Early Warning Systems in the Philippines:

Building resilience through mobile and digital technologies

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Acronyms and abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
ARG	Automated Rain Gauge
ASEAN	Association of Southeast Asian Nations
ASTI	Advanced Science and Technology Institute
AWLS	Automated Water Level Sensor
AWS	Automated Weather Station
CDR	Call Detail Record
CBEWS	Community-Based Early Warning System
CML	Commercial Microwave Link
CSO	Civil Society Organisation
DEWN	Disaster and Early Warning Network
DOST	Department of Science and Technology
DRR	Disaster Risk Reduction
DRRM	Disaster Risk Reduction and Management
EWS	Early Warning Systems
GMMA	Greater Manila Metro Area
ICT	Information and Communications Technology
IoT	Internet of Things
KDDI	Kokusai Denshin Denwa International (Japanese MNO)
LGU	Local Government Unit
LiDAR	Light Detection and Ranging
LMICs	Low- and Middle-Income Countries
ML	Machine Learning
MNO	Mobile Network Operator
NDRRMC	National Disaster Risk Reduction and Management Council
NGO	Non-Governmental Organisation
NOAH	Nationwide Operational Assessment of Hazards
OCD	Office of Civil Defense
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PDC	Pacific Disaster Center
PDRA	Pre-Disaster Risk Assessment
PDRF	Philippine Disaster Resilience Foundation
PHIVOLCS	Philippine Institute of Volcanology and Seismology
PRC	Philippine Red Cross
SMS	Short Messaging Service
TVWS	TV White Space
UNDP	United Nations Development Programme
WMO	World Meteorological Organization

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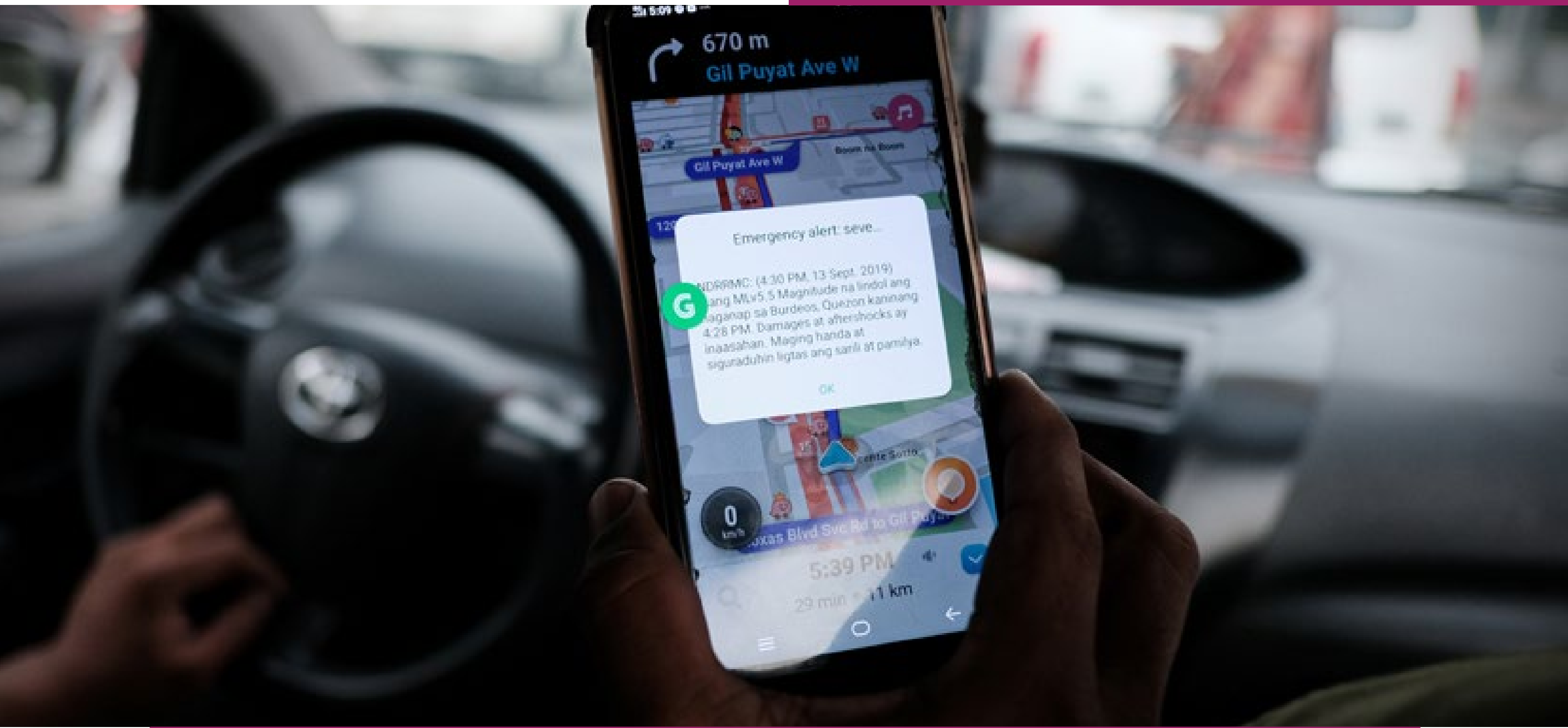

Executive summary

The Philippines consistently ranks as one of the countries most affected by natural hazards in the world. Typhoons, storms, floods, landslides or droughts are all common. In December 2021, the Philippines was hit by Typhoon Rai, which devastated island and coastal communities and flooded cities all over the country. It was recorded as the second deadliest disaster in the world that year. Extreme weather-related events such as these are expected to become more frequent with climate change, causing further loss of life and significant economic damage, especially for the country's most vulnerable.

Past disasters have prompted the Philippines to build capacity in implementing and strengthening early warning systems (EWS) to reduce the impacts of natural disasters. EWS rely on a variety of groups working together across four main areas: risk knowledge; forecasting and warning; dissemination and communication; and preparedness and response.

Mobile and digital technologies, such as the Internet of Things (IoT), big data and artificial intelligence (AI), play an important role in EWS in the Philippines, and various initiatives have been piloted by government agencies, the private sector and NGOs. Although progress has been made, the implementation of these solutions has been extremely fragmented, with overlapping solutions, inadequate coordination and data sharing between stakeholders, and a lack of impact forecasting at the local level.

Digital innovations have the potential to fill some of these gaps, and the Philippines can learn from and build on the experiences of other LMICs that have faced similar challenges with mobile and digital solutions and services. In Cambodia, for instance, IoT devices have been developed to provide fast, relevant and context-specific early warnings and updates. In Sri Lanka, the National Disaster Management Centre, in partnership with a private sector ICT specialist and a national MNO, have developed devices and APIs to improve the dissemination of alerts to communities that are not well connected. In Indonesia, a mobile app has been used to gather online communities in person to organise and respond to disasters.

To leverage these solutions, the Philippines will need to address several barriers to technology adoption and digital innovation. Many communities in the country, primarily in remote areas, either do not have network coverage or face other barriers to use. Closing the coverage gap is a prerequisite for digital EWS and will require expanding infrastructure, making it more resilient and improving connectivity. The usage gap will also need to be closed by addressing barriers to access, including the high costs of digital devices and services, lack of digital literacy and skills and low awareness of, and trust in, digital solutions. Inadequate data governance and regulatory frameworks may also reduce incentives to invest in and adopt mobile and digital technologies.

Addressing the gaps in EWS and tackling the barriers to technology adoption will require effective and genuine cross-sector collaboration and coordination at national, regional and local levels. First, there is a need to work on the factors that enable people to adopt technology, including the availability of and access to adequate infrastructure and high-quality connectivity, and their ability to own digital tools and services. Second, there is a need to address the fragmentation of EWS by streamlining overlapping solutions from the national to the local level. Third, it is essential to make impact forecasting more granular to better understand the risks and needs of local communities in specific areas and how best to prepare and respond to these risks.

The report provides detailed recommendations for key stakeholders to strengthen EWS through mobile and digital technologies in the Philippines. Government stakeholders should focus their efforts on enhancing risk knowledge and impact forecasting, improving data governance and regulations, and support digital literacy at all levels. MNOs, which are key actors at the dissemination and response stages, need to make mobile networks more resilient and expand coverage. They should support their customers in accessing information and work alongside other actors involved in the EWS ecosystem. For solution providers, complementing existing government platforms, designing for local needs and users, and adopting an inclusive design approach is essential. International donor organisations also have a role to play in addressing the specific needs of local actors and enhancing coordination with the development community.

Introduction

Climate change is one of the greatest threats facing humanity. As temperatures rise, weather patterns are becoming less predictable and more extreme. In their latest report, the Intergovernmental Panel on Climate Change (IPCC) outlined the significant climate-related impacts confronting the world and the short amount of time left to reduce greenhouse gas emissions (GHGs). The report also warns that some communities and ecosystems have already reached or are fast approaching the point of no return.[1] Cities and informal settlements are growing at an unprecedented rate and are extremely vulnerable as concentrated sites of risk exposure.

In another recent report, the World Meteorological Organization (WMO) estimates that a weather-related disaster has occurred every day on average for the past 50 years.[2] Weather- and climate-related hazards accounted for 50 per cent of all disasters and more than 70 per cent of all reported economic losses in that period. Hazards with the greatest human losses included droughts (~650,000 deaths), storms (~580,000 deaths), floods (~59,000 deaths) and extreme temperatures (~56,000 deaths). Storms were the most prevalent source of damage and caused the greatest economic losses.

While the effects of climate change will be felt globally, the impacts will not be felt equally. More than 91 per cent of deaths caused by weather- and climate-induced disasters occur in low- and middle-income countries (LMICs).[3] Many LMICs are in tropical and equatorial zones, and while these regions are already experiencing the most severe impacts of climate change, these effects will intensify as temperatures rise.[4] Often these countries have very little capacity to respond to and recover from the impacts of climate change, and may see years of economic development gains reversed.

1 IPCC. (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability.
2 World Meteorological Organization. (2021). WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019).
3 Ibid.
4 United Nations Department of Economic and Social Affairs. (2020). World Social Report 2020.

Vulnerability to climate change in the Philippines

Due to its geographical location and topography, the Philippines is one of the most disaster-prone countries in the world, consistently ranking among the top 10 countries most vulnerable to natural hazards.[5] Common hazards facing the country include floods, droughts, typhoons, landslides, earthquakes and volcanic eruptions. Typhoons such as Durian, Babs and Haiyan are among the worst global disasters ever recorded, causing thousands of deaths and significant economic damage.

In December 2021, Typhoon Rai (known locally as Odette) hit the Philippines, devastating island and coastal communities and flooding cities all over the country.[6] This was the strongest storm to ever hit the Philippines and was ranked the second deadliest disaster worldwide in 2021 after the Haiti earthquake.[7],[8] It affected approximately eight million people, with many losing their homes while also coping with the vulnerabilities brought about by the COVID-19 pandemic. Power lines, water supplies and communication networks were destroyed or interrupted across the country, exacerbating the challenges of emergency response efforts.[9] While more than 800,000 people had been evacuated in advance, nearly 300,000 were displaced and 160,000 were in evacuation centres by January 2022. It is estimated that more than $100 million will be needed to fund the recovery and rehabilitation of the two most-affected regions.[10]

Extreme weather events in the Philippines are expected to continue and become more frequent in a changing climate. Changes in hydrological patterns have increased and intensified extreme weather hazards, including tropical cyclones or typhoons.[11] Warming trends are projected, with the magnitude, frequency and duration of warming increasing in the future. Average mean temperature could increase by 0.9°C to 1.9°C by the middle of the century under different scenarios and could rise even more by the end of the century.[12] Prolonged rainfall is projected to decrease, but localised extreme rainfall events and tropical cyclones are expected to increase.

Such projections highlight the importance of being prepared for, and building resilience to, the impacts of climate change.[13] In the Philippines, EWS have already played an important role in reducing the loss of life: 400 lives were lost as a result of Typhoon Rai compared to the 6,300 deaths in 2013 from Typhoon Haiyan, even though both had similar strength.[14] There are opportunities to strengthen EWS even more, and digital and mobile technologies could play a transformational role.

Research objectives and methodology

Past disasters have led the Philippines to build capacity in strengthening EWS to reduce the impacts of disasters, including physical damage, economic losses and mortality. In the face of climate change, investing in and strengthening existing EWS will be essential.

This research aimed to understand EWS in the Philippines' climate-resilience strategy and identify opportunities for digital solutions to strengthen them and support efforts to build climate and disaster resilience. The focus was on rapid-onset hazards and climate change-related risks, i.e. those exacerbated by extreme weather events, including typhoons, flooding, heat and landslides.

The research followed a qualitative approach, including comprehensive desk-based research and interviews with key stakeholders in EWS for weather-related hazards, both in the Philippines and in other LMICs. A detailed methodology can be found in Annex 1.

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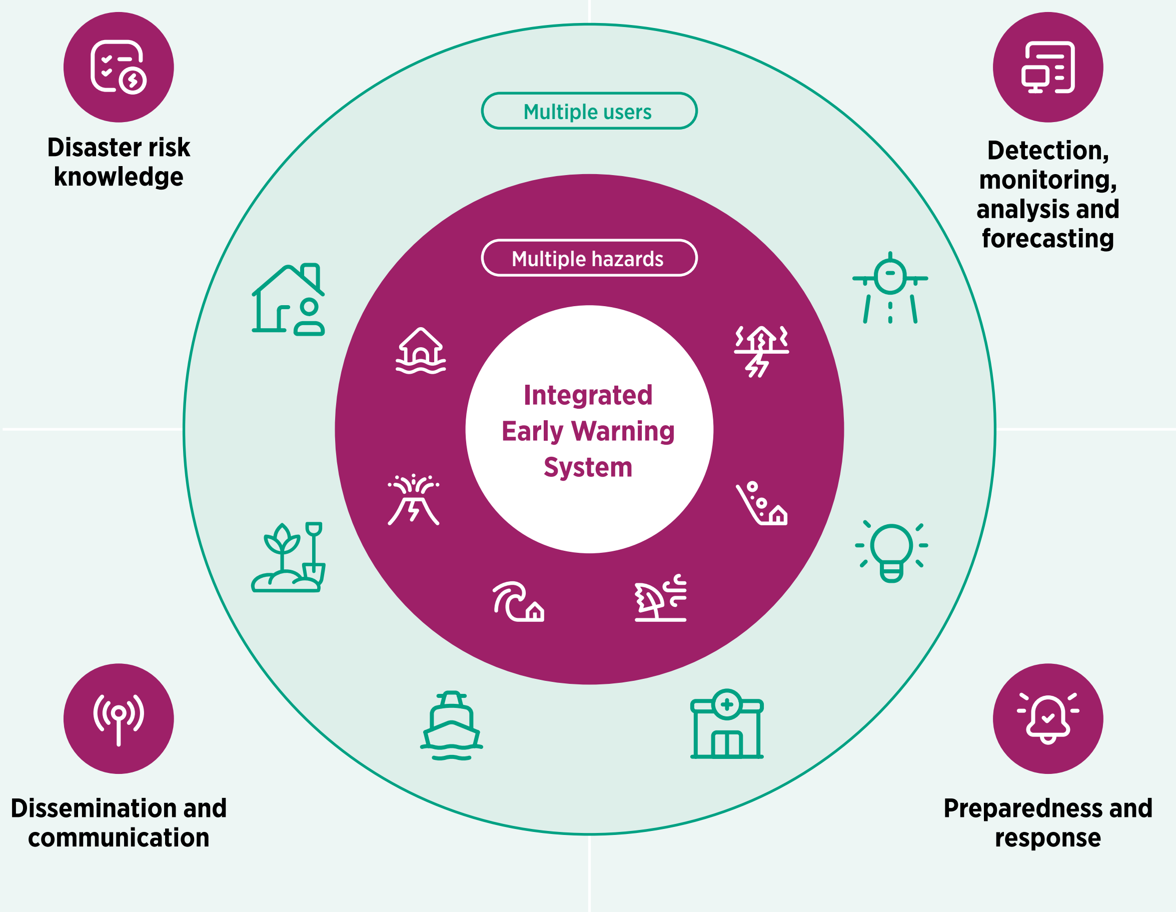
5 European Commission. (2022). "Country Risk Profile: Philippines". Disaster Risk Management Knowledge Centre.
6 International Federation of Red Cross and Red Crescent Societies. (2021). Emergency Appeal. Philippines, Asia Pacific. Typhoon Rai (Odette). Appeal No. MDRPH045.
7 Ibid.
8 United Nations Office for the Coordination of Humanitarian Affairs. (2022). Super Typhoon Rai. One month on: in numbers.
9 Ibid.
10 Ibid.
11 Alliance of Bioversity International, CIAT and World Food Programme. (2021). Philippine climate change and food security analysis.
12 See climate projections by PAGASA at: https://bagong.pagasa.dost.gov.ph/climate/climate-change/dynamic-downscaling.
13 World Meteorological Organization. (2021). WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019).
14 GSMA. (2022). Typhoon Rai Response: The role of the mobile industry.

Box 1 Understanding EWS

EWS integrate different systems and processes to monitor, forecast and predict hazards, assess risks and communicate and disseminate relevant information for people to take action in a hazardous event.[15] In general, EWS have four key stages: 1) disaster risk knowledge based on the systematic collection of risk data and disaster assessments; 2) detection, monitoring and forecasting of hazards and their impact; 3) dissemination and communication of warnings and information that are timely, accurate and actionable; and 4) preparedness to respond to warnings at all levels (see Figure 1).

EWS can be implemented for different types of hazards, such as geotectonic hazards (earthquakes, tsunamis, volcanic activity), hydrometeorological hazards (including floods, typhoons, cyclones, hurricanes and droughts), forest fires, biological and health hazards.[16] While multi-hazard EWS have been promoted in recent years, there are still some systems that only provide warnings for a single hazard. EWS are implemented at the local or community level, as well as at regional, national or global levels. In addition to ensuring sound technical implementation, EWS must also be people-centred and empower individuals and communities affected by natural hazards.

Figure 1
Stages of EWS



Source: World Meteorological Organization

15 United Nations Office for Disaster Risk Reduction. (n.d.). "Early Warning System".
16 United Nations Office for Outer Space Affairs. (n.d.). "Early Warning Systems". UN-SPIDER Knowledge Portal.

01

Strengthening EWS in the Philippines through digital innovation

Effective EWS are a critical part of disaster risk reduction and management (DRRM) and climate change adaptation strategies. When implemented effectively, EWS can significantly reduce mortality due to disasters.[17] Increasing the availability of and access to multi-hazard EWS is one of the seven priorities defined in the Sendai Framework for Disaster Risk Reduction 2015–2030 by the United Nations Office for Disaster Risk Reduction (UNDRR).[18] Mobile and digital innovations are vital to every stage of EWS and will play an increasingly important role in strengthening them.[19],[20]

Countries such as the Philippines are already experiencing the devastating effects of climate change and need to continuously evaluate and strengthen EWS, which are complex and involve multiple stakeholders at different stages. Mobile and digital technologies already play a role, but there are gaps and opportunities that need to be addressed if they are to enhance existing systems.

This section provides an overview of EWS in the Philippines, the current level of digitalisation and opportunities for mobile and digital innovation that have been seen in other LMICs. Insights are mapped against the four main stages of EWS as well as other cross-cutting aspects, as explained in Box 1.

17 Adopted by UN Member States in March 2025, the Sendai Framework for Disaster Risk Reduction 2015–2030 to reduce the socio-economic and environmental impact of disasters while also reducing the loss of life. It established seven targets and four priorities for action for all Member States. For more information, see: https://www.undrr.org/implementing-sendai-framework/what-sendai-framework and https://www.preventionweb.net/sendai-framework/sendai-framework-for-disaster-risk-reduction.

18 Ibid.

19 Ibid.

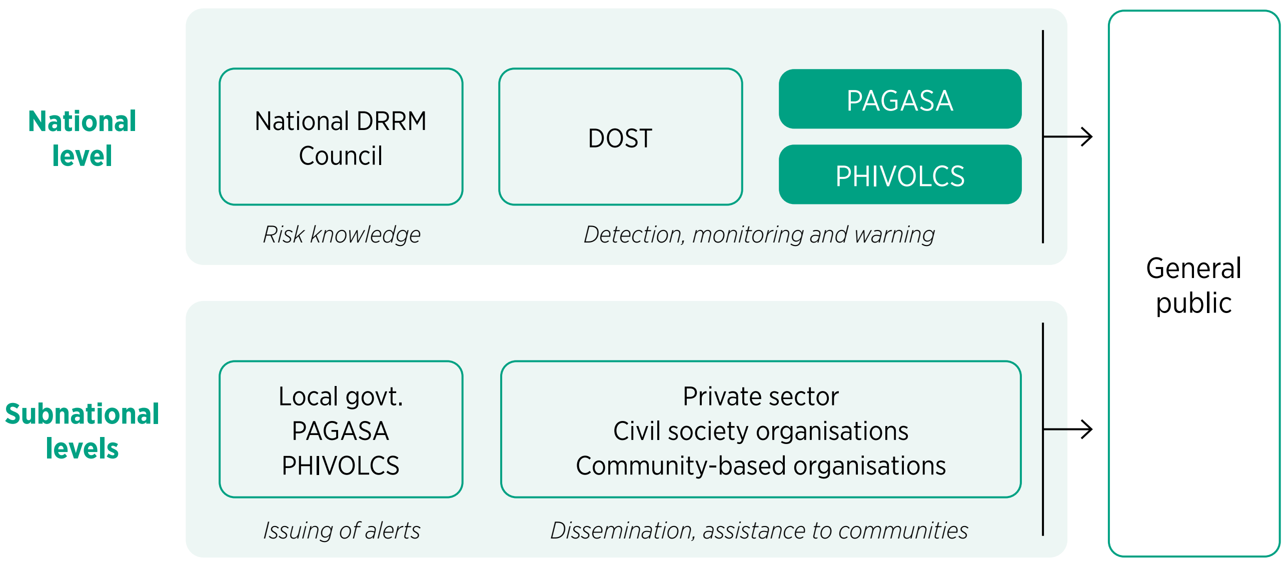
20 UNDP. (2019). Five approaches to build functional Early Warning Systems.

EWS stakeholders in the Philippines

The Philippines has a well-established system for DRRM. The Philippine DRRM Act of 2010 established the National Disaster Risk Reduction and Management Council (NDRRMC) as the main policymaking body at the national level, with similar structures at the regional, provincial, city/municipality and barangay (the smallest administration level in the Philippines) levels. Figure 2 provides an overview of the key government stakeholders involved in EWS.

The Department of Science and Technology (DOST) has a mandate to manage the prevention and mitigation of disasters and is responsible for issuing EWS through two agencies. The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) reports and issues warnings on weather-related hazards while the Philippine Institute of Volcanology and Seismology (PHIVOLCS) provides information and warnings on geotectonic events, including landslides, volcanic eruptions, earthquakes and tsunamis.[21]

Figure 2
Summary of EWS stakeholders in the Philippines



21 Aguirre-Ayerbe, I. et al. (2020). "An evaluation of availability and adequacy of multi-hazard early warning systems in Asian countries: a baseline study". International Journal of Disaster Risk Reduction. Vol. 49.

Data collection and risk assessment are undertaken by regional departments of PAGASA and PHIVOLCS while data processing and analysis are conducted at the national level. Based on these analyses, the NDRRMC issues warnings through the Office of Civil Defense (OCD) in the event of an impending disaster, which simultaneously triggers the activation of Emergency Operations Centres to coordinate early preparedness and action.[22] Warnings and alerts are provided continuously to guide response operations.

Through subnational DRRM councils, the OCD can also disseminate warnings to at-risk populations on multiple channels, including alerts and warnings via text to mobile phones. With the information received, subnational DRRM councils conduct pre-disaster risk assessments (PDRA) to discuss early preparedness actions and assist local government units (LGUs) and communities with implementation.

The national EWS operates independently of the more localised EWS that are operated by an increasing number of municipalities. The Department of Interior and Local Government (DILG) has developed protocols such as the Operation Listo programme, which provides guidance to local government officials on how to prepare and respond to disasters.

Government agencies also rely on other stakeholders to prepare and respond effectively to disasters. The private sector, including mobile network operators (MNOs), civil society organisations (CSOs) and community-based organisations (CBOs) all contribute to EWS, either by disseminating information or directly assisting communities with emergency response measures.

Box 2 **The Philippine Disaster Resilience Foundation**

The Philippine Disaster Resilience Foundation (PDRF) is the country's major private sector coordinator for DRRM. The PDRF aims to complement the central government's efforts in disaster preparedness and response by providing tools that help the private sector organise and participate in DRRM. Established in 2009, the PDRF has more than 60 members – corporations, MSMEs, communities and partner organisations – that are organised in clusters and provide support according to their core competencies.[23]

The PDRF coordinates actions and builds the capacity of the private sector in DRRM and operates a private sector-led Emergency Operations Centre. Their Disaster Information Management (DIM) system operates on a platform called the Hazard and Disaster Analysis for Business Resilience, or HANDA, which is a customised version of an online platform powered by ArcGIS[24] that provides geospatial information and interactive maps. HANDA allows the PDRF network to report and monitor natural hazard incidents and to provide consistent and reliable updates that members can access in real time.[25]

22 Office of Civil Defense. (2015). OCD Operation Manual for Response. Quezon City: OCD.
23 See: https://www.connectingbusiness.org/ourwork/philippines.
24 ArcGIS provides multiple tools to visualise and analyse data, and to collaborate and share insights via maps, apps, dashboards and reports.
25 PDRF website: https://www.pdrf.org/emergency-operations-center/disaster-information-management-system/.

Addressing gaps through mobile and digital innovations

The Philippines is a leader in Southeast Asia in the digitalisation of EWS, benefiting from comparatively high mobile penetration (see Figure 2). Several EWS initiatives with a digital component have been launched in the country (see Annex 3), but there are significant opportunities to further harness mobile and digital technologies.

Figure 3

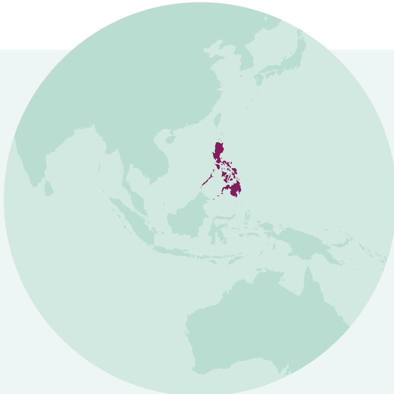
The digital landscape in the Philippines

With a population of ~112 million, the Philippines has relatively high mobile penetration and internet usage

74 million
unique subscribers[a]

99%
covered by 4G[b]

80%
of mobile connections were smartphones in 2021[c]



Expanding infrastructure for increased digitalisation is a priority in the Philippines

- One of the first countries in the Asian Pacific region to roll out 5G[c]
- National Broadband Plan and the 'Free Wi-Fi-For-All Program' aim to increase the internet access for hard-to-reach communities[d]
- Private sector actively improving and expanding ICT infrastructure to meet the growing demand for broadband access[d]

a GSMA Intelligence.
b GSMA (2022) Typhoon Rai Response: The role of the mobile industry.
c GSMA (2021). The Mobile Economy. Asia Pacific 2021.
d DICT (2019) E-Government Masterplan 2022. Republic of the Philippines.

Improving disaster risk knowledge with mobile and digital innovations

EWS stakeholders should be aware of the vulnerabilities of a particular area and understand what is causing them, for example, climate change or environmental degradation. Disaster risk knowledge entails the systematic collection of data and assessment of risks. The Philippines has a relatively advanced system for capturing climate data. Geographic Information Systems (GIS), Light Detection and Ranging (LiDAR), Interferometric Synthetic Aperture Radar (IfSAR), computer simulations and fault mapping are some of the technologies used by PAGASA and PHIVOLCS to capture information about exposure and risk vulnerability.[26]

Mobile and digital innovations are becoming increasingly important for generating disaster risk knowledge in the Philippines. For instance, in 2019, PAGASA launched an initiative to pilot a Multi-Hazard Impact-Based Forecasting and Early Warning System (MH-IBF-EWS), which will be implemented until 2027.[27] The project uses mobile technology to provide a knowledge and decision-support system (KDSS) to government agencies at national, provincial and local levels. Through a mobile app, users can visualise impact-based forecasts and warnings and disseminate response protocols. Standard operating procedures are communicated and disseminated to end users via the app to help them act early, before disasters strike.

Despite progress, accurate disaster risk knowledge is hampered by limited availability of context-specific and updated disaggregated data, especially at the local level where this type of data is often non-existent. There is also a lack of crowdsourced information about hazard risk, evolution and impact, which can be very useful for central agencies. In addition, poor connectivity often makes data collection and transmission challenging. Further use of digital innovation has the potential to address these challenges and enhance disaster risk knowledge.

26 UNDRR Regional Office for Asia and the Pacific. (2019). Disaster Risk Reduction in the Philippines: Status Report 2019.
27 Green Climate Fund. (2019). Multi-Hazard Impact-Based Forecasting and Early Warning System for the Philippines.

Digital innovations can help enhance weather trends observations

As the country's hydrometeorological agency, PAGASA operates a nationwide network for the observation and forecasting of weather, flooding and other conditions. PAGASA draws on multiple technologies[28] linked to their observation sites and central servers. In 2019, PAGASA teamed with Earth Networks, a global provider of weather information services, to implement the first nationwide severe weather monitoring and alerting network.[29] The partnership, which will last for 10 years, aims to implement a system to monitor risks at the mesoscale – an intermediate scale between weather systems and microclimates where atmospheric phenomena typically occur.[30] The system will be comprised of a network of lightning sensors and real-time automatic weather stations (AWS) that combine PAGASA's and Earth Networks' weather systems. It will generate alerts through a web-based weather monitoring platform and allow 'short-range' forecasting to improve emergency and disaster preparedness and response.

Like other LMICs,[31] the Philippines faces significant challenges in maintaining existing weather stations and expanding coverage. Particularly in remote areas, the timely maintenance, replacement and calibration of instruments can be challenging. Some interviewees reported that maintenance funding and technical staff are lacking, particularly at regional and local government levels.

Greater availability of AWS is critical to being able to collect data rapidly and feed it into PAGASA's risk knowledge system. There may also be an opportunity to test an innovative technology, commercial microwave links (CMLs), in the Philippines' mobile telecoms networks, as explained in Box 3.

Box 3 **Commercial microwave links for real-time rainfall monitoring in various LMICs**

In areas where ground instruments like weather stations are lacking, CMLs in mobile phone networks could be used to measure rainfall in high resolution and near-real time. The GSMA, in collaboration with Wageningen University & Research, Delft University of Technology and the Royal Netherlands Meteorological Institute (KNMI), has recently piloted CML-derived rainfall observations in Nigeria, Papua New Guinea[32] and Sri Lanka.[33] CMLs connect mobile towers and are disrupted by rainfall, causing signal levels to drop. These variations in signal strength provide a proxy indicator for rainfall intensity, helping to close the gap in observations available from rain gauges.

28 These include the extensive use of satellite data and images, telemetered data for rainfall and water levels, customised and standard rainfall intensity-duration-frequency (RIDF) data.
29 Earth Networks. (2019). "Earth Networks Announces Completion of Severe Weather Early Warning System for PAGASA".
30 American Meteorological Society. (n.d.). Mesoscale.
31 GSMA. (2019). Mobile technology for rural climate resilience: the role of mobile operators in bridging the data gap.
32 GSMA. (2022). Exploring opportunities for climate services in Papua New Guinea with Digicel.
33 Priebe, J. (1 November 2021). "Closing the weather data gap in LMICs using mobile networks." GSMA Mobile for Development Blog.

Mobile and digital innovations, such as mobile big data, can help collect localised vulnerability data and information to support local government units (LGUs) prepare for and respond to disasters

Localised, place-based risk information is critical to tailor preparedness and response strategies at the community level. Localised data can help reach underserved groups with appropriate warnings. However, limited data is available in the Philippines on population and infrastructure exposure to inform impact forecasting.[34] Interviewees highlighted the need for context-specific, real-time and disaggregated data at the local level across the Philippines. Key informants from civil society and international donor organisations also called for more inclusive EWS design by better understanding the needs of women and underserved groups in the early stages of data collection. Although local governments can support data gathering and improve local and national hazard exposure databases, these initiatives require greater use of digital tools and platforms for data collection. Indonesia's InaRisk portal, described in Box 4, provides an example of how digital platforms can help local governments capture data for hazard risk assessment in disaster-prone communities.

Box 4 InaRISK: a platform for efficient hazard data collection in Indonesia

InaRISK is a portal that summarises the results of local-level disaster risk assessments using ArcGIS. Data is entered by local governments following hazard risk assessments that describe disaster-prone areas, impacted populations, potential physical and economic losses and potential environmental damage.[35] InaRISK is linked to the disaster management planning process in Indonesia, which enables users to monitor the disaster risk index. It was established in 2016 by Indonesia's National Disaster Management Agency (Badan Nasional Penanggulangan Bencana or BNPB) in partnership with the United Nations Development Programme (UNDP).

Mobile big data, such as call detail records (CDR) and mobile positioning data (MPD), can also be used to accurately track population location and movement. This is currently lacking in the Philippines, and such data would help to inform models on population exposure to hazards. For example, Telefónica, in partnership with the Food and Agriculture Organization of the United Nations (FAO), used mobile big data to measure the internal displacement of citizens by mapping population movements from rural to urban areas in Latin America. In Colombia, this provided the government with better data to plan and implement social protection measures, reduce climate-related displacements and support communities to become more resilient.[36] Telefónica is also working with UNICEF on floods and landslides through LUCA, their big data services unit.[37] If mobile big data was available in real time, this would be an even more powerful tool and help to create targeted disaster response strategies.

34 Data from interviews with key informants in government and international organisations.
35 InaRISK Portal.
36 GSMA. (2019). Big Data for Social Good: Case Study on Building Communities Resilient to Climatic Extremes.
37 LUCA and UNICEF. (28 February 2017). Video: Big Data for Social Good in Colombia.

IoT sensors and automated systems can be integrated in local EWS to monitor hazards such as floods and landslides

Our research shows that EWS in the Philippines have limited capabilities to identify and provide warnings about hazards that often have devastating impacts on local communities, such as floods and landslides. Localised EWS, such as those that cover a specific area (e.g. a province, city or municipality, barangay or watershed), can help improve systems to monitor these types of hazards.[38] The use of digital innovations, such as connected sensors and IoT, can help implement local or community-based EWS (CBEWS).

In the Philippines, PHIVOLCS has also been implementing the Dynaslope Project, which develops local EWS for deep-seated landslides to help improve community resilience.[39,40] Fifty local EWS were installed using tilt and soil moisture sensors to gather technical measurements, combined with observations of movement and measurements of landslide displacements. Through mobile messages, a local landslide early warning committee then records these measurements.[41]

Systems such as Dynaslope rely heavily on the participation of people in the local community, often working as volunteers. The reliance on volunteers and human-led reporting may cause delays in data collection as well as reliability and accuracy issues. Integrating sensors and devices can help to address these problems. The Start Network,[42] a network of more than 50 organisations working on innovations for humanitarian action, recently piloted the use of internet-connected sensors in several provinces of the Philippines to identify and generate rainfall thresholds that could trigger landslides for municipalities. However, the pilot was constrained by lack of access to centralised PAGASA information on historical local rainfall data.

Despite the challenges experienced in the Philippines, examples from other countries have shown the value of integrating IoT-enabled sensors in local EWS, automated analysis using machine learning (ML) and automated dissemination of alerts via mobile. In Cambodia, for instance, a system called EWS 1294 integrated a network of sensors to automatically link to an analytical platform and then to issue an alert via the mobile network or social media (see Box 5).

Box 5 EWS 1294: IoT and mobile data for flood monitoring in Cambodia

EWS 1294 is a flood EWS operating in all provinces of Cambodia, developed by the Czech NGO People In Need. Using solar-powered and mobile data-enabled water gauges (IoT devices) with cloud hosting and interactive voice response (IVR), EWS 1294 provides fast, relevant and context-specific early warnings. Subscribed users dial FREE CALL 1294 and follow the prompts to register their province, district and commune, and then receive updates on flood warning status. Currently, the system has just over 125,000 registered users. The system has 25 active sensors, which emit data every 15 seconds, and will increase to 42 sensors by the end of 2022. The EWS received more than two million calls between 2017 and 2020. During the last major flooding in 2021, the system received 450,000 calls. Anecdotally, People in Need reports that one call typically results in approximately five individuals receiving advice. The NGO is currently negotiating a possible expansion to automated alerts disseminated by MNOs, although there are some disagreements on who should cover the costs.

38 An interesting example is the Baguio EWS for flooding, which uses smart devices to plan flood mitigation and deliver flood early warning. These include a smart flood early warning information system (FEWS) that captures real-time data in four river basins in Baguio City. For more information, see the AASCTF Policy Brief: Policy and Practice Recommendations for a Gender Transformative Flood Early Warning System in Baguio City.

39 Gumiran, B.A. and Daag, A. (2021). "Negotiated participatory action research for multi-stakeholder implementation of early warning systems for landslides." International Journal of Disaster Risk Reduction. 58.

40 For more information on the Dynaslope Project, see: https://www.phivolcs.dost.gov.ph/index.php/landslide/dynaslope-project.

41 Gumiran, B.A. and Daag, A. (2021). "Negotiated participatory action research for multi-stakeholder implementation of early warning systems for landslides." International Journal of Disaster Risk Reduction. 58.

42 The Start Network is a global network of NGOs made up of more than 50 national and international aid agencies from five continents.

Enhancing detection, monitoring and forecasting with mobile and digital innovations

Monitoring and forecasting are at the core of EWS and essential to generating accurate and timely warnings. Estimating when a hazard may strike can not only help to save lives, but also protect and reduce damage to infrastructure, where possible. To monitor hazards, PAGASA hosts a network of different types of field weather stations,[43] satellite receiving facilities, wind profilers, AWS and Automated Rain Gauges (ARGs), among others. Data is transferred from the observations network to PAGASA via an app called the Unified Meteorological Information System. In addition to PAGASA's network, the Advanced Science and Technology Institute (ASTI), another DOST agency, implemented the Deployment of Early Warning System in Disaster-prone Areas (DEWS) project, installing a system of hydrometer devices and warning stations in vulnerable areas to collect weather risk data.[44] The project collects data for ASTI, but the data is readily shared with PAGASA upon request.

Other organisations also support PAGASA and the OCD to monitor and forecast hazards. As shown in Box 6, The Pacific Disaster Centre's (PDC) PhilAWARE provides PAGASA and the OCD with impact modelling, helping to translate weather forecasting into likely impacts on populations and infrastructure. This is important for more targeted alerts in specific geographical areas and more informed disaster preparedness and response.

Box 6 **The Pacific Disaster Centre and PhilAWARE**

PhilAWARE, developed by the PDC, conducts impact forecasting of specific hazards in distinct geographical areas and infrastructure. Drawing on a wide range of data sources on the physical and environmental characteristics of these areas, the system estimates vulnerabilities and uses third-party models as well as PDC's own capability to estimate impact exposure. Population numbers are broken down by gender and age to understand likely impacts on different segments of the population. The output of the system is a series of easy-to-read and -understand infographics and dashboards, which are accessible to government and the general public.

PhilAWARE also relies on proprietary SmartAlert technology that allows users to receive early warning notifications based on hazard type and severity, as well as for multiple geographic areas and assets that users want to monitor. PhilAWARE is a localised version of DisasterAWARE, which has been implemented in other ASEAN countries including Thailand and Indonesia.

Although the Philippines has a well-developed system for monitoring and detecting risks, impact forecasting at the community level is limited due to a lack of local, accurate and real-time data. Since national-level data is often not sufficient to capture the hazards facing local communities, digital innovations have been piloted and adopted to achieve the level of granularity required to monitor hazards. FloodTags, described in Box 7, is an example of how social media posts can be used to gather flood incident information and disseminate warnings to a wide range of users and the general public.

43 These include: surface synoptic stations, upper air stations, radar stations, agrometeorological stations, official and cooperative rain stations, official and cooperative climatological stations, coastal port and airport synoptic stations, hydrometeorological and evaporation stations.

44 DOST-ASTI DEWS website.

Box 7 **Real-time flood monitoring enabled by crowdsourced data**

Floodtags, a Dutch company that monitors on-the-ground situations during disasters, partnered with the Philippine Red Cross (PRC) to create a tool that would quickly analyse social media in combination with hydrologic models to improve flood response and preparedness.[45] FloodTags analyses online media and social media and uses a digital elevation model to produce real-time flood reports. The tool combines natural language processing and flood modelling to improve risk information via social media activity and presents this information in the form of standardised maps, tables and graphs to support effective response and preparedness procedures.

Building on the expertise of the PRC, a tool called The Relevancer was developed that removes irrelevant information, adds labels to Twitter posts and then filters them to ensure that the PRC receives information customised to their needs. According to the Red Cross, this tool allows them to detect floods much earlier than before, within seconds rather than hours and sometimes even days.[46]

Digital innovations, such as mobile messaging and apps, can help address the challenges of detecting, forecasting and monitoring risks for local communities in the Philippines.

Frontier tech can improve the accuracy of data collection and analysis to support local, impact-based forecasting

While monitoring and forecasting have been strengthened for widescale hazards such as typhoons and flooding, interviews with stakeholders in the Philippines highlighted the need for a granular approach to identifying potential impacts and providing more targeted local warnings. This would not only protect communities but also lessen disruptions. For example, a granular approach can help to estimate localised impacts in a city that is forecasted to experience an adverse weather event, as well as the impact of a disaster on specific economic sectors or types of infrastructure. This helps in the dissemination of targeted 'alert blasts' to affected or vulnerable populations and locations. Impact forecasting can be made more inclusive by factoring in gender and disability, for example, where there is sufficient and disaggregated local population data.

The Philippines lacks capacity to predict the likelihood of how infrastructure such as roads, bridges, power and water may be damaged by a disaster. To address this challenge, DOST has launched a study that investigates the likely impacts of disasters on specific sectors, such as health, infrastructure, agriculture and the environment. Solutions such as the PDC DisasterAWARE capabilities, which will eventually be available to PhilAWARE, are looking at how to provide the required data granularity and are also assisting PAGASA and OCD with impact forecasting, as explained in Box 6.

The use of AI, such as ML, presents significant opportunities for more comprehensive impact forecasting. Through predictive analytics, data from past events can help forecast likely impacts on settlements, populations and infrastructure. In interviews, several stakeholders agreed that adding AI capabilities to existing hazard and impact monitoring and analysis could improve real-time risk assessment and impact forecasting capabilities. However, in the Philippines, AI is more often used in post-disaster damage impact assessment than for early warnings. For example, DOST's Advanced Science and Tech Institute (ASTI) gathers 24/7 satellite images from the Philippines Space Agency for major events, such as Typhoon Rai in 2021, and uses AI analysis of satellite images to rapidly assess the impact of wind damage, flooding and landslides.[47]

45 GFDRR Challenge Fund. (n.d.). Flood Tags: Using Twitter data to map flood risk.
46 Flood Tags. (n.d.). "Real-time flood monitor for the Philippine Red Cross".
47 Data from key informant interviews with international organisations.

Crowdsourcing can help to understand the real-time impact of hazards on communities

Disaster management and ongoing public alerts could be greatly enhanced in the Philippines with more detailed data on the real-time impacts of hazards on the ground. This can be gathered by crowdsourcing and can help to inform hazard risk, evolution and impact. Given that the average Filipino spends nearly four hours on social networking sites (the highest in the Asia Pacific region)[48] sharing real-time updates and crowdsourcing initiatives could be extremely useful in the dissemination of disaster information.

MapaKalamidad.ph (see Box 8) is an example of a crowd-based, social media-powered platform that was initially implemented in Indonesia and is now being replicated in the Philippines. A pilot version of the platform was launched in Quezon City and Pampanga in 2020[49] and a national version is being developed. Although the project is promising, interviewees raised concerns about the reliability of information received from citizens because of the resources (e.g. responders and assets) that are required to respond.

Box 8 **Using crowdsourcing to gather real-time impact data**

MapaKalamidad.ph is a crowd-based, social media-powered platform capable of collecting, organising and disseminating real-time flood information from both formal and informal sources. It was developed by Yayasan Peta Bencana in Indonesia with the support of the Urban Risk Lab at MIT. The National Agency for Disaster Management (BNPB) in Indonesia has adopted the solution, known as PetaBencana.id, and implemented it nationwide to harness the use of social media and instant messaging in Indonesia.[50]

By assessing the use of certain keywords during emergency events, the solution collects real-time, on-the-ground updates from users and displays them in the form of a live map. MapaKalamidad.ph aims to leverage the sharing of real-time posts and reports and serve as a platform that gathers, sorts and geospatially classifies this information for easy access by the public. The platform also includes AI-assisted 'humanitarian chatbots' that respond automatically to disaster-related posts on social media and ask users to confirm the situation through a disaster report. These reports are then verified and displayed on a data-light, mobile-centric, web-based map that is open and available to all users to view and share real-time flood information and make time-sensitive decisions to reduce risk.

48 Statista Research Department. (16 September 2021). "Social media in the Philippines – statistics & facts".
49 See: https://mapakalamidad.ph/map/National%20Capital%20Region.
50 Fadmastuti, M. (2019). "Selfies Save Lives (Digital Strategies for Flood Response in Indonesia)". IOP Conference Series: Earth Environmental Science. 338.

Expanding the reach of warnings and alerts with mobile and digital innovations

Clear and timely dissemination of warnings through messages containing relevant and tailored information are critical to enable adequate responses and save lives. Warnings and alerts typically rely on media and communication channels to reach populations at risk, but it is important to identify ways to reach those in remote locations that are appropriate for end users and last-mile communities, such as satellite and mobile cellular networks, social media, flags, sirens, bells, public address systems, radio, TV or door-to-door dispatch. It is often necessary to collaborate and coordinate with the private sector to deploy and use their resources where appropriate (e.g. mobile cellular networks, satellite, television, radio broadcasting, amateur radio, social media) to disseminate warnings and support communities in response actions.

In the Philippines, once hazards are identified by the monitoring agencies, information is communicated to the NDRRMC. Through the OCD, the NDRRMC maintains Emergency Operations Centres that operate around-the-clock to provide alert and warning messages to mobile phones via MNOS such as Globe and Smart, as well as TV. The NDRRMC also releases frequent updates through their situational reports. PAGASA has partnered with Google to ensure their warnings appear automatically in Google public alerts.

Agencies have adopted mobile and digital innovations to integrate risk data, forecasts and warnings. Since 2018, PHIVOLCS together with PAGASA, the OCD, the MGB and the National Mapping Resource Information Authority (NAMRIA), have started implementing impact-based forecast and warning services (IBFWS) in the country.[51],[52] Known as the Geospatial Information Management and Analysis Project for Hazards and Risk Assessment in the Philippines (GeoRiskPH), the system includes platforms[53] such as HazardHunterPH, GeoAnalyticsPH and GeoMapperPH, which are used to capture and share hazards, exposure and risk information to help people, communities, local governments and national agencies better prepare and plan for disasters (see Box 9).

Box 9 **Digital platforms for risk knowledge integration and warnings dissemination**

GeoRiskPH integrates a suite of online information, hazard assessment and visualisation tools to assess the exposure of an area to a range of hydrometeorological and seismic hazards. These are:

- **HazardHunterPH** – quickly generates initial hazard assessments of seismic, volcanic and hydrometeorological hazards in specific locations.
- **GeoMapperPH** – gathers hazard and exposure information from the field or office to provide correct and efficient updates in the database.
- **GeoAnalyticsPH** – visualises risk exposure to natural hazards and summarises hazard and risk assessments.

51 WMO. (2021). WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services Part II: Putting Multi-hazard IBFWS into Practice.
52 Although globally IBFWS implementations are at an early stage, these models are increasingly being accepted and adopted by the National Meteorological and Hydrological Services to understand how their hazard warning systems are being used to meet the needs of people and governments.
53 GeoRisk website.

MNOs play a significant role in EWS by providing essential dissemination and communication services, and by working to restore infrastructure in the aftermath of disasters. Based on the Republic Act No. 10639, MNOs are mandated to provide free mobile disaster alerts.[54] MNO Globe estimates that their cell broadcasts can reach about 70 per cent of the population[55] and the remaining 30 per cent can be reached through SMS blasts.[56] Smart's Infocast (Box 10) is an example of a web-based solution that helps to expand the dissemination of EWS alerts.

Box 10 **Smart's Infocast for more localised and targeted EWS alerts**

Initially designed for communication in schools, Infocast is a web-based broadcast solution that offers SMS facilities with multiple functions and capabilities. It provides general information, advisories and announcements to pre-registered Smart subscribers and can be used to disseminate EWS alerts to specific groups, such as LGUs and church dioceses.[57] Smart has been working with LGUs to create a use case for disaster preparedness and response, training them to design their own Infocast system, including pre-approved 'call trees' to rapidly disseminate alerts to people who are unlikely to receive mobile alerts.[58]

The Department of Information, Communication and Technology (DICT) operates an emergency warning broadcast system (EWBS) through Integrated Services Digital Broadcast Terrestrial (ISDB-T), which provides emergency announcements and up-to-date information from the NDRRMC. It also supports DRR information, education and communication (IEC) through cell broadcast, social media, traditional TV broadcast and radio broadcast.[59] TV White Space technology (TVWS),[60] which makes use of vacant television frequencies also known as white spaces, has also been trialled for alerts in the country. TVWS performs particularly well in rural areas where the spectrum is less congested, and has the potential to fill the gap left by the lack of traditional ICT infrastructure.[61]

At the subregional level, LGUs issue warnings through local DRRM councils via various channels, including SMS and social media, in combination with non-digital channels such as emergency vehicles with megaphones, batingaw (community bell) and church bells.

The dissemination of warnings and alerts in the Philippines is relatively effective,[62] but the same challenges are encountered in the other stages of EWS. In particular, the inability to provide context-specific information about local risks can explain why communities may not take appropriate action. Since definitions of risk concepts and terminologies are not always standardised or easy to understand in alerts, EWS are sometimes not responsive to a community's diverse needs. In addition, while these systems have provided life-saving assistance, many remote areas remain out of reach, often because they lack sufficient mobile network coverage or internet connectivity. In other cases, communities may fall into communication 'blackholes' if the digital infrastructure is destroyed in a disaster and they cannot receive further warnings or updates.

54 Tomacruz, S. (2018). "How NDRRMC Issues its emergency mobile warnings". Rappler.
55 While this estimate was reported in an interview, the shortfall might be explained by a range of factors, including the type of mobile phone and limitations in the handset display of messages, phone settings that block cell broadcasts or simply the lack of network coverage.
56 Data from key informant interview with Globe.
57 Smart.
58 Data from key informant interviews.
59 DICT. (2019). Early Warning Broadcast System (EWBS) Standard Operating Procedures (SOP).
60 TV white spaces are television frequencies that are vacant and located between broadcast TV channels.
61 NOMINET. (5 November 2015). "What is TV White Space?"
62 Aguirre-Ayerbe, I. et al. (2020). "An evaluation of availability and adequacy of Multi-Hazard Early Warning Systems in Asian countries: A baseline study." International Journal of Disaster Risk Reduction. 49, 101749.

More effective last-mile, mobile-enabled communication of alerts can help improve the effectiveness of risk communication

Inadequate context-specific risk communication was identified as a reason why people do not take appropriate action during disasters. Interviewees pointed to delayed warnings and bottlenecks as key issues in the dissemination of warnings, although this is not a new challenge. A 2011 study of the effectiveness of SMS alerts found that 78 per cent of those surveyed who had experienced flooding said they did not receive any early warning or flood bulletins.[63] Of those who received a flood warning, 85 per cent said they received the notice during and not before the flood event. Only eight per cent said that the information accessible to them was sufficient. These delays and bottlenecks were attributed to the technologies used for communications – SMS text blasts are prone to congestion on networks although less so than voice calls[64] – and to the delays in communication between the government and MNOs prior to the alerts being issued.

These challenges highlight the importance of resilient cell broadcast systems, which can instantaneously send an alert to millions of mobile phones without experiencing the congestion associated with SMS text blasts. Cell broadcast systems allow alerts to be sent while keeping recipients anonymous (since their numbers are not required) and sound warning tones without user interactions.[65] Messages can also be sent in multiple languages to people in target areas, which can be as wide as the entire network or as small as a single cell. However, the system only allows one-way communication and there are varying levels of support across handset models. Also, several interviewees mentioned the risk of cell broadcast being overused by the OCD and losing the sense of urgency.

Our analysis of the interviews also showed the importance of multi-channel communication for EWS alerts.[66] This is particularly relevant during disaster events when the mobile network coverage is absent or unreliable. Integrating radio broadcast and telecoms for early warning alerts can help ensure messages are disseminated effectively. In Sri Lanka, the DEWN Device is an example of how alerts from multiple sources can be integrated (see Box 11).

Box 11 DEWN: SMS-based solutions and APIs for alerts dissemination in Sri Lanka

Following the devastating 2004 Indian Ocean Tsunami, Sri Lanka's National Disaster Management Centre developed the Disaster and Early Warning Network (DEWN), with significant support from MicroImage, a private sector ICT specialist and Dialog, one of Sri Lanka's MNOs. The system has evolved to cover all disasters and uses multiple channels, such as SMS, cell broadcast, digital TV and alert subscribers. To improve the dissemination of alerts to communities not well covered by a telecoms network or where mobile phone penetration is low, the Dialog-University of Moratuwa Mobile Communications Research Laboratory has developed the DEWN device, which have been distributed to communities to alert the public in the event of a disaster.

Equipped with GSM functionality and an FM radio receiver, the devices can automatically trigger an in-built alarm siren and flashing light display. They can continue to operate during a disaster with a back-up battery, provide multilingual support with an easy-to-use graphical user interface (GUI) and colour touch screen and allow those caught up in a disaster to use a message acknowledgement function.[67] To make the system broadly accessible and allow third parties to build an ecosystem around it, an API has been integrated with centrally authenticated connections. This ensures the necessary government permissions have been provided and helps users to trust the sources of information.

63 Mateo, C. and Oki, T. (2011). "Filipinos' Perception About Flood Warning Systems and Their Behavior Towards Early Evacuation." Conference: The 9th International Symposium on Southeast Asian Water Environment.
64 Data from key informant interviews.
65 GSMA. (2021). Building a Resilient Industry: How Mobile Network Operators Prepare for and Respond to Natural Disasters: An Interactive Guide for MNOs Based on Experiences with the Humanitarian Connectivity Charter.
66 Data from key informant interviews in government and particularly CSOs.
67 GSMA. (2015). Disaster Response: Dewn – Dialog's Disaster And Emergency Warning Network.

AI-based tools can help to flag and remove redundant or outdated alert information

The Philippines DRRM system relies on a multitude of actors, many of which have their own platforms and resources to support the dissemination of warnings to communities. Some have their own alert system and advisories that they send to their office and field personnel, and these advisories are extended to their project partners and communities. Scientific organisations also generate advisories that benefit partner organisations as well as local communities.

However, interviews highlighted that sharing alerts and updates on social media can rapidly become redundant and outdated as circumstances on the ground change. This can either cause unnecessary stress if the situation has improved or it can prove deadly if the situation worsens and alerts fail to keep up. There is potential for digital innovation to improve this process and reduce the volume of outdated news being circulated. An AI-based system can help to compare key official messages to information across a range of media, helping to flag and clearly mark outdated information.

APIs can allow third-party entities make scientific information from warning agencies more relevant and easier to assimilate

According to interviewees from CSOs, risk information can be difficult to understand because it is usually presented in scientific and highly technical terms. More effective dissemination requires the risk knowledge provider to package the warning information, message or content in a way that is digestible, enhances understanding and initiates action from users, especially among marginalised communities. Several stakeholders interviewed believed that PAGASA could do more to produce and disseminate information that target different audiences. As shown by the example in Box 12, APIs can allow third-party entities to easily plug into PAGASA data to create tools and solutions that disseminate information via mobile apps, SMS or a range of other formats.

Box 12 **Info-BMKG: APIs for enhanced information dissemination in Indonesia**

BMKG, Indonesia's National Meteorological Organisation, maintains data on multiple types of hazards to provide real-time hazard monitoring when disasters hit the country. BMKG has been operating an app-based service, Info-BMKG, that makes it easier and faster for people to access information about disasters. Through APIs, BMKG uses a variety of technologies to gather data, using platforms such as InaRISK and others (to capture data such as geographical information, weather forecasts, hazard data), and disseminates information to warn the population about impending disasters, including through the app and social media (e.g. Twitter). An integrated approach such as this is key to the country's One Disaster Data Initiative, which aims to improve the use of disaster-related data and build community resilience.[68]

68 Pujiono, P. (2019). Indonesia One Disaster Data. BNPB: Jakarta.

User-centric design approaches make digitally-enabled EWS more inclusive

Reaching everyone in society, including women, the elderly, persons with vision or hearing disabilities and Indigenous peoples, remains a major challenge for EWS. Persistent gaps in digital inclusion can further limit their access to EWS when these systems are heavily reliant on digital technologies. Very few early warning channels in the Philippines have been designed and developed to be inclusive. For example, there is a need to design the format of alerts to be accessible for persons with hearing and/or vision disabilities. Several stakeholders interviewed believed that the assistive tech functions of a typical mobile phone would be sufficient. Disability advocates interviewed pointed out that warnings in English could be more accessible than in Tagalog, as they could be read out loud by the text-to-speech technology available in mobile phones. There is also a diverse set of dialects throughout the country, which adds to the challenge. Multimedia EWS should also be more inclusive to ensure that all persons with disabilities can access and understand messages.[69]

69 GAATES. (2015). Guideline on Inclusive Disaster Risk Reduction: Early Warnings and Accessible Broadcasting.

Strengthening preparedness and response with mobile and digital innovations

The Department of Interior and Local Government (DILG) leads disaster preparedness in the Philippines and assists LGUs in taking early action. Through the Operation Listo Programme, the DILG establishes local protocols for early preparations, response actions and monitoring of LGUs; implements community-based DRRM; and provides guidance to families and households in undertaking preparedness measures.[70] Other organisations are also active in disaster preparedness and response. For instance, Yayasan PetaBencana has conducted disaster preparedness events with more than 1,000 barangay community leaders from all over the Philippines. As the data collected by MapaKalamidad.ph is automatically integrated in OCD's PhilAWARE Disaster Monitoring platform, the tool can help connect each barangay to central agencies (see Box 8).[71]

MNOs play a significant role in ensuring that mobile networks are resilient to climate hazards and invest significant resources to recover infrastructure after a disaster. For instance, during Typhoon Rai, Globe and Smart, the main MNOs in the Philippines, played a key role in preparing for and responding to the disaster.[72] Some of their early preparedness actions included running simulation drills and pre-positioning aid and supplies in risky areas. When the typhoon was impending, they delivered emergency alerts and warnings, provided broadband connectivity tools and activated quick response teams to ensure continuity of operations. In the immediate aftermath of the disaster, they re-established major infrastructure and provided free charging stations or generator sets to ensure people remained connected. The MNOs also supported their customers by providing more flexibility with bills and payments.

Strengthening preparedness and response systems in the Philippines must involve addressing the needs of local communities and individuals to help them cope with the impact of disasters, particularly groups that are already marginalised.

Box 13 The Humanitarian Connectivity Charter

Since 2012, the GSMA has been working with MNOs and policymakers as they navigate disasters and crises. In 2015, the GSMA launched the Humanitarian Connectivity Charter (HCC), an industry initiative to support MNOs in providing improved access to communication and information for those affected by crises to reduce loss of life and positively contribute to humanitarian responses.

MNOs Global and Smart in the Philippines are both signatories of the HCC and have long been lauded as excellent examples, both regionally and globally, of MNOs with strong disaster preparedness and response protocols and business continuity management (BCM) plans. More information on the HCC and how Smart and Globe prepare for and respond to natural hazards can be found in the GSMA report, Building a Resilient Industry: How Mobile Network Operators Prepare for and Respond to Natural Disasters.

70 Local Government Academy. (2015). Local Government Disaster Preparedness Manual. Checklist for MLGOOs, COPs and FMs. Typhoon Edition v2.
71 PetaBencana. (1 March 2022). "Over 1,600 community leaders join MapaKalamadid.ph in an unprecendented nation-wide disaster preparedness training event!"
72 See more here.

Mobile and digital technologies can help improve communities' awareness and disaster response knowledge

Several interviewees, particularly government representatives, indicated that building local capacity and training community members is a crucial step in the successful implementation of digital solutions in EWS. For example, in many communities where water levels are monitored locally (e.g. at the barangay level), water lines are painted on the walls of houses. However, the community may not be informed of how these measurements relate to the water level at the bridge and they are not always aware of the meaning of a siren. Apps and dashboards that can help to educate people about disaster response could be very useful.

As described in Box 4, InaRISK was developed to compile risk and vulnerability information in an online dashboard and help governments prepare and respond to disasters. A version was also developed for personal use to disseminate risk and disaster knowledge and information (see Box 14). However, if implemented in the Philippines, these solutions would need to have a strong and integrated focus on digital inclusion. Those who lack disaster response capability, such as the elderly, persons with disabilities, migrant workers, the very poorest and Indigenous peoples, are often likely to be those without access to mobile devices.[73]

Box 14 **InaRISK Personal: mobile apps for dissemination and preparedness and response in Indonesia**

InaRISK Personal is a mobile app that provides people with information about risks – based on the risk and vulnerability data also provided to the government – and helps them take anticipatory actions, including those that mitigate the impact and recommend evacuation in the event of a disaster.[74] The app is being used by Indonesia's education system, from primary schools to high schools, as part of the Disaster Safe Education Unit (SPAB) programme implemented by the Ministry of Education, Culture and Research and Technology (Kemendikbudristek) to help improve the disaster knowledge of students and staff.[75]

There are also gender disparities in the response capability of local communities. Several interviewees mentioned that while the public is targeted in capacity building programmes – which are often designed with gender inclusion requirements – there are persistent patriarchal views that perceive men as better at responding to disasters than women, even though women are often more active in local disaster preparedness meetings.[76] As a consequence, women do not always receive the training they need to make effective decisions when alerts are received. This could be changed with well-targeted digital communications combined with on-the-ground training events that address these gender dynamics.

73 Data from key informant interviews with CSOs.
74 Badan Penanggulangan Bencana Daerah (BPBD). (29 July 2021). "inaRISK Personal".
75 Asria, D. (27 April 2022). "Ministry of Education, Culture and Research and Technology invites education units to implement SPAB". KabarBanten.com.
76 Data from key informant interviews with CSOs.

Mobile apps with a community focus can build social capital and community resilience

Local EWS have been observed to work better when the community has organised groups that address disaster preparedness and response proactively. As highlighted earlier, Dynaslope is a project that illustrates the importance of community participation in local EWS. Community members who participate widely in capacity building programmes gain the appropriate skills to address local disaster risks. Often they work closely with the barangay DRRM committee, using SMS, messaging apps and social media to communicate. They might also actively seek out partnerships with academia, CSOs and the private sector to enhance their risk knowledge and disaster readiness. Interviewees advocated for the role of digital tools in facilitating this process, such as AtmaGo in Indonesia (see Box 15).

Box 15 **AtmaGo: mobile app for community disaster preparedness in Indonesia**

AtmaGo is a news, information sharing and job advertising app that also serves as a multi-hazard EWS, using information shared by a city/town/neighbourhood user group. The app allows the online community to join forces in person, such as at an AtmaGo resilience event where they learn how to unclog drains and prevent flooding. These actions are later shared by participants on AtmaGo to organise the community and find local solutions to local problems.[77]

Finally, it is crucial to include disadvantaged groups in EWS as there have been instances where they have been left behind. In interviews, we heard anecdotal reports that children with autism have been left behind by their parents during typhoon evacuations.[78] There is not only a lack of adequate tools to communicate emergency information to people with autism, but also a lack of information on how they and their relatives and caregivers should respond in the event of a disaster. Appropriate digital tools can be designed to support sensitive but urgent communication between individuals. For example, as part of a recent NGO initiative for last-mile disaster preparedness in the Philippines, communication cards and inclusive EWS kits were distributed in very remote locations. These cards enabled community members to receive alerts digitally and then disseminate alerts in person to vulnerable community members, including persons with disabilities.[79]

77 See the Principles for Digital Development AtmaGo case study.
78 Data from key informant interview with CSOs.
79 Ibid.

Summary of opportunities for digital innovation to strengthen EWS

There are many opportunities for digital- and mobile-enabled solutions to address existing gaps and strengthen EWS in the Philippines. Table 1 summarises the digital technologies typically deployed across the four stages of EWS.

Table 1

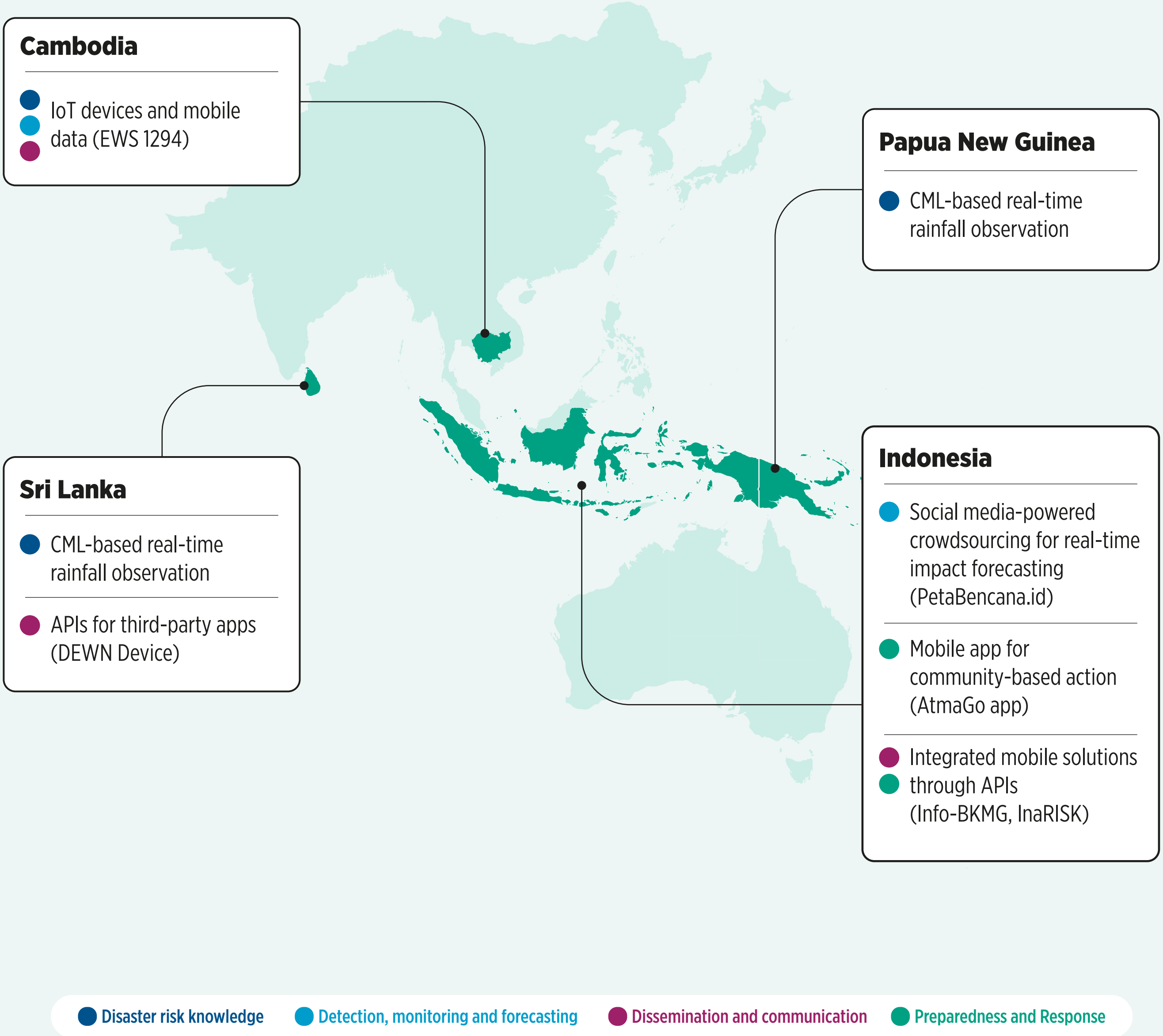
Opportunities for digital and mobile-enabled solutions in EWS

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
Integrating automated synoptic and surface weather stations **Solutions:** Weather instruments connected through IoT	Data analysis to more accurately forecast the impact of disasters **Solutions:** AI/ML tools that identify correlations, such as between forecasted flooding and economic impacts	Using mobile technology to actively disseminate timely warnings and alerts **Solutions:** SMS, cell broadcasting services and mobile apps	Raising community awareness of disaster and response actions **Solutions:** Mobile apps that compile relevant information for at-risk populations
Generating risk data and knowledge (e.g. rainfall, temperature) **Solutions:** CML analysis as a proxy indicator for rainfall data, mobile big data analysis of smartphone sensors for air pressure and temperature (e.g. using battery temperature)	Generating real-time hazard and incident information at the community level to issue alerts and prepare appropriate disaster responses **Solutions:** AI/ML tools and big data analytics of crowdsourced data	Providing additional opportunities to disseminated EWS alerts through mobile **Solutions:** Voice Message Broadcast (VMB), hotlines, interactive voice services, AI-enabled chatbots, etc.	Building social capital and enabling greater community-based resilience **Solutions:** Mobile apps to enable coordinated community action
Integrating sensors for water flow and landslide risk, air temperature, wind speed, etc. **Solutions:** Weather instruments connected through IoT	Support data sharing and analysis of intergovernmental or public open data platforms **Solutions:** APIs can integrate multiple digital platforms	Improving EWS-related communications within government or between government and other actors **Solutions:** Mobile-based information-sharing platforms and group communication apps (e.g. WhatsApp)	
Collecting data to understand risk vulnerability and impact **Solutions:** Mobile-based data collection tools and platforms, mobile big data analysis		Disseminating official alerts to the wider community or specific groups **Solutions:** Mobile messaging solutions (e.g. SMS, WeChat, WhatsApp) and digital platforms (e.g. Infocast and InaRISK Personal)	
Mapping hazard risk at different levels (e.g. community, barangay) **Solutions:** GIS mapping, open-source mapping, drones, satellite mapping		Identifying and flagging outdated and misleading information **Solutions:** AI/ML to evaluate and validate data	Evaluation of EWS dissemination and effectiveness of response **Solutions:** Mobile surveys, big data analysis supported by ML tools
		Generating accessible digital information and alerts for persons with disabilities and different language speakers **Solutions:** Mobile-assistive technology and mobile-based translators	
		Disseminating information from a warning agency to specific user groups **Solutions:** APIs to enable third parties to modify and disseminate selected information	

Source: GSMA Mobile for Development

Figure 4

Examples of technologies used at different stages of EWS in Southeast Asian countries



02

Addressing barriers to digital inclusion to strengthen EWS

Although the Philippines has an advanced EWS that integrates mobile and digital technologies, there are still barriers to the adoption of digital solutions. This section explores these barriers and highlights issues to take into consideration to overcome them and drive digital inclusion.

Driving digital inclusion in the Philippines

Our research identifies six key enablers of technology adoption and digital inclusion that need to be enhanced to unlock mobile and digital opportunities for EWS in the Philippines: mobile connectivity, affordability of digital solutions, digital literacy, relevance and inclusion, awareness and trust, and data governance policy and regulatory framework.

Mobile connectivity

Broadband connectivity is key to the digital readiness of EWS. In the Philippines, many remote areas still lack sufficient mobile network coverage, which is an issue for last-mile alerts. While MNOs are actively working to make their infrastructure more resilient, several interviewees[80] highlighted the urgent need to expand and strengthen digital and telecommunications infrastructure. Because universal coverage requires massive upfront investment, MNOs need to be provided with the right incentives to expand in areas with low density of population and low-income groups. In these areas, regional stakeholders indicated that it is possible to use an SMS-based system that shares information in areas with insufficient MNO infrastructure to avoid the lag time in data transfer, and relies on radio as a back-up. Many informants also pointed to the limitations of using websites, social media and television in geographically isolated and disadvantaged areas, especially islands with limited or no electricity and limited mobile network connectivity and access to broadband.

For MNOs around the world, improving the resilience of mobile network infrastructure is a priority. Ensuring that physical infrastructure and business operations can withstand natural hazards is key to ensuring that mobile networks remain operational following a disaster.[81] KDDI in Japan is one example, as described in Box 16.

Box 16 Resilience of KDDI's telecoms network in Japan

Japanese MNO KDDI is a good example of proactive investment enabling a resilient mobile telecoms network. Recognising the importance of base station structure and stability, KDDI has reinforced telecoms buildings and facilities to ensure their physical networks are as resilient to natural disasters as possible. Learning from past disasters, KDDI has improved the design requirements of their network facilities and strives to meet or go beyond the requirement for earthquake-resilient structures as per Japanese law. [82]

Since Japan is prone to earthquakes, the Meteorological Department has set up a fully automated EWS that automatically sends alerts to mobile phones via the KDDI network. KDDI also conducts comprehensive staff and government drills to identify challenges in restoring network coverage as rapidly as possible. In addition, the MNO takes the following steps to enhance resilience:

- The KDDI Ocean Link is a ship that can be harboured in a nearby port and provide connectivity to coastal areas if a disaster affects local KDDI base stations.
- KDDI has various types of vehicles pre-positioned with network equipment that travel to affected areas to provide temporary connectivity. The vehicles are equipped with satellite receivers that receive a satellite connection, convert it and then transmit it to the surrounding area. For example, KDDI has network equipment on a commercial car that is easily powered by the car's battery and takes only 15 minutes to set up (a typical network on wheels takes up to 40 minutes) and start operating.
- KDDI has more than 600 mobile generators on wheels that they have located across different regions of Japan. In a crisis, it can mobilise them in affected areas.
- KDDI's MAPSTAR tool provides the KDDI team with a live map of the number of connected users in each of their sites. This map not only enables the MNO to identify and manage areas with high traffic, but can also provide indications of population migration after a large-scale disaster.

80 This was strongly highlighted by government stakeholders interviewed.
81 GSMA. (2021). Building a Resilient Industry: How Mobile Network Operators Prepare for and Respond to Natural Disasters: An Interactive Guide for MNOs Based on Experiences with the Humanitarian Connectivity Charter.
82 Ibid.

Affordability of mobile and digital technologies

Affordability of devices and data is critical for digital adoption and digital inclusion. Those who remain unconnected sometimes live in an area already covered by mobile broadband but lack the financial resources to tap into it. Although 99 per cent of the population are covered by 4G, it is estimated that in 2021 around 74 per cent of Filipinos were mobile internet users.[83] In the Philippines, the costs of mobile phones and mobile internet services can be high, particularly for those with the lowest incomes.[84]

Based on the GSMA Mobile Internet Connectivity Index,[85] the Philippines is classified as a transitioner country.[86] Despite significant advances in connectivity, the country scores lower than the average in the region for affordability due to the high costs of handsets and mobile services. According to the Inclusive Internet Index, the Philippines has the fourth most expensive mobile internet services in Southeast Asia, after Singapore, Brunei and Malaysia.[87] As more EWS embed mobile technologies, addressing the affordability of mobile devices and services will be critical to ensure that everyone can access timely information and is able to respond when disasters strike.

For governments, affordable digital solutions are important for the deployment of localised EWS. Several interviewees mentioned that many local communities lack the incentive or financial resources to maintain early warning equipment, such as AWS and rain gauges. Theft and vandalism also affect observation and data collection on the ground. Cost issues could be addressed through innovative business models, but the solutions that are deployed need to address the needs of local communities and consider their willingness to pay.

83 Statista Research Department. (2021). “Mobile Internet User Penetration Philippines 2017–2025”.
84 Alliance for Affordable Internet. (2022). “Mobile data costs have increased, making internet connectivity unaffordable for many”.
85 The Mobile Internet Connectivity Index is a tool developed by the GSMA that measures the performance of 165 countries against enablers of internet adoption: infrastructure, affordability, consumer readiness and content and services. For more information, see: https://www.mobileconnectivityindex.com.
86 Transitioner countries have a score above 50 and perform well on at least two enablers of mobile internet connectivity. The Philippines has a score of 62.8/100 and performs relatively well on infrastructure, consumer readiness and content and services (GSMA Intelligence).
87 Economic Intelligence Unit. (2019). The Inclusive Internet Index.

Digital literacy and skills

Digital literacy and skills are a prerequisite for technology adoption, both for the actors managing digitally-enabled EWS and for the end users who benefit from these solutions. Among the wider population, many lack the necessary skills to engage effectively with digitally-enabled EWS. According to the Philippines Digital Economy Report 2020 by the World Bank, Filipinos are far behind in digital skills compared to their middle-income peers in the region.[88] As more mobile and digitally-enabled solutions are adopted, this lack of digital skills will limit opportunities for people to access information that helps them prepare and respond to disaster. This is likely to affect groups that have higher rates of digital exclusion, including women, persons with disabilities, elderly people and others.

Government agencies at all levels need to upskill and deepen digital competencies to design, maintain, invest in and regulate digital platforms and data use. Several interviewees indicated that most of the LGUs in the Philippines do not use digital platforms for data collection and risk assessment of hazards.

The use of frontier technology requires high-level technical skills that local stakeholders often lack due to limited financial and human resources. At the local level, where mobile and digital technologies can make a significant contribution to community resilience, several programmes have attempted to implement local EWS but failed to build the right foundation. Often there is little interest in the public sector to adopt more advanced digital platforms, in part due to a lack of digital skills and knowledge of how to use the technology. Education and training are imperative for government officials to understand the benefits of the technology and increase uptake.

Finally, the multiple platforms in use can make it confusing and overwhelming for officers in charge of DRRM processes. Information sources in government agencies are often fragmented and the digital innovations for EWS have emerged rapidly and are constantly evolving, making it more difficult to adapt. More generally, there has been little support provided to agencies to adopt new technologies.

Relevance and inclusion

Mobile- and digitally-enabled solutions for EWS need to be relevant for users and inclusive of underserved groups. Our interview findings showed that local government (i.e. LGUs) often fails to involve local communities and stakeholders in the design of EWS. As a result, the needs and preferences of underserved groups, such as women, persons with disabilities, the elderly, youth, Indigenous peoples and others, are not considered. This can result in solutions that are not only inaccessible for many people, but also fail to address their needs. Some interviewees acknowledged that existing EWS tools may not be inclusive. For instance, persons with vision or hearing disabilities or those who cannot read or write require specialised interfaces or digital communication channels to use mobile technologies.

Underserved groups are important stakeholders, and their voices should be heard. Some of the issues mentioned above can be addressed by ensuring communities and underserved groups are included in the design and implementation of EWS. In the Philippines, local governments have developed barangay DRRM plans with multi-stakeholder participation. The 'purok system'[89] in the city of Cebu is an example of how inclusive participation can help communities identify and prioritise the needs of vulnerable groups and identify appropriate actions to take when alert warnings are issued.

88 World Bank. (2020). Philippines Digital Economy Report 2020: A Better Normal Under COVID-19 – Digitalizing the Philippine Economy Now.
89 The purok system in the Philippines is a community-based organization at the sub-village level which strengthens community resilience to natural hazards.

Awareness and trust

Many people may still not use and benefit from mobile internet because they are not aware of the value it can offer. The transition to digital solutions for EWS therefore requires careful planning and adequate training, particularly for remote and Indigenous communities, which are less likely to be familiar with mobile and other digital technologies. For communities to take ownership of these solutions, it is essential to build on their early warning practices rather than replacing them entirely with mobile and digital technologies. Building trust with end users and asking for feedback, while also being responsive to the diverse needs of communities, are all critical to the uptake of innovative solutions. Several interviewees highlighted that many communities still rely on Indigenous and traditional methods of early warning systems, such as changes in wind direction, waves or bird behaviour. In Marikina City and Rizal Province, coloured flags are used to indicate disaster levels and, across the country, people traditionally rely on bandillo, the custom of physically visiting each house to alert residents.[90]

Data governance policy and regulatory framework

Effective data governance policies and adequate regulatory frameworks are critical to strengthening EWS through digital innovation. Data governance policies and regulations define how data is collected, used and shared. This, in turn, influences the accuracy of risk assessments and the timeliness and targeting of warnings. Ideally, data governance should allow for harmonised national and subnational data policies and standard-setting processes to increase the speed of data processing. Data governance often depends on whether stakeholders consider tech adoption a priority issue and on their willingness to invest the necessary financial and human resources.

Data governance structures in the Philippines are inefficient. A lack of consistent and accurate data, weak system interoperability and the absence of data use policies have all made it difficult to establish digital EWS. Several interviewees mentioned the need to improve interoperability and data management between different authorities, explaining that departments do not always share information with each other due to competition, personal interests or political affiliations (which also often leads to duplication).[91] Data sharing is a key issue in the Philippines and poses a significant barrier to digital solutions for EWS, which depend on high levels of data availability and sharing to support better analysis and real-time assessment of the population's exposure to hazards.

Beyond improving collaboration between government agencies, there is also a need for the public sector to collaborate more closely with academia and the private sector. Open data systems can help improve data governance and enable data sharing. An example is the joint work of the UNDP Country Office, the OCD, the Department of Information and Communication Technology's Information Interoperability Framework (IIF)[92] and Open Data Philippines. Together they are developing a data governance framework that will include disaster risk data to support the NDRRMC.

90 Data from key informant interview with government.
91 Ibid.
92 DICT. (27 April 2015). Memorandum No. 2015-1003 on approval of Electronic Government Interoperability Framework.

Looking ahead: promising opportunities for digital innovation in EWS

Our research suggests there is potential for the digital innovations outlined in Section 1 to be implemented and to learn from best practices in other LMICs. In addition, rapidly evolving technologies will provide even greater opportunities for digital innovation to enhance EWS in the Philippines. In most cases these are beyond the current state of digital readiness in the Philippines, but it is expected they will soon offer viable new solutions. These include:

- **5G:** As internet connections become significantly faster with 5G in the coming years, this will affect how data is collected, transferred and analysed to inform EWS and communicate alerts. For example, IoT-connected sensors have the potential to play an important role in monitoring aspects such as water levels in rivers, air temperatures and water saturation of slopes prone to landslide risk. Cambodia's EWS 1294 is an example of a project that could benefit from innovation in connectivity.
- **Edge computing:** Unlike traditional models, which rely on centralised data centers, edge computing uses local networks and devices to conduct data analysis closer to where it is being generated. This means that data can be processed at greater speeds and volumes. [93] Previous research has shown that edge-computing can provide more effective and reliable data for disaster monitoring and early warning.[94] There are already examples of pilots that have applied edge computing to EWS, including analysing data from IoT sensors for flood prediction[95] and real-time monitoring of landslides.[96]
- **Mobile big data:** Insights from passively generated mobile big data, such as call detail records and mobile positioning data, can play an important role in addressing data gaps on population vulnerability and infrastructure exposure. Mobile big data has the potential to make context-specific, real-time and disaggregated data available, and can therefore inform impact forecasting and response measures. Telefónica's partnership with FAO shows that mobile big data could be leveraged to understand population movement in the face of a disaster and plan response measures adequately to help communities become more resilient.

93 Accenture (n.d.). "What is edge computing?"
94 Hao, S. et al. (2021). "Landslide Monitoring and Early Warning System based on Edge Computing". IOP Conference Series Earth and Environmental Science. 861(4): 042056.
95 Samika, E. et al. (2018). "Flood prediction using IoT and artificial neural network with edge computing". IEEE.
96 Elmoulat, M. et al. (2021). "Towards landslides early warning systems with fog-edge computing and artificial intelligence". International Journal of Ubiquitous Systems and Pervasive Networks. 15(2), pp. 11–17.

03

Conclusions and recommendations

Digital innovation has the potential to make EWS better integrated and more efficient, and to improve the dissemination of warnings, helping them fulfil their fundamental objective of making populations safer. As one of the world's most disaster-prone countries, the Philippines is likely to remain extremely vulnerable to the impacts of weather-related events for many decades to come. Continuously investing in and strengthening existing EWS will be essential as climate change is expected to create significant and ongoing humanitarian need and economic losses.

Early warning systems in the Philippines already rely on mobile and digital technologies, but these could also be harnessed to address the gaps in these systems. The Philippines can learn from and build on the experiences of other LMICs where innovative solutions for EWS have been leveraged. Some countries have used mobile and digital technologies to conduct real-time risk assessments or to share data and information to better inform decision-making. They have also been used as platforms by community user groups to create support systems and prepare for disasters.

The research suggests there are three priority areas where stakeholders should focus their efforts. First, there is a need to work on the key enablers of technology adoption that are prerequisites for digital solutions. In particular, it is essential that infrastructure is resilient to natural disasters and that network coverage is expanded in remote areas to ensure that no one is left behind and EWS are more inclusive. Similarly, it is important to improve the digital literacy of end users and the capacity of stakeholders to take ownership of innovative solutions. This will require more resources, especially at the local level. Second, there is a need to streamline existing solutions from the national to the local level to address the overlapping tools and platforms that leave EWS fragmented. Third, there is a need for more granular impact forecasting to better understand the risks and needs of local communities in specific areas, and how best to prepare and respond to these risks.

Tackling these various challenges requires effective and genuine cross-sector collaboration and coordination between different stakeholders at the national, regional and local levels. Table 2 provides more detailed recommendations for stakeholders to strengthen EWS through mobile and digital technologies in the Philippines.

Table 2

Lessons from the Philippines to strengthen EWS through mobile and digital innovations: recommendations for stakeholders

Recommendations for government stakeholders

Enhance risk knowledge and impact forecasting

- Government stakeholders, at all levels of governance, have a role to play in addressing data gaps and improving disaster risk knowledge and impact forecasting. More specifically, government agencies need to enhance their ability to conduct real-time risk assessments and monitor hazards to identify potential and likely impacts on communities, infrastructure and economic sectors.
- In the Philippines, accurate risk knowledge and impact-based forecasting is hampered by a significant lack of context-specific and updated disaggregated data at the local level. Central bodies should seek to increase local stakeholders' capacity (e.g. PAGASA local offices, local DRRM councils, LGUs) to collect and analyse granular and reliable data on hazard risks, population distribution and characteristics, and critical infrastructure to enable greater impact-based forecasting and support PDRA processes.
- National Meteorological Agencies should seek to build capacity for context-specific understanding of risks and multi-hazard impact-based forecasting, which is essential to disseminate relevant and timely warnings, and take preparedness and response measures accordingly.
- There is a significant opportunity to leverage innovative data sources, such as CML, IoT sensors, and analysis of crowdsourced social media data or mobile big data to tackle data gaps, which requires increased human and financial resources.
- The central government could also consider supporting private sector innovators to develop digital solutions, through regulatory and policy reforms that gives them the right incentives to innovate.

Improve data governance

- Governments stakeholders should work to improve data governance and foster better collaboration and coordination between stakeholders. Government agencies, which have the political mandate over DRRM, can take the lead in addressing challenges in data governance by incentivising all stakeholders involved in EWS to work together across sectors and across different levels of governance, instead of working in silos, in order to reduce existing fragmentations in these systems.
- The ability to share data, to interpret data, or to integrate data from multiple sources, requires the creation of information systems and data governance frameworks with common standards. In the Philippines, government agencies (e.g. PAGASA and PHIVOLCS through the NDRRMC) should encourage and invest resources to develop a standardised, coherent, and accessible system that breaks down siloed technology and data collection systems.
- Government agencies should prioritise interoperable digital tools and frameworks that promote open-source solutions, which may require a change in mindset to see data openness as an advantage. Recent initiatives, such the work undertaken by UNDP Philippines, OCD, DICT and Open Data Philippines, are promising but still need to fulfil their potential. Particular attention needs to be given to the way information is treated and how data is collected, managed, stored and used to ensure transparency, accountability, and legitimacy.

Support digital literacy at all levels:

- Government stakeholders should seek to expand and strengthen digital literacy and skills, which are a pre-requisite for well-functioning digitally-led EWS. In the Philippines, the government can play a key role in in upskilling and deepening digital competencies of EWS experts to design, implement and maintain digital platforms. The use of frontier technology requires technical skills that local stakeholders are often lacking, meaning that continuous education and training are imperative for them to understand the benefits of digital technologies and increase uptake.
- Improving digital skills among the wider population is equally important to ensure everyone, including those most likely to be left behind, such as persons with disabilities, indigenous people, the elderly and women, can engage effectively with digital solutions and access adequate information to prepare and react to disasters. Building trust is critical to guarantee uptake of digital tools and services, and requires taking a human-centred and context-specific approach to tailor these solutions to local realities and address social and cultural norms.

Recommendations for MNOs

Make mobile networks resilient

- For MNOs, such as Smart and Globe, it is important to continue investing in resilient networks, which are critical for the timely dissemination of information and warnings. MNOs should build resilience into cell towers and other core equipment such as data centres and network operation centres, which are vulnerable to both widespread and local disasters. They should also create structures that analyse risks and ensure continuity of services when disasters hit. Power systems-related preparedness plans should be in place to guarantee alternative power systems if there is an outage in commercial grids. There are important lessons to be learned from KDDI's experience in Japan, which recognises the importance of base station structure and stability and has reinforced telecom buildings and facilities.

Support customers in accessing information

- Supporting customers is key to make sure they have access to updated and relevant information. For instance, MNOs can provide free credit for data, calls and SMS, or permit national inter-operator roaming to enable users to access whichever network is functioning in their area after a disaster. Importantly, they should seek to maximise the accessibility of EWS warnings by making sure alerts are accessible to persons with disabilities, those who are illiterate or have low levels of educations, and those who only speak a local dialect.

Strengthen collaboration with other actors involved in EWS

- MNOs should ensure effective collaboration with other actors involved in EWS, including their suppliers and the third sector. By working closely with their suppliers, such as network providers, MNOs can ensure that supply chains are resilient.
- By fostering collaboration with humanitarian responders, such as international agencies and NGOs, MNOs can ensure that these organisations have critical connectivity when a disaster hits. MNOs also have the potential to provide direct humanitarian assistance, for example by running text-to-donate campaigns to channel relief funds to responders.

Recommendations for solution providers

Seek ways to complement existing government platforms

- Private sector innovators, NGOs and research institutions that design digital solutions used in EWS, should seek ways to link their solutions to existing systems. In order to support a holistic nation-wide approach in EWS, it is important that digital tools and apps are linked to - and add value to - existing government platforms such as data portals and warning agency information.

Design for local needs and local users

- Solution providers have an important role to play in designing local EWS systems for localised hazards such as flooding and landslides. To help support real-time knowledge risk and warnings at the local level, solution providers can draw on IoT connected sensors and automated first alerts, and on the analysis of crowdsourced data. This way it will be possible to develop digital tools that can support response capability for individuals and communities, at the province, municipal or community level.
- In coordination with other stakeholders, they should also support the implementation of open data resources that can improve data sharing to inform risk knowledge and impact forecasting and unleash private sector innovation for EWS.

Adopt an inclusive design approach

- Solution providers need to implement human-centred design approaches to ensure the solutions they develop empower those individuals and communities affected by natural hazards, with a clear shift towards inclusion, rights, gender and place-based divides. They should prioritise the voices of those most likely to be left behind in terms of usage, including persons with disabilities, indigenous people, the elderly and women, and tailor solutions to their specific needs to maximise impact.
- In many areas of the Philippines, the digital ecosystem is still nascent, which means that there cannot be a one-size-fits-all approach. Initiatives aimed at improving access to information through mobile and digital technologies and strengthen response capabilities should be aligned with the needs of end-users and take into account local dynamics such as customs or languages to build trust and maximise uptake. Ultimately, content, products and services need to be context-specific and correspond to users' capabilities and needs.

Recommendations for international donor organisations

Address specific needs of local actors

- International donors have an important role to play in supporting government with capacity building and technical assistance, especially for impact-based forecasting and improving data governance. This study highlights the need to build capacity in the Philippines at local community level. It is therefore important for donors to align with government priorities in order to prioritise localised interventions.
- Donors can also support solution providers engaged in EWS at different stages such as those offering tools to disseminate context-specific and timely information to communities. While donors can play a key role in promoting international best practices, including frontier technologies, it is important that they maintain a focus on co- mutual knowledge sharing, taking into account local dynamics and constraints.
- Donors have also a role to play in supporting government by providing trainings, for example in partnership with CSOs working on advancing the digital skills and literacy of the general population, including in geographically isolated and disadvantaged areas.

Enhance coordination with the development community

- To be effective, international donors must coordinate approaches, financing, and support to avoid duplication of efforts on digital transformation and EWS. There is a significant opportunity to engage in a new cooperation paradigm that disrupts current approaches to development support and breaks down silos. In addition, focusing on underlying challenges, such as coordinating multilateral efforts, improving public procurement, and supporting financial and project continuity, will be particularly important to ensure solutions are impactful and sustainable.

Annex 1: Detailed methodology

The aim of this research was to assess current capacity in the Philippines to forecast and disseminate early warnings for climate-related risks and provide recommendations to optimise existing EWS with digital technologies.

The research was conducted between November 2021 and March 2022 by a team of national and international disaster risk reduction and digital innovation specialists. It followed a qualitative approach, including comprehensive desk-based research of relevant academic papers and reports in the grey literature from relevant institutions and organisations; 23 semi-structured interviews with key stakeholders in the Philippines who have been involved in the design and implementation of EWS for weather-related hazards; and 10 interviews with stakeholders who have developed and deployed digital and mobile technologies to strengthen EWS in LMICs. The main components of the methodology are explained below.

Phase 1: Desk-based research

The first main task was to undertake secondary research to gather information on the characteristics of climate-related risks in the Philippines and existing EWS; the digitalisation of the country and adoption of mobile and digital tools for EWS and warning communication and dissemination channels; and lessons to enable or strengthen the digital solutions implemented in LMICs. A review of secondary sources was also conducted, such as academic peer-reviewed journals and grey literature from NGOs and donor institutions.

Phase 2: Primary research (qualitative) / stakeholder interviews

Once the team had completed the desk research, interviews were conducted to validate the findings and cover gaps in the literature. The team conducted 23 semi-structured interviews with relevant EWS experts and stakeholders in the Philippines. Key informants were selected to provide representation of national and subnational government agencies, CSOs, tech innovators, international organisations and academic institutions. Contacts were drawn from the team's extensive networks in the DRR sector in the Philippines and included some new introductions.

Interview guides for each stakeholder group (government, civil society, community organisations, tech companies, etc.) were produced during the inception phase and then adapted in line with the Phase 1 desk research findings and analysis. An interview guide framework was developed, which is shown in Table A1.1. The four EWS processes appear along the top and cross-cutting aspects in the left column. Several relevant questions were designed for each intersecting point, and key informants were asked the questions that were most relevant to their expertise.

Table A1.1
Interview guide framework concept

Effective governance and institutional arrangements

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
What are the typical arrangements and barriers to data management and sharing between government agencies? What are the challenges and opportunities which digital solutions could support in terms of high-quality data collection? What are the current practices and opportunities for improvement in local to national level data sharing? How effective is the current integration / collaboration of actors within government and between government and other partners, in terms of digital tools for EWS?	To what extent are their shared terminology and data collection and management standards relating to the processes of implementing EWS? How strong is the ability to identify and monitor the right climate related hazard parameters and to judge evolving risks? To what extent could digital solutions support this? How robust is the current ability to generate timely and accurate warnings for typhoon, flooding, landslide and extreme heat?	In your view, what level of digital readiness does the Philippines have for implementing EWS dissemination via digital and mobile systems? To what extent are fail-safe or back-up systems in place to support the communication and dissemination of EWS alerts? What are these and could they be strengthened by digital solutions? Is there an ability to communicate a withdrawal of the warning when the local environment is safe? If so, how does this currently work?	Are there opportunities for digital and mobile solutions to support training of local government and communities in appropriate responses to EWS, inc. simulation / drills? Are there opportunities for digital and mobile solutions to play a role in keeping effective EWS response plans up to date based on changing contexts? What are the typical political and financial barriers or opportunities related to the points above, if not already covered?

Technology, data collection and analysis capabilities

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
To what extent are digital tools for data collection to inform hazard risk and EWS, including analyzing and presenting data? How effective are these technologies in providing effective early warnings, and what are the limitations? How are frontier technologies such as AI / Machine Learning, Big Data Analytics etc. currently being used for data collection and analysis at the local or national level as part of EWS in the Philippines? (E.g. Big Data to support forecasting based on historical data) What opportunities are there for such technologies to improve hazard risk understanding? Q. To what extent is there sufficient access at local level to ICT equipment, mapping software, map sources, internet connectivity etc.?	To what extent is data from mobile phone users currently used as a local input to EWS? Is there a role for digital solutions to improve sound scientific basis for forecasting? (This could include: IoT sensors to monitor hydrological factors; AI, BD/ML; Big data analytics etc.)	What digital and mobile technologies applications are being used/implemented in the communication and dissemination aspects of EWS in the Philippines? Are systems currently in place to understand and evaluate the effectiveness of EWS dissemination (no. of recipients, amplification via social networks, etc.)? Could digital or mobile based tools help with this process? Is data from EWS dissemination routinely archived and made accessible to stakeholders for further research?	To what extent do EWS response plans build on local capacities and knowledge? Can digital and mobile solutions help reinforce this link? Are systems currently in place to understand and evaluate the effectiveness of local response to EWS (no. of recipients, amplification via social networks, etc.)? Could digital or mobile based tools help with this process?

Gender and inclusion aspects

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
What gender and social inclusion aspects are currently considered in the data collection and analysis processes that feed into hazard vulnerability mapping and EWS? What can be improved in this regard and how could digital solutions play a role? To what extent are gender and inclusion dimensions of risk recorded, for example via data disaggregated by sex and other variables? To what extent is there an understanding of vulnerability of persons with disabilities at the community level? (Could be enabled via Washington Group questions, for example).	To what extent are EWS based on the needs of stakeholders at community level? Is the role of traditional warning systems integrated into EWS at the local level? Are there issues with local trust in the EWS information? Could this be increased by other means of verification, supported by digital and mobile solutions?	To what extent are EWS currently disseminated via mobile phone or smartphone in the Philippines? To what extent is the ability of individuals to receive and understand alerts via mobile phone or smartphone considered in EWS in the Philippines? What are the typical barriers? To what extent is EWS content made relevant to typically marginalised groups in communities, who may not be literate, for example? What are the gaps and opportunities for digital and mobile solutions improving EWS services for persons with disabilities?	What issues are there currently in terms of everyone in society being able to respond to EWS alerts? What measures are typically in place for communities to support vulnerable individuals? Is there a role for digital and mobile solutions to support this? Are there any barriers to effective response of EWS caused by cultural factors, such as discrimination of certain groups?

Multi-hazard approach considerations

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
To what extent is there an integration of data sources into relevant agencies responsible for EWS in the Philippines? Is there a centralized approach for mapping multi-hazards, that combines the data and efforts of multiple agencies? To what extent could these aspects be improved by digital or mobile solutions?	To what extent is there an integration of data from many sources to inform a multi-hazard warning and monitoring system for EWS? Is there consistency of warning terminology and communication channels between agencies? How could digital solutions support this?	To what extent can multiple hazard warnings currently be integrated into one EWS or digital platform?	How could digital and mobile solutions support knowledge sharing or training related to multi-hazard EWS response at the community level? (For example, on connections between types of hazard, such as between typhoon and flooding from storm surge

Partnerships for effective EWS

Risk knowledge	Warning and monitoring	Dissemination and communication	Preparedness and response
What are the potential roles for MNOs, tech companies and startups etc. in data collection and analysis to support EWS risk knowledge processes in the Philippines? To what extent is open data made available in relation to EWS systems and how could open data partnerships be supported to play a more effective role for risk knowledge?	What are the potential roles for MNOs, tech companies and startups etc. in data collection and analysis to support EWS monitoring and warning processes in the Philippines? To what extent is open data made available in relation to EWS systems and how could open data partnerships be supported to play a more effective role for monitoring and warning?	Is there currently a role for MNOs, tech companies and startups etc. to disseminate warnings or develop EWS platforms? What changes would be beneficial in this regard? What are gaps and opportunities in partnering with ICT and other companies (MNOs) that can facilitate digital information collection, analysis and dissemination to vulnerable groups?	To what extent do MNOs, NGOs etc. play a role in raising community awareness of EWS and recommended responses? Is there a role for digital and mobile solutions to support this?

Source: Consultant

Once the research revealed how digital solutions could address the current challenges or weaknesses with EWS in the Philippines, another 10 semi-structured interviews were conducted with innovators and tech developers of digital solutions for EWS in LMICs, especially in Southeast Asia. The international interviewees were selected based on their ability to provide an example of relevant digital innovation required in the Philippines, in the hope that lessons could be transferred. In all cases, examples were from Southeast Asia or East Asia, to ensure they were relevant to the geographic and socio-economic context. However, many of the selected international examples did not respond to a request for an interview, which can be considered a limitation of the research.

Interviewing approach

At the start of each interview, interviewees were asked verbally for their consent to participate and, where possible, to be recorded by the researcher. Interviews lasted for approximately one hour each. Verbatim transcripts in English were produced for each interview. The Consultant recorded each interview and used AI-based software to convert recordings into verbatim text. This method of producing a transcript is usually around 95 per cent accurate and requires some light editing to make it fully accurate and robust for the coding analysis. Transcripts could only be produced in this way for interviews conducted in English. Approximately 25 per cent of the stakeholder interviews were conducted in Tagalog to enable key informants to express themselves as clearly as possible. These interviews were recorded, manually transcribed to Tagalog and then translated into English.

Phase 3: Analysis

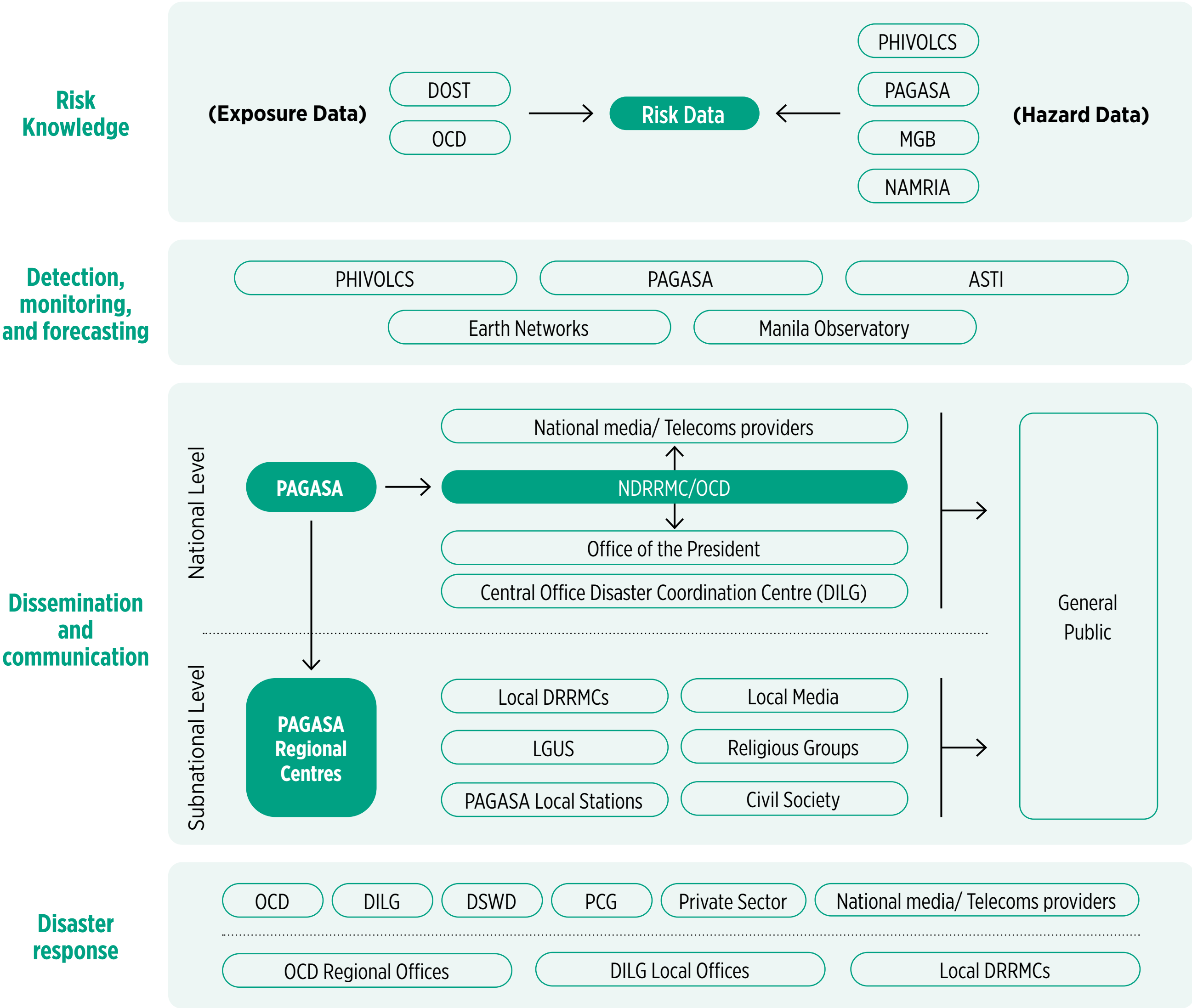
All findings from desk research, literature and interviews provided substantial insights into the digital innovation landscape in the Philippines, and the opportunities, barriers and risks related to disease surveillance and control systems.

Interview transcripts were analysed through thematic coding, identifying emerging themes and documenting them in an Excel spreadsheet. These were later cross-referenced with themes that emerged from the analytical framework developed for the literature review. These processes enabled the identification of gaps in EWS processes and the barriers to, and opportunities for, relevant digital solutions. The coding results were grouped by: 1) Philippines national government and subnational government; 2) other Philippines stakeholders from civil society, academic institutions and international donor programmes; and 3) international experts and EWS examples. This analysis helped to reinforce particular points and recommendations.

Annex 2:
EWS stakeholders in the Philippines

Figure A2.1

Key stakeholders in the Philippines' EWS ecosystem



Source: Risk knowledge and Dissemination and communication stages adapted from Monteverde, C. et al. (2020); Detection, monitoring and forecasting and Disaster response stages by GSMA Mobile for Development (based on qualitative interviews). DOST: Department of Science and Technology | OCD: Office of Civil Defense | PHIVOLCS: Philippine Institute of Volcanology and Seismology | PAGASA: Philippine Atmospheric, Geophysical and Astronomical Services Administration | MGB: Mines and Geosciences Bureau | NAMRIA: National Mapping and Resource Information Authority | ASTI: Advanced Science and Technology Institute | NDRRMC: National Disaster Risk Reduction and Management Council | DILG: Department of the Interior and Local Government | DSWD: Department of Social Welfare and Development | PCG: Philippine Coast Guard

Annex 3:
Projects driving the digitalisation of EWS in the Philippines

Over the past two decades, several DRRM initiatives with digital components were rolled out in the Philippines. These include:

REINA Project (2005):

A multi-agency DRR hazard and exposure mapping effort spearheaded by the DOST. The project produced high-resolution hazard maps of flooding, storm surges, landslides and earthquakes in Real, Infanta and General Nakar in Quezon province, using satellite images from the European Remote Sensing (ERS) satellites and the Satellite pour l'Observation de la Terre (SPOT).[97] Hard copies of these maps were provided to LGUs while digital copies were made available to the public on the PHIVOLCS website.

Rapid Earthquake Damage Assessment System (REDAS) (2006):

Developed by PHIVOLCS to assist LGUs in simulating earthquake hazards, such as ground shaking, liquefaction, landslides and tsunami, and computing the impacts in terms of physical damage, casualties and economic loss to aid local planning. Impact assessment modules now include hydrometeorological hazards such as floods, storm surge and rain-induced landslides. It uses GIS and GPS for risk mapping.

READY Project (2006–2013):

Supported by UNDP, the project developed high-resolution hazard maps to support planning by LGUs and implement community-based disaster risk management. As part of the project, a CBEWS was implemented for floods in 13 provinces and for tsunamis in 18 coastal communities in partnership with PHIVOLCS and PAGASA. The CBEWS introduced digital technologies in the communities, including rain gauges to measure rainfall and two-way radios to set up communication systems at the community level. These were operated by locally identified watchers and linked to regional forecasting centres. Mobile phones were also provided to dedicated persons (trained watchers) in the communities in charge of communicating warnings.[98] In addition, the Mining and Geoscience Bureau (MGB) installed warning signs in areas identified as vulnerable to earthquake-and rain-induced landslides.

97 Agustin, Nicatio Angelo. (2016). Project Terminal Evaluation GMMA Ready Project. Enhancing Greater Metro Manila's Institutional Capacities for Effective Disaster/Climate Risk Management towards Sustainable Development Project. UNDP.

98 Ibid.

Project NOAH (2012–2017):

The Nationwide Operational Assessment of Hazards (NOAH) was launched by the DOST in July 2012 and was designed to support evidence-based decision making by LGUs. A responsive disaster management programme using advanced scientific research and cutting-edge technology to reduce risks in highly vulnerable communities, their main objective is to enable warning agencies to provide a six-hour advance warning of impending floods. NOAH provided Typhoon Yolanda's highest predicted storm surge and tide two days before landfall, which was essential information for citizens to prepare and evacuate. The project developed detailed barangay-level landslide, flood and storm surge inundation maps that identify safe areas for people using LiDAR and Interferometric Synthetic Aperture Radar (IfSAR) that capture high-resolution topographies. NOAH was one of several initiatives supported by the UK Met Office in the Philippines.[99] NOAH has the following components:

- Sensor development and deployment of 1,500 AWS, ARG and AWLS.
- Disaster Risk Exposure Assessment for Mitigation-Light Detection and Ranging (DREAM-LIDAR) project produces more accurate flood inundation and hazard maps in 3D for flood-prone areas and major river systems and watersheds.
- Enhancing Geohazards Mapping through the use of LIDAR technology and computer-assisted analyses to precisely identify areas prone to landslides.
- Coastal Hazards and Storm Surge Assessment and Mitigation (CHASSAM) to generate wave surge, wave refraction and coastal circulation models to understand and recommend solutions for coastal erosion.
- Flood Information Network (FloodNET) Project to provide timely and accurate information for flood EWS. FloodNET will generate computer models for the Philippines' critical river basins, automate data gathering, modelling and information outputs and release flood forecasts.
- Local Development of Doppler Radar Systems (LaDDeRS) develops local capacity to design, fabricate and operate subsystems of Doppler radar for remote sensing of the dynamic parameters of the sea surface, such as wave, wind field and surface current velocity.
- Landslide Sensors Development Project is a low-cost, locally developed, sensor-based EWS for landslides, slope failures and debris flow.
- Weather Information Integration for System Enhancement (WISE) enhances weather-prediction capabilities using high-performance computing (HPC) and smart analytics.

99 Met Office. (2017). Improving resilience to severe weather and climate change in the Philippines.

DX4Resilience project (2020–present):[100]

Also known as Accelerating Disaster Risk Reduction and Enhancing Crisis Response through Digital Solutions, this initiative was implemented by the UNDP-Bangkok Regional Hub (BRH). It aims to strengthen disaster risk reduction and response by improving the digitalisation of data through innovative partnerships and solutions to support risk-informed development. Funded by the Ministry of Foreign Affairs (MOFA) of Japan, it is also being implemented in the Philippines, Indonesia, Nepal and Sri Lanka.

There have been several subnational government initiatives to create EWS for climate-related hazards, including the following three examples:

- **Enhancing Greater Metro Manila's Institutional Capacities for Effective Disaster/Climate Risk Management towards Sustainable Development (GMMA-READY Project) (2011–2016):** Assessed the Greater Manila Metro Area's (GMMA) vulnerabilities to disaster and climate risks and to mainstream disaster and climate risk management in development plans. Among the outputs were consolidated multi-hazard data/information for Metro Manila and four provinces; climate scenario and disaggregated socio-economic/health data sets for selected GMMA LGUs; enhanced flood, landslide and storm surge hazard maps and updated seismic and geologic hazard maps; vulnerability and adaptation assessments of the impact of climate change on health and socio-economic sectors of target Metro Manila cities; and CBEWS for flooding, landslides, tsunamis and storm surges were established and monitoring teams trained.
- **Greater Manila Metro Area (GMMA) Risk Analysis Project (RAP) (2013):** analysed the risk of flooding, severe winds and earthquakes in the GMMA by developing datasets, high-resolution digital models and information on hazard, exposure and vulnerability to natural hazard risk and climate change impacts. This data has helped PAGASA analyse the risk and impacts of high-wind conditions and tropical cyclones, and PHIVOLCS to better understand earthquakes. The GMMA-RAP provided high-resolution digital elevation data acquired with LiDAR covering the GMMA, and the datasets enabled the first multi-hazard risk assessment of a megacity.
- **Baguio City Flooding EWS:** Implemented under the ASEAN Australia Smart Cities Trust Fund (AASCTF), funded by the Asian Development Bank (ADB) and DFAT. The project is assisting Baguio City with both the planning for flood mitigation and the delivery of the services of flood early warning and responses, using smart technologies. These include a smart flood early warning information system (FEWS), real-time data capture system in four river basins in Baguio City.[101]

100 See the UNDP DX4Resilience website.
101 AASCTF. (2021). AASCTF Policy Brief: Policy and Practice Recommendations for a Gender Transformative Flood Early Warning System in Baguio City.

Glossary of terms

Automatic weather stations (AWS)	Automatic system that integrates multiple components that measure, record and, sometimes, shares weather data.[102]
Big data	Large amounts of digital data, often generated passively by mobile and other digital technologies.[103] It is often generated in large volumes, from various resources and at a fast speed.[104] In this report, we use 'mobile big data' to specify instances where big data is generated specifically by mobile technology.
Digital technologies	In this report, digital technologies include those technological solutions supported by connectivity and data, that enable more intelligent and data driven services. These include Big Data, Artificial Intelligence (AI), machine learning, IoT and blockchain technology. Occasionally in this report we use 'frontier technologies' as a synonym for digital technologies.
Early warning systems (EWS)	EWS integrate different systems and processes to monitor, forecast and predict hazards, assess risks and communicate and disseminate relevant information for people to act in case of a hazardous event.
Internet of Things (IoT)	IoT refers to internet-connected devices, appliances, systems and sensors.[105]
Impact-based forecasting	Forecasts and warnings designed to express the expected impacts of hazards in a community as a result of the expected weather. The difference between traditional weather forecasting systems and impact-based warnings and systems is that they include the vulnerability of people, livelihoods and property in relation to the hydrometeorological hazard.[106]
Mobile Technologies	Mobile technology is the technology used for cellular communication. It consists of portable two-way communications devices, computing devices and the networking technology that connects them.
Rapid onset (hazard)	These events can include floods, storm surges, tropical cyclones, wildfires, heatwaves and heavy rainfall.
Sensors	A device that produces a voltage or current output that represents a physical property being measured (e.g. speed, temperature, flow).[107]
Slow onset (hazard)	Such events can include desertification, sea level rise, salinisation, land and forest degradation, loss of biodiversity, glacial retreat, drought, ocean acidification and increased temperatures.

102 Earth Networks. (n.d.). What is an automatic weather station?
103 United Nations. (n.d.). Big Data for Sustainable Development.
104 GSMA. (2018). IoT Big Data Framework Architecture. Version 2.0.
105 Ibid.
106 World Meteorological Organization. (2015). WMO Guidelines on multi-hazard impact-based forecast and warning services.
107 Computer Security Resource Center. (n.d.). "Sensor". National Institute of Standards and Technology.

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