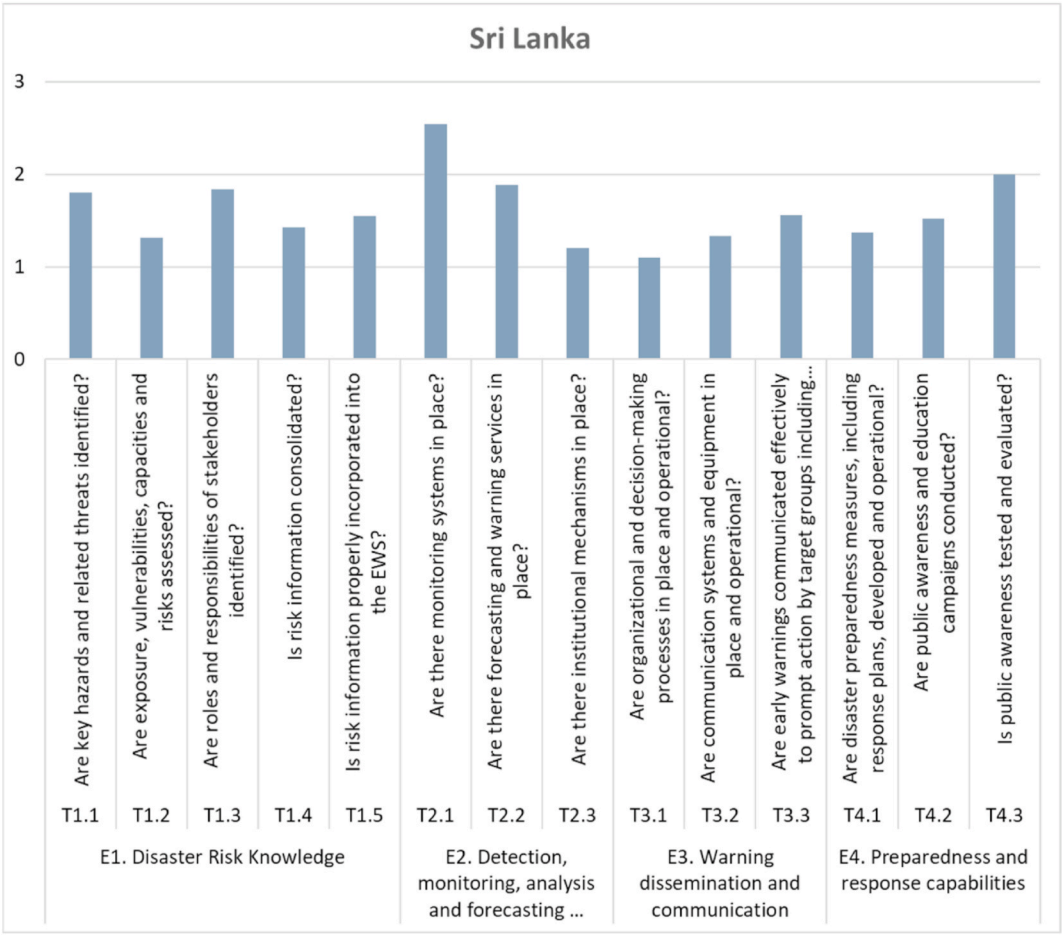

Fig. 4. Level of development and operationalization of major themes in Sri Lanka.

the MHEWS with the highest value; however, their answers to specific questions indicate that the four elements are not fully implemented and operational; only 44% of answers were scored with the highest value. As in the case of the Maldives, respondents from Myanmar also tend to slightly overestimate the availability and adequacy of MHEWS when asked directly.

Focusing on the results obtained from the four main sections (i.e., Q5 to Q115), the following paragraphs present the analysis of the adequacy of the four elements of MHEWS for each country, based on the answers to specific questions. Considering the average value of all respondents and countries, the most developed/operational element of MHEWS is *E2 -Detection, monitoring, analysis, and forecasting of the hazards and possible consequences* whereas element *E1 - Disaster Risk Knowledge* and *E3 - Dissemination and communication* are still in the first stages of development. This is applicable for the Maldives, Sri Lanka and the Philippines, but in Myanmar, interviewees indicated that *E1- Disaster Risk Management* is the less implemented element, obtaining *E4 -Preparedness and response capabilities* the highest score (see Fig. 2).

In the Maldives, *E2 - Detection, monitoring, analysis, and forecasting of the hazards and possible consequences* obtained the highest average value (see Fig. 2); within this element, the monitoring systems (T2.1) are fully developed and operational (see Fig. 3). Only some specific questions under other major themes obtained low scores; among them, the most remarkable aspects are the lack of impact-based EWS, and the low presence of the private sector in EWS (Q44 and Q67 respectively).

According to stakeholders in the Maldives, elements *E3 - Dissemination and communication* and *E4 - Preparedness and response capabilities* are in an intermediate development stage. Under E3, organization and decision-making processes and early communication of warnings are not fully developed (T3.1 and T3.3 respectively). In addition, specific aspects have not been yet addressed as mechanisms to verify reception of warnings, agreements to utilize private sector resources where appropriate, evaluation of communication channels and early warning system hardware, and the existence of automated systems to mitigate impacts (i.e.: automatic stop of transport) (Q72, Q82, Q85, Q86 and Q91 respectively). Under E4, only the testing and evaluation of public awareness (T4.3) is fully developed (but not operational); aspects that not been yet been addressed include the preparedness for long return-periods and cascading hazard events, and the design of awareness campaigns to specific needs of vulnerable groups (Q102 and Q113).

Finally, *E1 -Disaster Risk Knowledge,* especially the major themes related to the identification of hazards, assessment of exposure, vulnerability and risks, and consolidation and incorporation of risk information into EWS are poorly developed (T1.1, T1.2, T1.4 and T1.5 respectively). Only those aspects related to the identification of stakeholders (T 1.3) are developed and operational (see Fig. 3).

In Sri Lanka, none of the four elements of the MHEWS and major themes has been assessed as fully developed, except the existence of monitoring systems (T2.1) (see Fig. 4).

This major theme is considered well developed but not operational; under this element, some specific aspects are already operational as the monitoring network for different hazards, the technical equipment and modelling suitable to local conditions, the reception of monitoring data in an interoperable format in real-time or near real-time, and the automation of detection and monitoring systems (Q32, Q34, Q36 and Q40 respectively). In addition, specific aspects related to the existence of forecasting and warning services (T2.2) are considered well developed and operational as the availability of warning centres 24/7 with trained

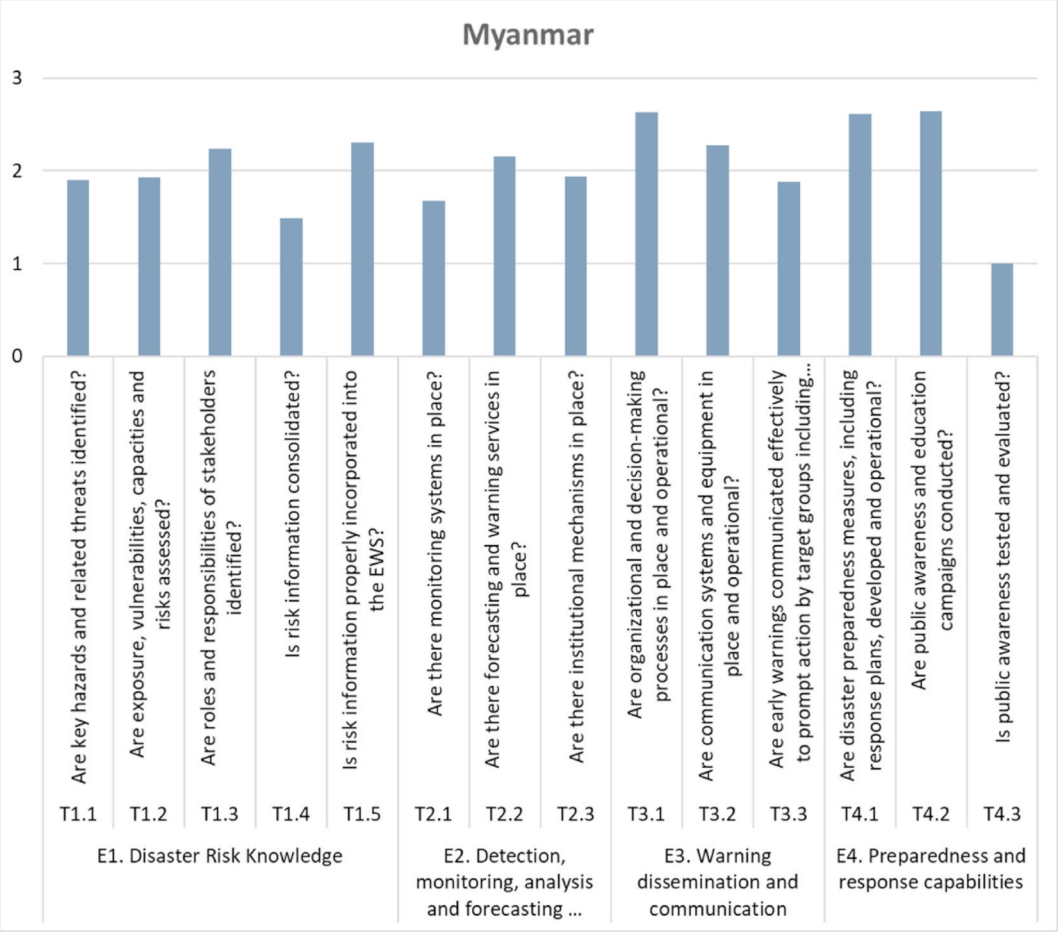

Fig. 5. Level of development and operationalization of major themes in Sri Lanka.

staff, and the adequacy of warning messages (Q47 and Q48).

All other major themes have obtained intermediate values that indicate a low or medium level of development. The theme with a higher percentage of answers reflecting low development is related to the consolidation of risk information (T.14). Within this theme, it is remarkable the low establishment of national standards (Q22), the lack of standardized vulnerability data (Q24), the lack of processes established to update hazard data (Q25) and of sustainable funds for EWS (Q27).

Finally, it is remarkable that there are discrepancies between Sri Lankan interviewees in some answers under element *E4 - Preparedness and response capabilities.* These are related to the existence of protocols or mechanisms to reach emergency and health services and the population at risk with enough time to take early action; integration of EWS within DRR plans and future planning; education of people about how warnings are disseminated, and the existence of public awareness education campaigns tailored to the specific needs of vulnerable groups (Q103, Q108, Q106, Q107, Q111 and Q113).

The analysis of results in Myanmar has revealed strong inconsistencies in the responses of interviewees from different agencies and even some within the same agency. This could be interpreted as lack of inter and intra-institutional communication. In summary, the less-developed element of MHEWS for the DMH is *E1 - Disaster Risk Knowledge*, whereas for the DDR is *E2 - Detection, monitoring, analysis, and forecasting of the hazards and possible consequences*. However, both institutions coincide in scoring element *E4 - Preparedness and response capabilities* as the most developed element of MHEWS in Myanmar.

Considering average values from all respondents from Myanmar, 50% of major themes are fully developed or fully developed and operational (see Fig. 5). From these major themes, the organizational and decision-making processes, the existence of disaster preparedness measures and the implementation of public awareness campaigns are the most developed themes (T3.1, T4.1 and T4.2, respectively) (see Fig. 6).

Regarding the existence of disaster preparedness measures (T4.1), DRM and DDR agree (considering a coincidence in more than the 50% of responses to single questions) in the high level of development and operation of most actions and in the low provision of funding to support early action and response options.

There is also agreement in the less developed themes, as the consolidation of risk information and the lack of forecasting and warning services (T1.4 and T2.2). Under T1.4, they coincide in the low development of a central standardized repository, lack of standardized vulnerability data, and the low level of development in updating hazard data with roles and responsibilities of stakeholders, and finally the lack of sustainable funds for EWS (Q21, Q24, Q25 and Q27 respectively). Under T2.2, both agencies agree on the high level of development and operation of hazard-based EWS, that are operational at all times (Q43 and Q47); also on the generation and dissemination of warnings in an efficient and timely manner for each type of hazard, the existence of processes to verify that warnings have reached the principal stakeholders and people at risk; the development of strategies to build credibility and trust in warning, and the existence of warning and forecast archival processes and systems (Q51, Q53, Q57 and Q59).

In the Philippines, results indicate that MHEWS are well developed and operational, especially in regard to *E1) Disaster Risk Knowledge* and *E2- Detection, monitoring, analysis, and forecasting of the hazards and possible consequences.*

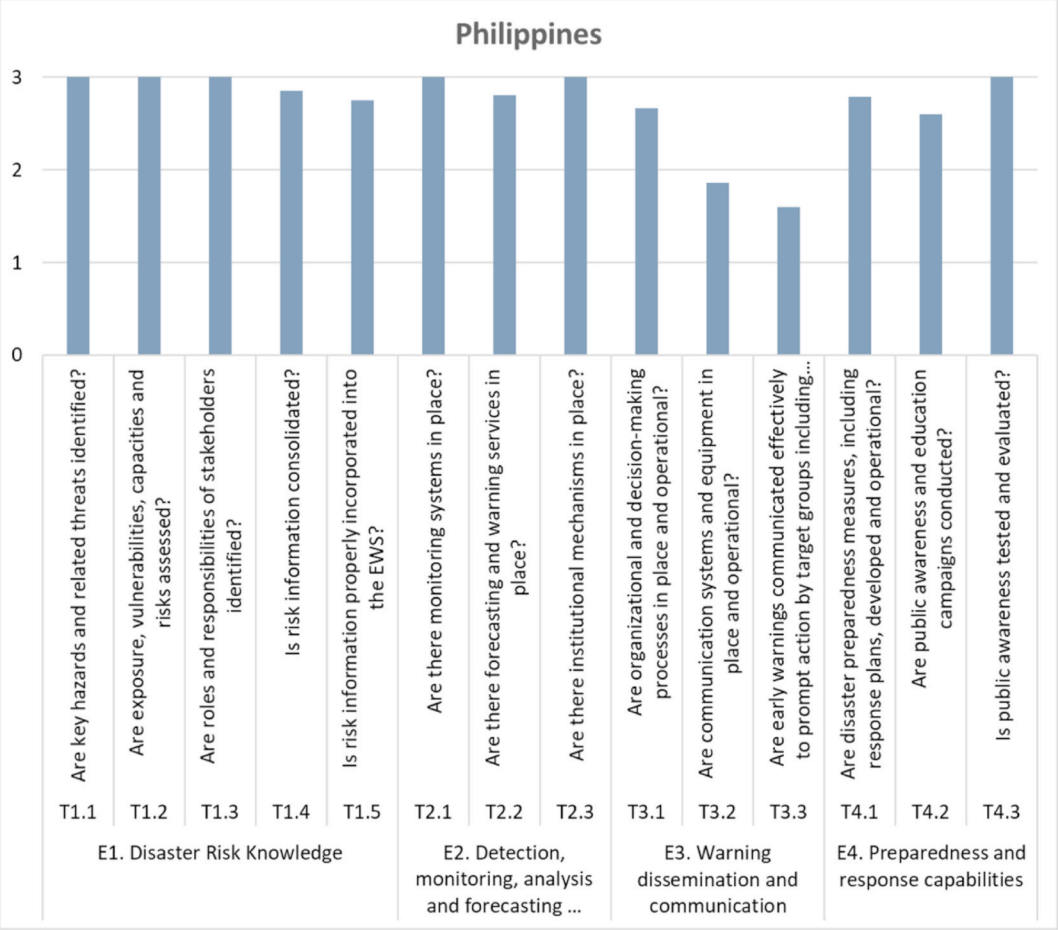

Fig. 6. Level of development and operationalization of major themes in the Philippines.

Under element E1, some specific questions are unknown for respondents, as they might be more appropriately answered by the other institutions not represented during the conduct of the survey, such as how EWS consider socio-economic, environmental and infrastructural vulnerability factors; integration of historical and indigenous knowledge into risk assessments; and how activities that increase or compound risks (e.g. urbanization and land use) are identified and evaluated (Q9, Q10, Q11 and Q12). Under element E2 only one aspect is partially developed, which is the periodical update of software and data analyses (Q49).

Element E4 is also well developed, with more than 85% of responses described as fully developed and operational. Under this element, only the following aspects are not fully developed: consideration of the needs of people with different degrees of vulnerability for the identification of disaster preparedness measures; the assessment of community's ability to communicate in response to early warnings; and the design of awareness campaigns to specific needs of vulnerable groups (Q97, Q99 and Q113).

Finally, the element which has a lower level of implementation is *E3 - Dissemination and communication*; 48% of responses under this element have been described as partially developed. The aspects related to the communication systems and equipment (T3.2) and the effective communication of early warning to target groups (T3.3) are the only themes partially developed in the Philippines.

5. Conclusions and major findings

Conclusions and major findings are oriented to summarize strengths and weaknesses found as a result of this scoping study, to identify specific topics for further improvement in each target country.

According to the results obtained from the literature review and stakeholder consultation, the multi-hazard approach is being adopted in target Asian countries, although with different levels of development and operationalization (see Table 3 and Fig. 2). In countries as Myanmar, MHEWS are formally established and defined and in other countries as the Maldives, these are constituted by the integration and coordination of the different upstream and downstream elements of EWS for single hazards.

A common element of warning systems analysed is the existence of a coordinating agency that integrates information from other agencies related to the upstream phase, in charge of detection, monitoring and forecasting activities. These agencies are necessarily focused on single hazard or group of similar hazards (i.e.: hydrometeorological or geological hazards), due to the specific requirements in terms of data sources, numerical modelling or equipment. As shown in Fig. 2, in the Maldives and Sri Lanka, activities related to detection, monitoring, analysis, and forecasting of the hazards are well developed, being fully operational in the Philippines.

Second, the role of the coordinating bodies is usually related to the dissemination of warning messages, emergency coordination or promotion of preparedness strategies in the downstream phase. Therefore, the functions of the coordinating agency and the coordination mechanisms between agencies should be clearly defined, avoiding gaps or overlaps, in order to ensure that warning issues reach the communities in a timely and effective manner. In this regard, dissemination and communication elements of the EWS are still in the first stages of development in the target countries, Myanmar being the country with a higher level of implementation (see Fig. 2).

The analysis has also revealed that specific aspects need to be

Table 4
Aspects that need to be addressed and developed in all target countries.

Elements (E) and major themes (T)		Aspects
E1 - Disaster Risk Knowledge	T1.2. Are exposure, vulnerabilities, capacities and risks assessed?	- Lack of consideration to vulnerability factors such as gender, disability, access to infrastructure, economic diversity, societal inequalities and environmental sensitivities. - Lack of assessment of vulnerabilities of key economic sectors at national to local levels. - Poor integration of historical and indigenous knowledge into risk assessments. - Poor identification and evaluation of activities that increase or compound risks (e.g. urbanization and land use).
	T1.4. Is risk information consolidated?	- Lack of standardized vulnerability data and information disaggregated by sex, age and disability, critical infrastructures and assets. - Lack of establishment and standardization of process to maintain, regularly review, and update hazard data, including information on any new or emerging hazards, identifying the roles and responsibilities of stakeholders, supported by appropriate funding. - Insufficient sustainable allocations/funding defined for early warning systems.
E2 - Detection, monitoring, analysis and forecasting…	T2.2. Are there forecasting and warning services in place?	- Early warning systems are not impact-based (i.e., information refers to expected impacts, even reaching the individual, activity or community level).
	T2.3. Are there institutional mechanisms in place?	- Insufficient active participation of private sector in the early warning systems.
E3 - Warning dissemination and communication	T3.1. Are organizational and decision-making processes in place and operational?	- Lack of feedback mechanisms in place to verify that warnings have been received and to correct potential failures in dissemination and communication.
	T3.2. Are there communication systems and equipment in place and operational?	- Non-existent communication and dissemination systems tailored to the different needs of specific population groups (urban and rural populations, women and men, older people and youth, people with disabilities, etc.). - Poor understanding of last-mile connectivity to know which population groups can be reached by different services, including mobile-cellular, satellite and radio services. - Agreements and interagency protocols are not established to ensure consistency of warning language and communication channels where different hazards are handled by different agencies - Lack of advanced evaluation of resilience of communication channels and early warning system hardware to reduce the impact of events on the infrastructure. - Incomplete assessment of coverage of communication channels and multiple-channel systems to identify gaps and possible points of failure that may increase vulnerability.
	T3.3. Are early warnings communicated effectively to prompt action by target groups including the general public?	- Automated systems are not in place to mitigate impacts (e.g. automatic stop of transport, activation of red lights in tunnels, stopping elevators on the closest floor, the opening of fire-truck gates, etc.) in the case of events with a short time-frame for reaction (e.g. earthquake early warning). - Early warnings do not take into account the different risks and needs of subpopulations, including differential vulnerabilities (urban and rural, women and men, older people and youth, people with disabilities, etc.). - Insufficient warnings products that are specifically developed for different sectors (i.e.: ports, industries, agriculture, services, urban planning, etc…).
E4 - Preparedness and response capabilities	T4.1. Are there disaster preparedness measures, including response plans, developed and operational?	- Lack of clear linkage of early action and response options across time and geographical scales to the provision of funding to support them. - Lack of strategies implemented to maintain preparedness for longer return-periods and cascading hazard events.
	T4.2. Are public awareness and education campaigns conducted?	- Public awareness and education campaigns are not tailored to the specific needs of vulnerable groups (e.g. women, children, older people and people with disabilities).

addressed and developed in all target countries, as presented in Table 4. These are mainly related to (i) the consideration of human and infrastructural vulnerability characteristics for risk assessments, communication strategies and the implementation of public awareness campaigns; (ii) integration of local knowledge and existent socio-economic circumstances into EWS; (iii) existence of automated systems in the case of events with a short time-frame for a reaction; (iv) evaluation of resilience and coverage of communications channels and EWS; (v) establishment of processes to update hazard data; (vi) allocation of sustainable funds for EWS; (vii) existence of impact-based EWS; (viii) engagement of private sector into EWS; (ix) ensuring and verifying reception of warning messages; and (x) implementation of preparedness strategies for long return-period events.

Finally, the importance of regional cooperation in Asia is remarkable. Currently, most of the existing EWS at the national level, in addition to their own resources, receive data and/or warnings from regional and international systems.

At the regional and national level, the identification of strengths and weaknesses of each country can be used to define tailored partnership and collaboration strategies between countries to reinforce the development and operationalization of EWS. Lessons learnt from successful MHEWS frameworks and existing knowledge can be shared among countries to enhance existing systems and move towards more resilient communities. Moreover, the methodology and analysis proposed under this study can be applied to other Asian countries as a baseline for the identification of opportunities for more effective and people-centred MHEWS.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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