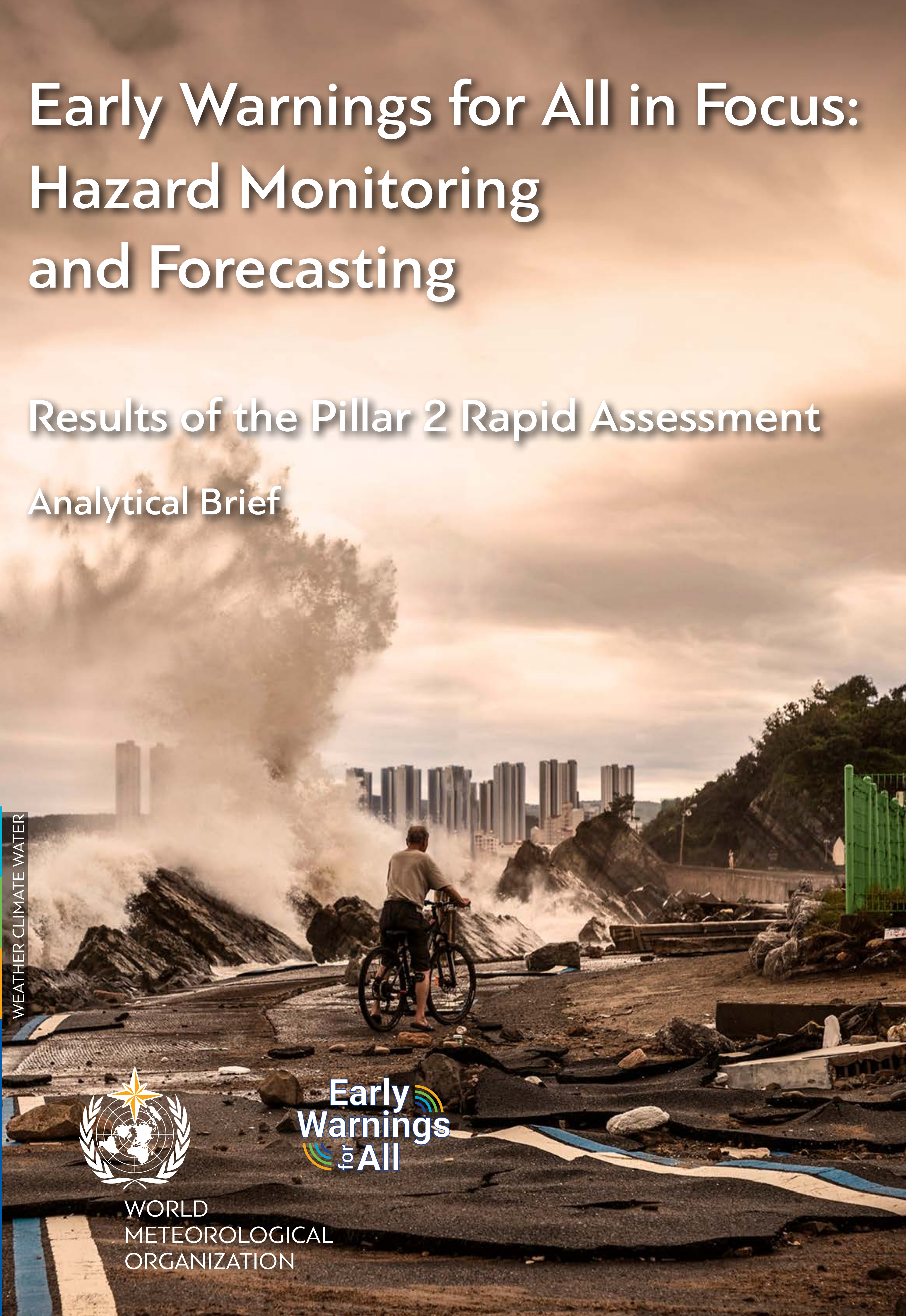
# Early Warnings for All in Focus: Hazard Monitoring and Forecasting

## Results of the Pillar 2 Rapid Assessment

### Analytical Brief



WEATHER CLIMATE WATER

Early Warnings for All

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# About the rapid assessment

To inform planning and better target assistance, WMO conducted a Rapid Assessment of the hazard monitoring and forecasting capacity of the 30 countries selected for initial support under the Early Warnings for All (EW4All) Initiative.[1]

The assessment was structured along the following seven elements of the hydrometeorological value chain: legal framework and institutional mechanisms of the National Meteorological and Hydrological Services (NMHSs); observation infrastructure; hazard monitoring capacity; use of remote-sensing data; use of numerical weather prediction (NWP) models and forecasting tool application; impact-based forecasting capacity; as well as warning services and early warning system operations. It was also aligned with outcomes of the Pillar 2 Implementation Strategy.

For each of the seven elements, a set of quantitative and qualitative data was collected in the course of structured interviews based on established early warning system (EWS) assessment methodologies (Multi-hazard Early Warning System (MHEWS) Checklist,[2] Country Hydromet Diagnostics (CHD)[3]). The responses were then weighted and analysed to determine capacity levels for each element. These levels were ranked on a scale of 1 to 5, where 5 represents advanced capacity and 1 represents no or less than basic capacity.

In addition to appraising the general hazard monitoring and forecasting capacity of the 30 countries, the Rapid Assessment examined their preparedness to address the top five hazards (self-identified) from a hydrometeorological perspective. Whereas more in-depth analysis by hazard is required, the assessment served to detect gaps in the observing and forecasting capacity for these specific hazards. Important enabling environment factors have further been considered, such as the existence of legislation, governance mechanisms and financial as well as technological capabilities.

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[1] Antigua and Barbuda, Bangladesh, Barbados, Cambodia, Chad, Comoros, Djibouti, Ecuador, Ethiopia, Fiji, Guatemala, Guyana, Haiti, Kiribati, Lao People's Democratic Republic, Liberia, Madagascar, Maldives, Mauritius, Mozambique, Nepal, Niger, Samoa, Solomon Islands, Somalia, South Sudan, Sudan, Tajikistan, Tonga, Uganda

[2] World Meteorological Organization (WMO). *Multi-hazard Early Warning Systems: A Checklist*; WMO: Geneva, 2018.

[3] The CHD has been developed by the Alliance for Hydromet Development under WMO leadership and with the guidance of a multiparty Working Group. It is based on a peer approach where advanced NMHSs from both developed and developing countries undertake the diagnostics, following the standardized methodology. CHD provides a maturity assessment of NMHS operations along 10 elements of the hydrometeorological value chain. Behind each element sit various indicators, which are informed by data sources and by direct interviews and observation for validation purposes.

# I. General hazard monitoring and forecasting capacity

Figure 1 presents the aggregate results of the Rapid Assessment, which show that almost a quarter (23%) of the 30 countries operate with less than basic monitoring and forecasting capacity for their priority hazards, while over half rely on basic monitoring and forecasting to support their early warning systems.

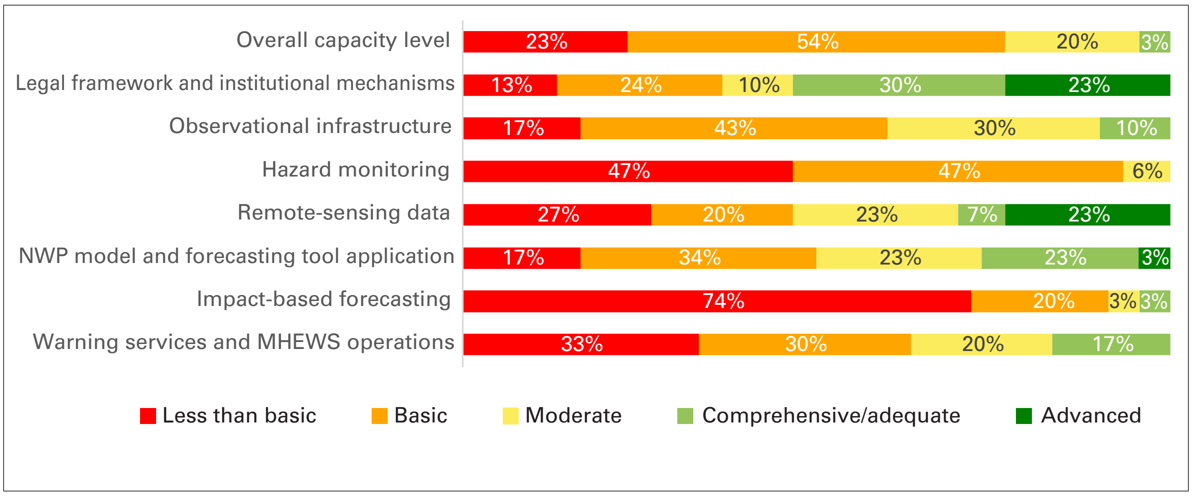


**Figure 1.** Pillar 2 capacity levels of 30 selected countries (data collected by WMO, 2023)

## LEGAL FRAMEWORK AND INSTITUTIONAL MECHANISMS

Various types of legislative frameworks give NMHSs general mandates to monitor, forecast and produce warnings for the hydrometeorological hazards affecting their countries. However, many fall short of establishing clear roles and responsibilities for all institutions involved in the national MHEWS, and most fail to implement systematic data exchange protocols across agencies.

Thirty-seven percent of the assessed NMHSs reported that no legal framework exists for MHEWS in their country, while only 26% reported operating under a law or a comprehensive national warning policy. A large proportion (37%) reported relying on a decree or other type of legislative act, as can be seen in Figure 2.

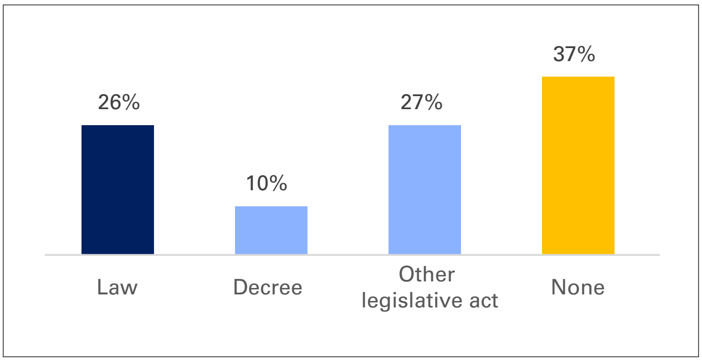


**Figure 2.** Existence of a law, decree or other legislative act on MHEWS in 30 selected countries (data collected by WMO, 2023)

Further analysis reveals common attributes and gaps in the institutional setting surrounding early warning systems. Indeed, the vast majority of the assessed NMHSs (87%) are officially recognized as the national alerting authority for hydrometeorological hazards in their country, and most (83%) are part of governmental national disaster risk reduction coordination platforms. Nevertheless, 47% reported missing clear roles and responsibilities established by legislation for all institutions generating and issuing warnings for some or all of their priority hazards. Only 13% reported benefiting from fully established agreements and inter-agency protocols for the exchange of the monitoring and baseline data necessary to produce hazard forecasts and warnings. This has implications at the operational level, as only 7% receive observational data from other agencies to monitor all their priority hazards.

## OBSERVATION INFRASTRUCTURE AND MONITORING SYSTEMS

All countries assessed face challenges with observation gaps in their infrastructure network, and most are further impeded by a large percentage of inoperable stations that cripple the monitoring capacity of their existing infrastructure. The issue is compounded by a lack of capacity to perform appropriate maintenance, calibration and quality control of their stations and instruments.

The assessed NMHSs reported operating observation infrastructure networks of varying sizes (comprising from 0 to 1 000+ observation stations), with 30% having less than 10 synoptic surface observation stations, and 57% indicating that no upper-air observations were being conducted at all in their country (whether by the NMHS itself or by another mandated entity, such as the civil aviation authority).

Across all network sizes and capacity levels, all NMHSs reported significant observation gaps (that is, areas where observations are missing). Most (77%) of the temporal frequencies of observation reported were not in compliance with the WMO Global Basic Observing System (GBON) requirements, with surface stations only reporting observation data every three hours or more. For the minority of respondents with upper-air observations, only 38% reported compliant frequencies (twice a day).

Challenges with increasing the frequency of data transmission partially stem from the operational constraints of manual observations. A third of the assessed NMHSs rely primarily upon manual observation networks as opposed to automated observing systems (Figure 3). Other issues impacting data transmission include financial limitations linked to high telemetry costs as well as inoperable stations.

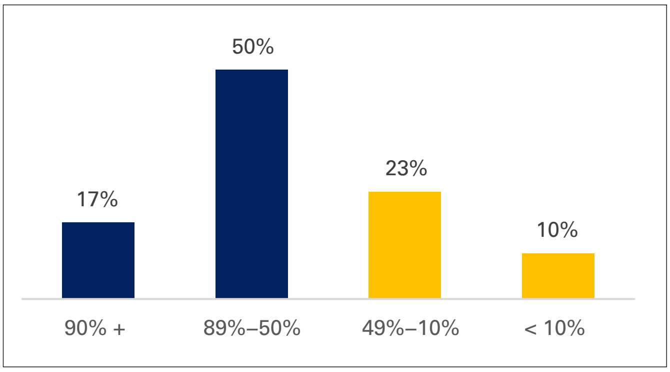


**Figure 3.** Percentage of the NMHSs' observing networks that has been automated, in 30 selected countries (data collected by WMO, 2023)

Most notably, 53% of the assessed NMHSs reported that more than half of their infrastructure is inoperable (Figure 4). These silent stations, existing but non-functioning, hamper hazard monitoring capacity. They are in part the result of lack of maintenance capacity, and indeed 57% of the assessed NMHSs reported being unable to perform regular calibration, quality control and maintenance of their observing systems, with 37% more being only partially able to attend to their infrastructure. Of these, only a minority (21%) reported receiving support from a WMO Regional Instrument Centre to assist with the calibration of their stations.

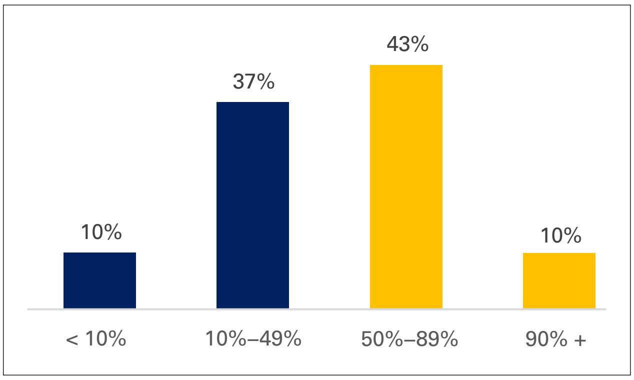


**Figure 4.** Estimated percentage of inoperable (silent) stations in 30 selected countries (data collected by WMO, 2023)

## REMOTE-SENSING DATA

Almost all NMHSs use satellite imagery and data to complement their observation infrastructure. However, many lack the training to use these resources for monitoring all of their priority hazards, and are restricted in their access by unstable, insufficient broadband connection.

Although most NMHSs assessed (57%) do not have access to radar observations, almost all access satellite data to complement their in situ observations. However, only a minority reported using them to monitor all of their priority hazards (17%). About a third do not use satellite data at all to monitor the hazards affecting their country. This is in part due to a lack of training in access and use of the data products available to monitor hydrometeorological hazards. As depicted in Figure 5, the forecasters of almost half of the assessed NMHSs have not received any training on using satellite data for hazard monitoring.

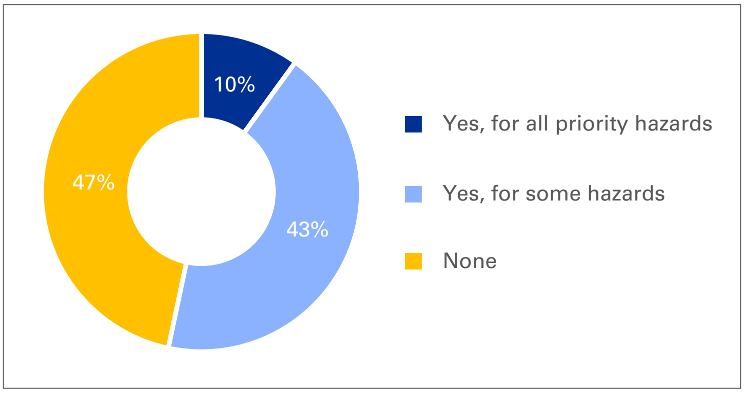


**Figure 5.** NMHS forecasters who are trained to access and use satellite data to monitor hazards, in 30 selected countries (data collected by WMO, 2023)

In addition to these limitations, the NMHSs also face connectivity challenges which impede their ability to take advantage of remote-sensing data. Sixty percent of the assessed NMHSs rely on an unstable internet connection, with frequent loss of connectivity and drop in bandwidth, which creates significant disruptions to their workflows. Analysis of the reported broadband speed available at the national forecasting centres reveals that a majority of them (63%) are limited by slow connection (<50 megabits per second (Mbps)) (Figure 6).

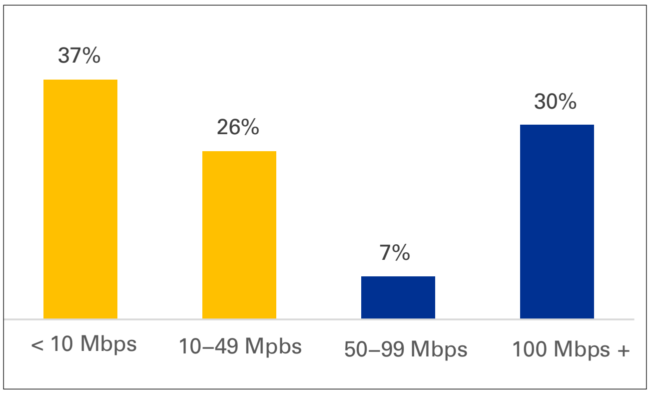


**Figure 6.** Maximum download speed available at the national forecasting centre in 30 selected countries (data collected by WMO, 2023)

## NUMERICAL WEATHER PREDICTION MODEL AND FORECASTING TOOL APPLICATION

Most of the assessed NMHSs produce forecasts entirely based on global or regional model outputs, and many are constrained in the use of the WMO Integrated Processing and Prediction System (WIPPS) by insufficient technical resources and training.

Thirteen percent of the assessed NMHSs produce forecasts without numerical weather prediction (NWP) model guidance, while 40% rely solely upon global and/or regional deterministic models (Weather Research and Forecasting (WRF), Global Forecast System (GFS), the models run at the European Centre for Medium-Range Weather Forecasts (ECMWF) and so forth). Only a minority (16%) reported having the capacity to post-process numerical weather prediction, including ensemble prediction system products.

Although 83% of NMHSs access data and products made available by the World Meteorological Centres (WMCs) and the Regional Specialized Meteorological Centres (RSMCs) via WIPPS, the operational use of these resources is often constrained by technological limitations. Such limitations include insufficient equipment and limited connectivity (see the Remote-sensing data section above) as well as a lack of competency development. The staff of 43% of the assessed NMHSs have not been trained in access and use of WMCs'/RSMCs' products and guidance to forecast the priority hazards in their country.

Through WMO programmes and initiatives (such as the Tropical Cyclone Programme, Severe Weather Forecasting Programme and Flood Forecasting Guidance System), RSMCs provide advisories on severe weather and specific hazards affecting the countries and territories in their region. These guidance products provide support to NMHSs in forecasting and producing warnings for their priority hazards.

Two thirds of the NMHSs assessed use RSMC guidance to support the forecasting and warning of their priority hazards (Figure 7). Of the remaining one third, 7% host RSMCs, hence this specific data point is not applicable. The appetite demonstrated by NMHSs for RSMC hazard advisories and guidance bolsters the need to expand both the geographical coverage of these programmes as well as the range of hazard products provided to foster EWS capacity around the world.

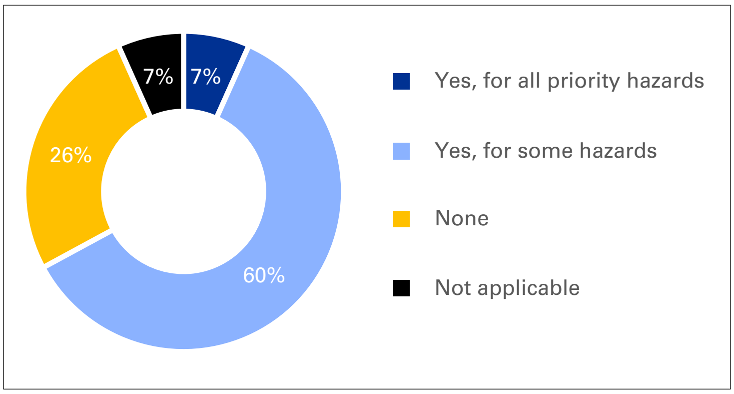


**Figure 7.** NMHS use of RSMC guidance in 30 selected countries (data collected by WMO, 2023)

## IMPACT-BASED FORECASTING

Impact-based forecasting capacity, which is essential to prevent disaster loss and damage, is lacking in most of the reviewed countries, as their NMHSs do not possess the human resources, training, technical solutions and necessary vulnerability and impact data.

Multi-hazard impact-based forecasting and warning services are an essential component of early warning systems in terms of translating meteorological and hydrological hazards into sector- and location-specific impacts, as well as enabling the development of responses and early actions to reduce disaster loss and damage. Of the 30 selected countries, only 7% reported producing impact-based forecasts and warnings for all their priority hazards. More than three quarters do not implement impact-based forecasting at all (Figure 8).

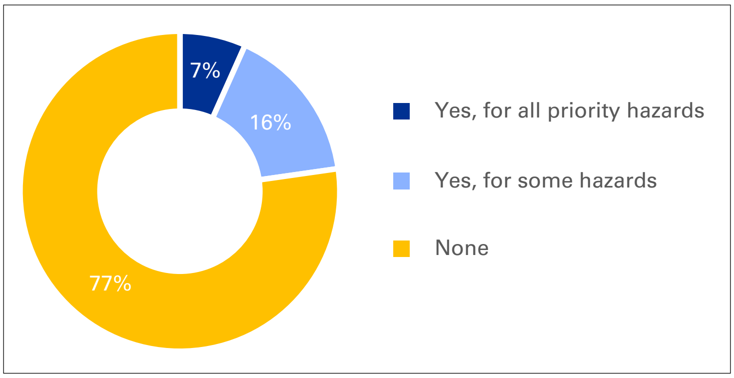


**Figure 8.** NMHSs that produce impact-based forecasts and warnings for their priority hazards in 30 selected countries (data collected by WMO, 2023)

Most NMHSs face challenges that prevent them from implementing impact-based forecasting. Firstly, there is a lack of competency and human resources, with 87% having no or very few of their forecasters trained in applying impact-based forecasting for their country's priority hazards (Figure 9). Moreover, 93% indicated not having enough trained forecasters to provide early warning services for all their priority hazards.

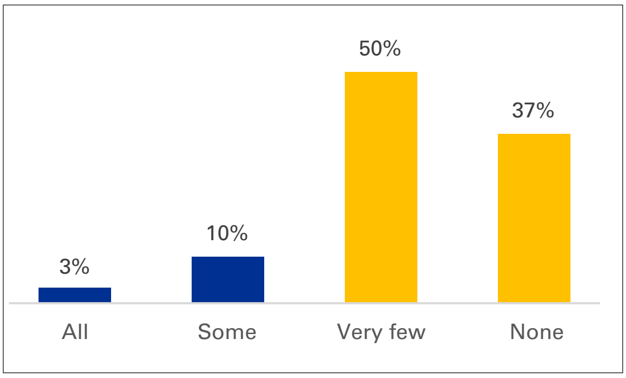


**Figure 9.** NMHS forecasters trained in applying impact-based forecasting principles and methods in 30 selected countries (data collected by WMO, 2023)

Equally relevant is the lack of access to the ancillary and impact data necessary to implement impact-based forecasting. Over three quarters of the assessed NMHSs do not have hazard exposure and vulnerability information, such as risk maps, to use as input into the development of forecasts and warnings. Similarly, the vast majority of the assessed NMHSs do not have access to impact information and post-disaster analytics from relevant stakeholders (Figure 10). Another barrier lies in the lack of appropriate technical resources available, with 93% not having access to the software tools necessary.

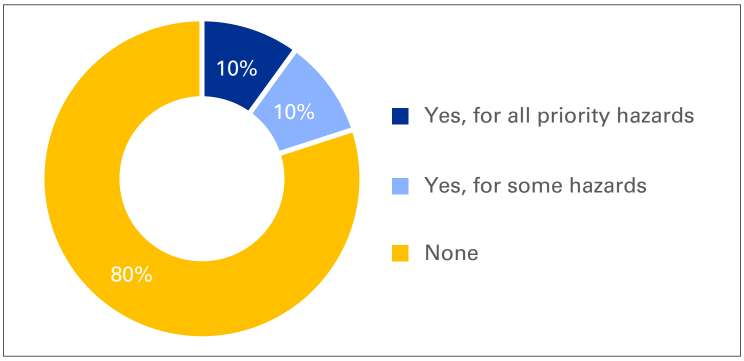


**Figure 10.** Access to impact information and post-disaster analytics to incorporate in impact-based forecasting in 30 selected countries (data collected by WMO, 2023)

## WARNING SERVICES AND MULTI-HAZARD EARLY WARNING SYSTEM OPERATIONS

Integrated MHEWS are missing in most countries, which are thus lacking capacity to forecast cumulative hazards and their cascading impacts. Furthermore, the operational inter-agency mechanisms required to sustain a functional early warning system, including standard alerting procedures and warning verification processes, often prove insufficient.

The analysis of the early warning system operations and warning services of the 30 NMHSs revealed significant gaps. Over 80% do not have an integrated MHEWS in place. Two thirds do not have systems operational to monitor and forecast multiple hazards occurring simultaneously or cumulatively over time, and 90% do not have the capacity to produce forecasts and warnings for cascading impacts of occurring hazards.

Established inter-agency operational early warning system mechanisms are further missing in a large portion of the 30 countries assessed. Eighty percent of their NHMSs do not have standard alerting procedures in place for some or all of their priority hazards (Figure 11). Furthermore, 83% do not have functional user feedback mechanisms to verify warnings (including for relevance, timeliness and so forth) and improve operations (Figure 12).

Lastly, about half of the assessed NMHSs operate warning and alert services on a continuous basis (24/7) all year long, while the remaining half lack the resources to so. Only 6% have fully operational fail-safe systems, backups and redundancies to ensure the continuity of warning services in case of an incident, while 50% only rely on partial systems primarily covering power generation. Forty-four percent have no contingencies in place at all.

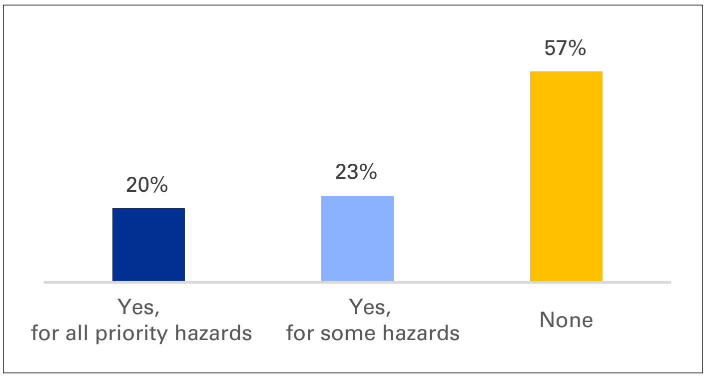


**Figure 11.** Standard alerting procedures in place with alerting authorities in 30 selected countries (data collected by WMO, 2023)

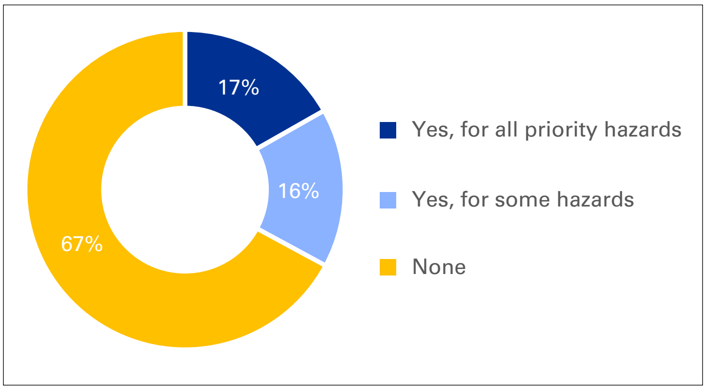


**Figure 12.** User feedback mechanism established to verify warnings in 30 selected countries (data collected by WMO, 2023)

# II. Monitoring capacity of priority hazards

According to the current assessment based on updated figures from the *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes*, a total of 1 472 reported disasters were attributed to weather, climate and water extremes in the 30 selected countries between 1970 and 2021 (Figure 13).[4] Floods were the leading cause, with riverine and flash floods accounting for 30% of the reported disasters.

Reported disasters in the 30 countries caused 1 260 816 deaths (Figure 14), accounting for 60% of globally reported deaths between 1970 and 2021. More than half of the reported

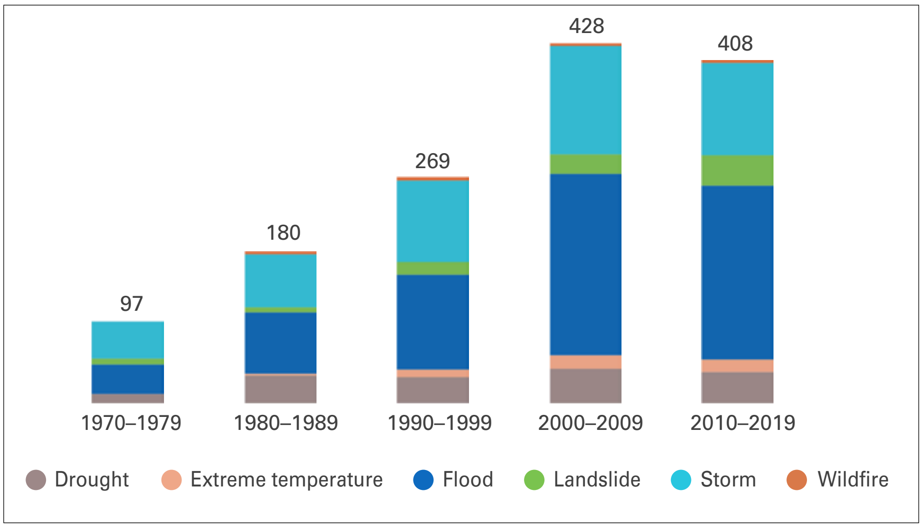


**Figure 13.** Number of reported disasters by decade by hazard type[5] in 30 selected countries (*WMO Atlas of Mortality and Economic Losses from Weather, Climate, and Water Extremes (1970–2019)*, 2022 update)

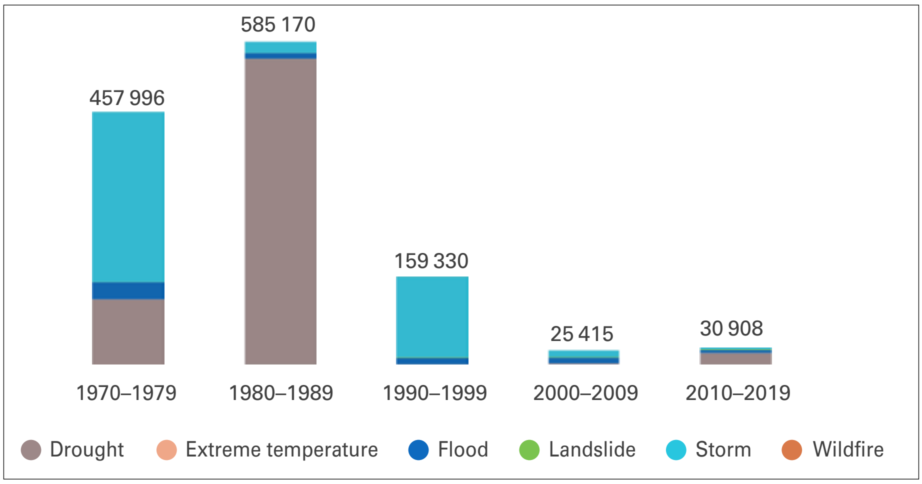


**Figure 14.** Number of reported deaths by decade, 30 selected countries (*WMO Atlas of Mortality and Economic Losses from Weather, Climate, and Water Extremes (1970–2019)*, 2022 update)

[4] World Meteorological Organization (WMO). *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)* (WMO No. 1267) 2022 update; WMO: Geneva, 2022. See also World Meteorological Organization (WMO). *Economic costs of weather-related disasters soars but early warnings save lives* [Press release]. 22 May 2023.

[5] Refers to the EM-DAT disaster classification system: https://doc.emdat.be/docs/data-structure-and-content/disaster-classification-system/

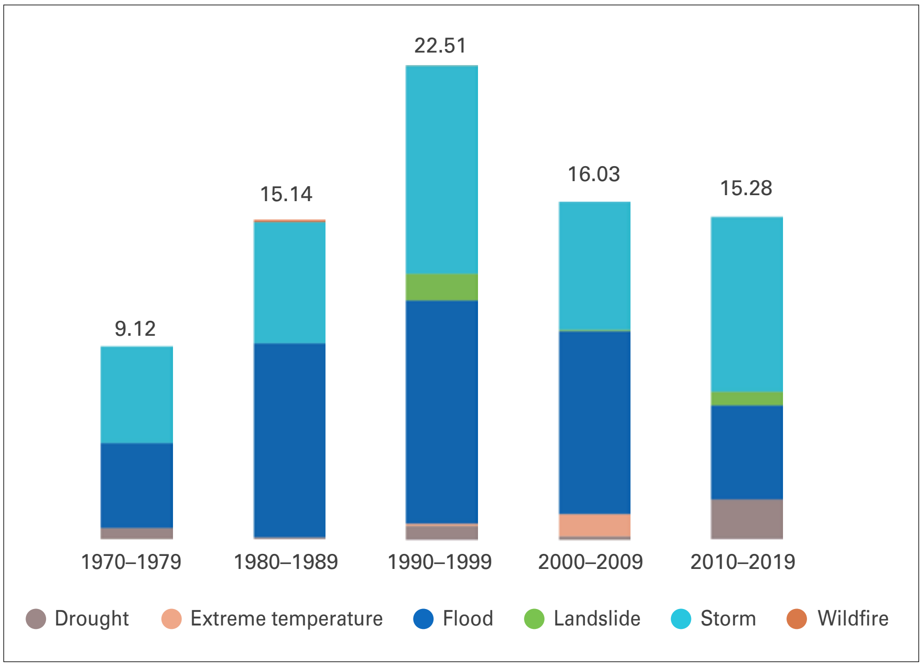


**Figure 15.** Reported economic losses in USD billion by decade, 30 selected countries
(*WMO Atlas of Mortality and Economic Losses from Weather, Climate, and Water Extremes (1970–2019)*, 2022 update)

deaths in these countries were drought related. In economic terms, the 30 selected countries incurred 82.2 billion US dollars (USD) in losses[6] due to weather, climate and water-related disasters over that period (Figure 15).

While developed economies accounted for 60% of globally reported economic losses[7] between 1970 and 2021, the economic impacts of most disasters amounted to less than 0.1% of the respective Gross Domestic Products (GDPs) at the country level (Figure 16(a)). The 30 countries selected for initial EW4All assistance experienced disproportionately higher impacts in relation to the size of their economies. Tropical cyclones were among the hazards with the strongest adverse impact in these countries, with some causing economic losses above 150% of the respective GDPs (Figure 16(b)).

The most common hazards identified by NMHSs in the Rapid Assessment largely align with the above statistics, and include droughts, floods (including riverine, coastal and flash floods) as well as landslides, tropical cyclones and thunderstorms.

As part of the assessment, the 30 NMHSs were also asked to rate their capacity to monitor their priority hazards. They were particularly requested to consider the coverage and temporal and spatial resolution of their hazard observations, the automation of their infrastructure network, data quality, their use of remote-sensing products and of advanced measurements across observation types, as well as their compliance with the relevant WMO regulations and guidelines.

[6] Economic losses are reported in 2021 USD values.

[7] Economic losses are reported in 2021 USD values.

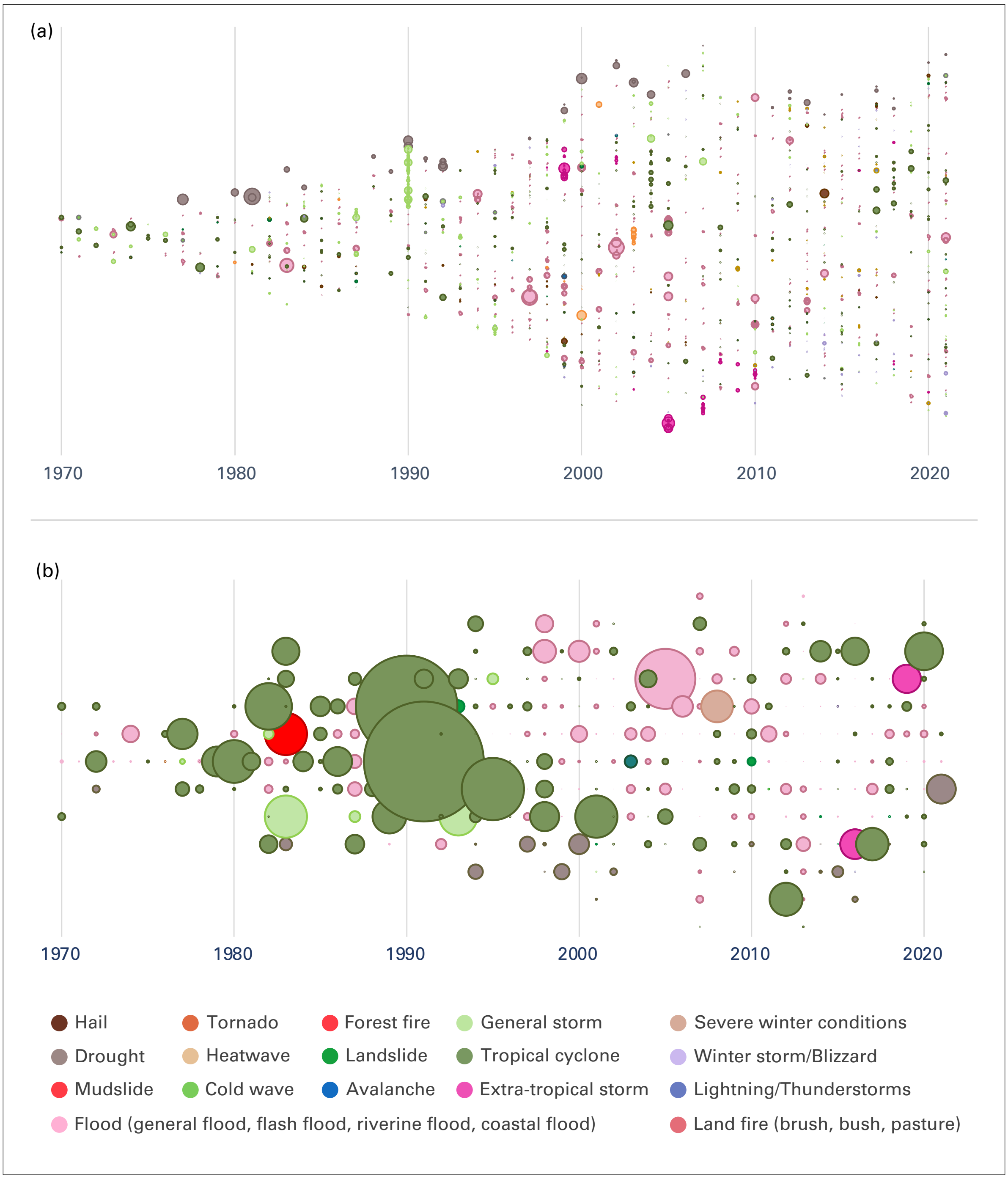


**Figure 16.** (a) Reported economic losses as a percentage of developed economies' GDP[8] (1970–2021);
(b) Reported economic losses as a percentage of 30 EW4All initial group of countries' GDP (1970–2021) (*WMO Atlas of Mortality and Economic Losses, from Weather, Climate, and Water Extremes (1970–2019)*, 2022 update).[9]

*Note*: The bubbles are event-specific; the size of the bubble relates reported economic losses from weather, climate and water extremes to countries' annual GDPs.

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[8] The World Bank. *Data, GDP (current USD)* web page, 2023: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

[9] The hazard classification is based on the EM-DAT disaster classification system.

Reflecting the challenges detailed in the preceding section, the NMHSs indicated relying on basic or less than basic observations for 70% of their identified priority hazards. Moderate monitoring capacity is available for a quarter of the hazards, while only a slim minority of the hazards (4%) are monitored through comprehensive or advanced observing systems (Figure 17).

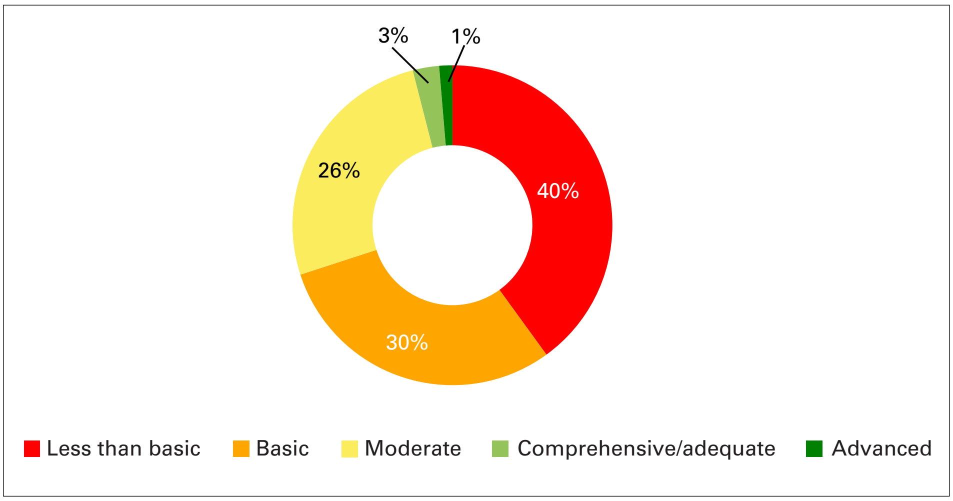


**Figure 17.** Self-assessed monitoring capacity of all identified priority hazards in 30 selected countries (data collected by WMO, 2023)

Effective monitoring systems for floods and droughts – which are consistently reported as the most frequent priority hazards and most impactful disasters – depend on hydrological and marine observations as well as on extensive historical observation data and ancillary information (such as digital elevation models, catchment boundaries and soil properties). All of these are common capacity gaps reported by the 30 NMHSs.

In addition to the hazards presented on Figure 18, the NMHSs also identified less statistically impactful yet significant hazards for which early warning capacity is also needed. These

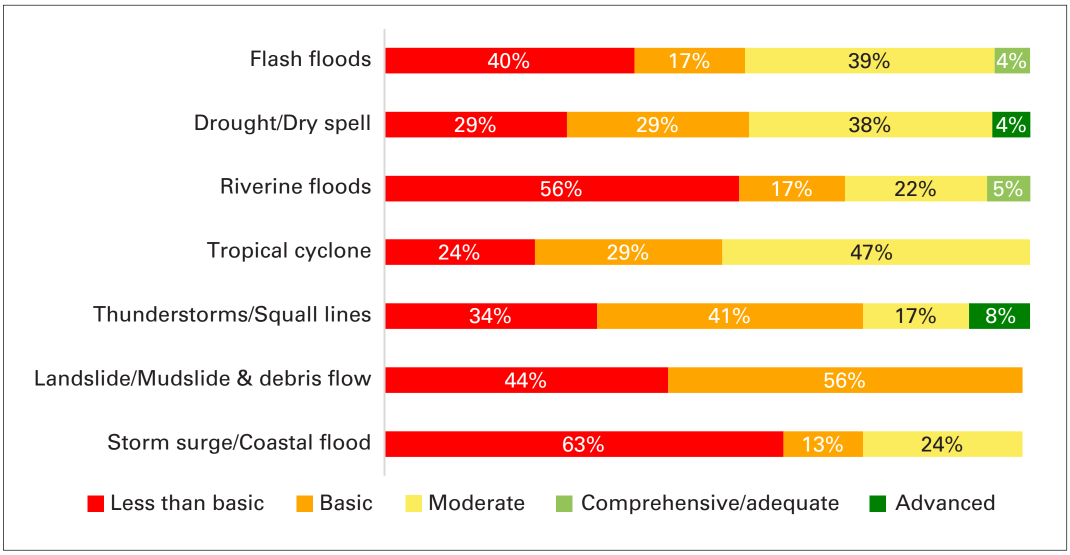


**Figure 18.** Self-assessed monitoring capacity of the most frequently identified priority hazards in 30 selected countries (data collected by WMO, 2023)

hazards, which include haze events, avalanches, hailstorms, frost, sand and dust storms, volcanic ashfall and more, were recognized as posing significant threats to the economic sectors (such as agriculture and transport) and marginalized groups (such as rural and pastoral communities) of their countries. Taken as a whole, the monitoring capacity of the 30 NMHSs for these "minority" hazards showed wide capacity gaps, as evident from Figure 19.

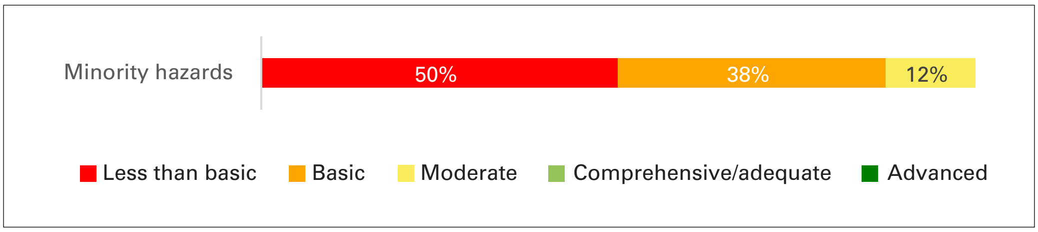


**Figure 19.** Self-assessed monitoring capacity of the least frequently identified priority hazards[10] in 30 selected countries (data collected by WMO, 2023)

[10] Priority hazards identified in 1% of cases by the NMHSs of the 30 initially selected countries

# Conclusion

The results of the WMO Rapid Assessment highlight the need for NMHSs to develop comprehensive monitoring and forecasting capacity through holistic early warning systems. This would ensure that countries are prepared not only for the most statistically significant hazards but also for all substantial risks to their communities and ecosystems.

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