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Strengthening India's Disaster Preparedness with Technology

A Case for Effective Early Warning Systems

Shreya Wadhawan

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Peer reviewers: Dr Bapon Fakhruddin, Water Resources Management, Senior Specialist, Division of Mitigation and Adaptation, Green Climate Fund; Manabendra Saharia, Ph.D. Assistant Professor, Department of Civil Engineering, Associate Faculty, Yardi School of Artificial Intelligence, Indian Institute of Technology Delhi; Tanushree Ganguly, Programme Lead, CEEW; and Mohammad Rafiuddin, Programme Associate, CEEW.

Publication team: Kartikeya Jain (CEEW); Alina Sen (CEEW); The Clean Copy; Twig Designs; and FRIENDS Digital Colour Solutions.

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Council on Energy, Environment and Water
ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi – 110070, India
+91 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia

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ceew.in

Early Warning Systems (EWS) provide a 10-fold return on investment that is much higher than any other adaptation measure (GCA 2019).

Image: Pattabi Raman/Climate Visuals

About CEEW

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and one of the world's leading climate think tanks. **The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources**. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW has been extensively involved in research on pathways to net-zero emissions and the required investments.

The Council's illustrious Board comprises Mr Jamshyd Godrej (Chairperson), Mr Tarun Das, Dr Anil Kakodkar, Mr S. Ramadorai, Mr Montek Singh Ahluwalia, Dr Naushad Forbes, Ambassador Nengcha Lhouvum Mukhopadhaya, and Dr Janmejaya Sinha. The nearly 200-strong executive team is led by Dr Arunabha Ghosh. **CEEW was certified a Great Place To Work® in 2020 and 2021.**

In 2021, CEEW once again featured extensively across ten categories in the *2020 Global Go To Think Tank Index Report*, including being ranked as **South Asia's top think tank (15th globally) in our category for the eighth year in a row**. CEEW has also been ranked as South Asia's top energy and resource policy think tank for the third year running. It has consistently featured among the world's best managed and independent think tanks, and twice among the world's 20 best climate think tanks.

In twelve years of operations, The Council has engaged in nearly 400 research projects, published 320+ peer-reviewed books, policy reports and papers, created 160+ databases or improved access to data, advised governments around the world 1100+ times, promoted bilateral and multilateral initiatives on 110+ occasions, and organised 460+ seminars and conferences. In July 2019, Minister Dharmendra Pradhan and Dr Fatih Birol (IEA) launched the CEEW Centre for Energy Finance. In August 2020, Powering Livelihoods — a CEEW and Villgro initiative for rural start-ups — was launched by Minister Mr Piyush Goyal, Dr Rajiv Kumar (NITI Aayog), and H.E. Ms Damilola Ogunbiyi (SEforAll).

The Council's major contributions include: The 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; the first independent evaluation of the *National Solar Mission*; India's first report on global governance, submitted to the National Security Adviser; irrigation reform for Bihar; the birth of the Clean Energy Access Network; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); critical minerals for *Make in India*; modelling uncertainties across 200+ scenarios for India's low-carbon pathways; India's largest multidimensional energy access survey (ACCESS); climate geoengineering governance; circular economy of water and waste; and the flagship event, Energy Horizons. It recently published Jobs, Growth and Sustainability: A New Social Contract for India's Recovery.

The Council's current initiatives include: A go-to-market programme for decentralised renewable energy-powered livelihood appliances; examining country-wide residential energy consumption patterns; raising consumer engagement on power issues; piloting business models for solar rooftop adoption; developing a renewable energy project performance dashboard; green hydrogen for industry decarbonisation; state-level modelling for energy and climate policy; reallocating water for faster economic growth; creating a democratic demand for clean air; raising consumer awareness on sustainable cooling; and supporting India's electric vehicle and battery ambitions. It also analyses the energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka and Vietnam.

The Council has a footprint in 22 Indian states, working extensively with state governments and grassroots NGOs. It is supporting power sector reforms in Uttar Pradesh and Tamil Nadu, scaling up solar-powered irrigation in Chhattisgarh, supporting climate action plans in Gujarat and Madhya Pradesh, evaluating community-based natural farming in Andhra Pradesh, examining crop residue burning in Punjab, promoting and deploying solar rooftops in Delhi, Bihar and Meghalaya.

Natural disasters caused an estimated loss and damage of USD 35.6 billion to Asian countries in 2021 (WMO 2022a).

Image: iStock

डॉ. मृत्युंजय महापात्र
मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
एवं कार्यकारी परिषद के सदस्य

Dr. Mrutyunjay Mohapatra
Director General of Meteorology,
Permanent Representative of India with WMO,
Member of Executive Council, WMO

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम भवन, लोदी रोड़
नई दिल्ली–110003
Government of India
Ministry of Earth Sciences
India Meteorological Department
Mausam Bhawan, Lodi Road
New Delhi - 110003

Foreword

In the past few decades, the intensity and frequency of extreme weather events have increased and have directly impacted people and infrastructure, especially in developing and least developed countries. The climate risk landscape in India is constantly evolving, which is presenting us with unique challenges. India's vulnerability to the impacts of extreme weather events, such as cyclones, heavy rainfall, heatwaves, and droughts, necessitates the continuous development of robust mechanisms for predictions and issue of alert well in advance in order to enhance disaster preparedness. Investment in early warning systems has emerged as a very fruitful intervention in our efforts to build climate resilience and protect the lives and livelihoods of our fellow citizens. It has been demonstrated in the case of cyclones, heatwaves & heavy rainfall in recent decade.

As we have seen this year, in the case of 'Biparjoy cyclone', India's disaster preparedness was boosted by the cyclone and associated multihazard early warning systems of IMD that helped us respond in a timely and effective manner and reduce the loss of people, livestock, and infrastructure.

The insights provided by CEEW's team of experts have shed light on the importance of strengthening our nation's forecasting capabilities, enhancing data collection and analysis techniques, and fostering collaborative partnerships among various stakeholders. This research not only serves as a guiding light for policymakers but also paves the way for innovative solutions that can be implemented at different levels, from national to local, ensuring effective preparedness and response.

India's presidency in the G20 this year has been exemplary, and the formation of the working group on Disaster risk reduction for the first time since the inception of G20 in 1999 shows India's commitment to bringing world leaders together in reducing disaster risk across the world.

We recognise that climate change is a global challenge that requires collective action. India's pursuit of early warning systems is not confined to safeguarding only our population. However, by sharing our experiences, expertise, and research outcomes, we hope to contribute to the global discourse on disaster risk reduction and inspire other nations to adopt similar strategies to build their climate resilience.

I extend my sincere appreciation to CEEW for its unwavering commitment to advancing the science and practice of early warning systems in India. This research helps in enhancing our nation's resilience and preparedness. I am confident that the findings presented in this publication will help in shaping our strategies and accelerate our progress towards a safer, more secure, and sustainable future.

(Mrutyunjay Mohapatra)

Phone : 91-11-24611842, Fax : 91-11-24611792
E-mail : directorgeneral.imd@imd.gov.in / dgmmet@gmail.com / m.mohapatra@imd.gov.in

More than USD 3-16 billion worth loss and damage could be saved by spending USD 800 million on EWS in developing countries (UN 2022).

Image: Alamy

Contents

Every USD 1 invested in disaster risk reduction and prevention can save up to USD 15 in post-disaster recovery (UNDRR 2023).

Image: Sujan Sarkar/Climate Visuals

Executive summary

India is highly vulnerable to extreme climate events such as floods, droughts, and cyclones. A study released by the Council on Energy, Environment and Water (CEEW) in 2021 found that 27 of 35 Indian states and union territories (UTs) are now vulnerable to extreme hydro-met disasters and their compounding impacts (Mohanty and Wadhawan 2021). Eighty per cent of India's population resides in these vulnerable regions. However, India has been taking steps to build its resilience to the impacts of such extreme events by increasing preparedness and investing in early warning systems (EWS). These systems are being deployed throughout the world as essential instruments for disaster risk reduction (DRR). But, substantial gaps exist, especially in providing timely, comprehensible, and actionable warnings to the "last-mile", i.e., the most isolated and vulnerable groups at the community level. To overcome these gaps, several UN General Assembly resolutions have emphasised the need for **impact-based, people-centred, end-to-end multi-hazard early warning systems (MHEWS)** to reduce vulnerabilities and build resilience (Briceno 2007).

At COP 27, UN Secretary-General Antonio Guterres unveiled an Executive Action Plan to provide *Early Warnings for All*, stating that "one out of three persons globally, primarily in Small Island Developing States (SIDS) and Least Developed Countries (LDCs), lack access to effective early warning systems" (Baker, et al. 2022). This plan requires an investment of USD 3.1 billion from 2023 to 2027 (WMO 2021) to make EWS available to everyone across the globe. EWS are designed to detect potential threats or hazards and provide advance notice or warning to individuals or organisations at risk. The launch of this Action Plan is a welcome announcement as the ten most expensive climate-related disasters in 2022 cost the world close to USD 170 billion in insured damages (Christian Aid 2021). Meanwhile, a report by the Global Commission on Adaptation found that spending just USD 800 million on EWS in developing countries could help avert losses worth USD 3–16 billion annually (UN 2022).

The study aims to assess the effectiveness of nationally operated EWS and MHEWS in mitigating the impacts for hydrometeorological hazards with a focus on floods and cyclones in India. To assess how EWS and MHEWS contribute to the resilience of Indian states, a novel **vulnerability to resilience model** has been proposed. Resilience within EWS is a function of

i. **availability**: the presence or absence of EWS and MHEWS stations;

ii. **accessibility**: the share of people that have access to information to take immediate action;

iii. **effectiveness**: the presence of good governance and financial frameworks established for the installation and implementation of EWS and MHEWS (ERRC 2014).

- **The availability of EWS and MHEWS** in hotspot districts was assessed by conducting a thorough literature review of the available gray literature and an in-depth analysis of reports published by different government agencies.
- **To quantify the accessibility of EWS and MHEWS**, the number of people covered through early warning dissemination systems were considered using the teledensity[1] scope. The teledensity scope was quantified using the *Telecom Subscriptions Reports* – TRAI subscribers' database (TRAI 2021) of both wireline and wireless subscribers for all telecom companies.
- **The effectiveness of EWS** was evaluated using a systematic flow to comprehend the governance of the EWS at the national, state, and district levels.

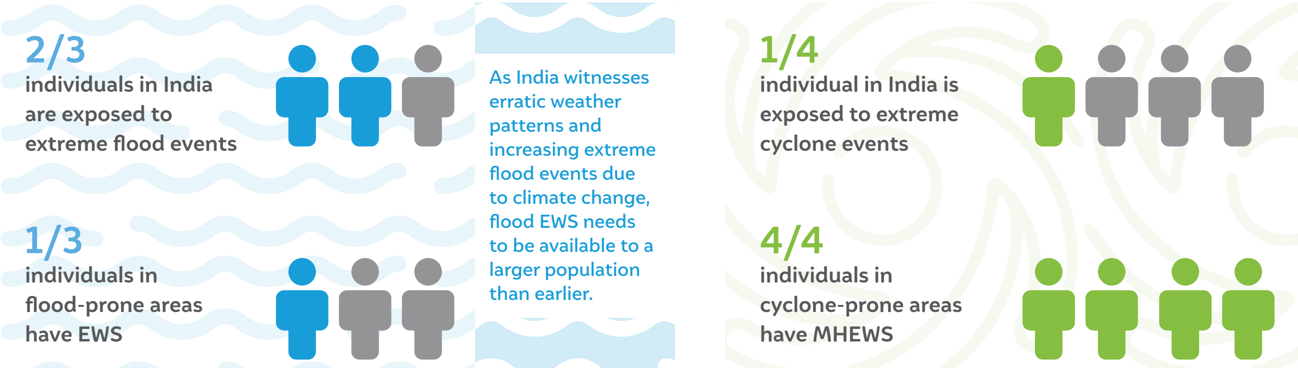
A. Key findings

Availability of EWS in India

- Approximately 66 per cent of individuals in India are exposed to extreme flood events; however, only 33 per cent of the exposed individuals are covered by flood EWS.
- Meanwhile, 25 per cent of individuals in India are exposed to cyclones and their impacts, but cyclone warnings are available to 100 per cent of the exposed population.

1. Telephone density or teledensity is the number of telephone connections for every hundred individuals living within an area. It varies widely across the nations and also between urban and rural areas within a country.

Figure ES1 Majority of people exposed to extreme floods have limited availability of flood EWS



Source: Author's analysis

Accessibility to EWS in India

- Most of the exposed population in India can access early warning information through a mobile or telephone connection.
- More than 88 per cent of Indian states that are exposed to floods and 100 per cent of the states exposed to extreme cyclone events have a high teledensity ratio.

Effectiveness of EWS in India

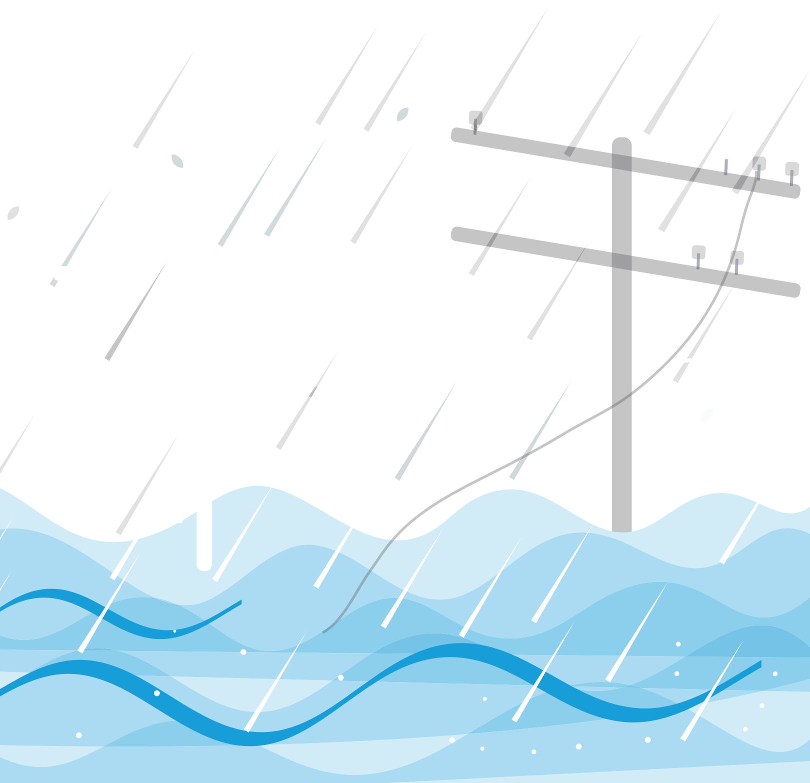
- Nine states with high exposure to extreme flood events have highly effective flood EWS.
- Ten states with high exposure to extreme cyclone events also have high to moderately effective cyclone EWS.

Figure ES2 Majority of people in India have high means of accessibility to flood and cyclone EWS

Source: Author's analysis

Resilience through EWS in India

- In total, 14 out of 32 states that are exposed to floods, and 9 out of 17 states exposed to cyclones, are highly resilient owing to the availability, accessibility, and effectiveness of EWS and MHEWS.
- Furthermore, states such as Andhra Pradesh, Odisha, Goa, Karnataka, Kerala, and West Bengal are at the forefront of building resilience by establishing cyclone EWS.



B. Key recommendations

- **States should mainstream inclusive, impact-based, and community-led MHEWS.** Leveraging self-help groups (SHGs) and youth volunteers from local communities will enable states to achieve last-mile connectivity and efficient end-to-end information dissemination.

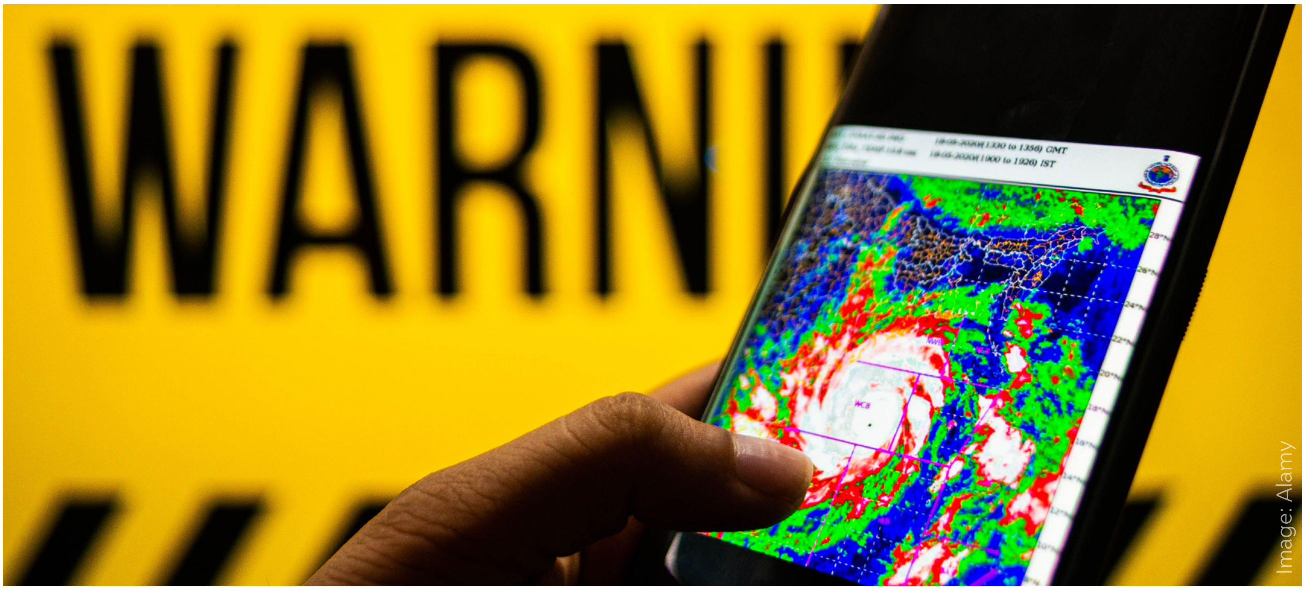
- **States should strengthen early warning dissemination systems (EWDS)[2] by leveraging new-age technologies** such as the Internet of Things (IoT), cloud computing, and artificial intelligence, which can assist in the monitoring, forecasting, and alarm generation aspects of EWS by providing the tools to sense, clean, process, and analyse the data coming from the environment.

- **The central and state governments should invest in regional real-time flood monitoring microsensors.** This will enable accurate and real-time collection of data, which can then be shared with the Central Water Commission (CWC) and combined with their flood monitoring data to make flood forecasts more targeted and accurate.

- **State and central governments should promote collaborations with the private sector to improve MHEWS efficiency, especially using technology.** Fostering public–private partnerships will accelerate innovation and the scaling of technological solutions for disaster risk reduction (DRR). Involving private companies can also aid fund mobilisation, bringing more transparency and accountability to the flow of finance towards EWS.

- **Leveraging knowledge transfer through international collaboration.** Enabling international collaborations enhances understanding of key components such as data collection, risk assessment, information dissemination, and community engagement for effective EWS. This knowledge exchange facilitates the adoption of cutting-edge technologies for early detection, enabling proactive response and impact mitigation in India and other countries.

To ensure that climate change adaptation is incorporated into national and local DRR policies, we need to invest more in comprehensive disaster risk management. Establishing effective EWS is a low-hanging fruit in helping accomplish our DRR targets. Leveraging its position as the G20 presidency, India should promote the agenda of making early warnings available to all and champion impact-based people-centric MHEWS.



The National Disaster Management Authority (NDMA) of India has envisioned a CAP-based Integrated Alert System on Pan India basis. The project involves near real-time dissemination of early warning through multiple technologies using geo-intelligence (NDMA 2023).

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2. Early warning dissemination systems (EWDS) are fool-proof communication systems to address existing gaps in disseminating disaster warnings by strengthening emergency operation centres at the state, district, and block level. It aims to save the lives and property of people residing in coastal areas (OSDMA 2021).

1. Introduction

Extreme weather and climate events account for the majority of the recorded economic damage caused by natural disasters (OECD 2015). Between 1970 and 2019, weather and extreme climate events constituted 79 per cent of all disasters globally, accounted for 74 per cent of all reported economic losses, and 45 per cent of all reported deaths. Meanwhile small island developing states (SIDS)[3] lost more than USD 150 billion due to such extreme events, and over 91 per cent of these deaths were reported from developing countries (WMO 2021b). As the frequency and intensity of extreme events rise, the percentage of disasters associated with weather and climate has increased by 9 per cent in the last decade (WMO 2020), making the situation particularly grim for SIDS and developing countries. However, developed countries are not immune to the impacts of changing climate either, as, currently, the United States and Europe deal with scorching heat waves and record-high temperatures. From 1980 to 2020, extreme climate events have caused economic losses amounting to USD 535 billion in the 27 EU member states (EEA 2022). Evidently, as the impacts of climate change grow in magnitude, the damage caused by extreme weather events is likely to worsen. Building resilience to these impacts is, therefore, of utmost importance (C2ES 2021).

"Climate resilience is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate. Improving climate resilience involves assessing how climate change will create new, or alter current, climate-related risks, and taking steps to better cope with these risks." (C2ES 2021)

Focussed steps to increase preparedness can help save lives and boost economies through accelerated development, poverty reduction, and enhanced adaptive capacity. Increasing adaptive capacity is an essential component of building resilience and can be achieved via multiple solutions. Climate-proofing infrastructures, scaling nature-based solutions, making risk-informed decisions, and investing in effective early warning systems (EWS) are increasingly being seen as key elements in building national and international resilience. Ensuring the timely implementation of these solutions is crucial in building long-term resilience. However, this study is focused on **building resilience through effective early warning and multi-hazard early warning systems**.

The 2019 Global Commission on Adaptation's flagship report, *Adapt Now*, found that EWS provides more than a ten-fold return on investment – far higher than any other adaptation measures included in the report. The report also found that issuing a warning just 24 hours before a coming storm or heatwave can cut the ensuing damage by 30 per cent. Furthermore, spending USD 800 million on such systems in developing countries would help prevent losses of USD 3–16 billion annually (UN 2022). Thus, investing in establishing an effective EWS will serve the dual purpose of saving lives and protecting economies while building long-term climate resilience. An effective EWS is the first step towards building resilience as it enables policymakers, public officials, administrators, and communities to plan ahead and safeguard lives and livelihoods.

Under India's G20 presidency this year, a working group on disaster risk reduction (DRR) has been formed for the first time since 1999. Further, EWS remains one of the key priorities throughout India's G20 presidency. This is also in agreement with the Prime Minister's *Ten Point Agenda* for DRR. Given that one of the main focus areas for the G20 DRR Working Group is the collation of data and the co-development of a compendium on early warning and early action, this study aims to assess the i) availability, ii) accessibility, and iii) effectiveness of nationally operated EWS and MHEWS in mitigating the damage caused by hydrometeorological hazards with a focus on floods and cyclones in India.

> **G20 countries have a high level of exposure to disaster risk, with a combined estimated Annual Average Loss of USD 218 billion (NDMA 2023).**

3. Small island developing states (SIDS) are a distinct group of 38 UN member states and 20 non-UN members and associate members of UN regional commissions that face unique social, economic, and environmental vulnerabilities.

Disaster Risk Reduction Working Group

G20 I Presidency of India I NDMA

Priority 1

Global coverage of early warning systems for all hydro-meteorological disasters.

Prime Minister's Ten Point Agenda for Disaster Risk Reduction

Agenda 5

Leverage technology to enhance the efficiency of disaster risk management efforts.

Efforts must be made to leverage technology to enhance the efficiency of our disaster risk management efforts. ... to increase the efficacy of early warning systems for all major hazards through the application of technology.

1.1 What is an early warning system?

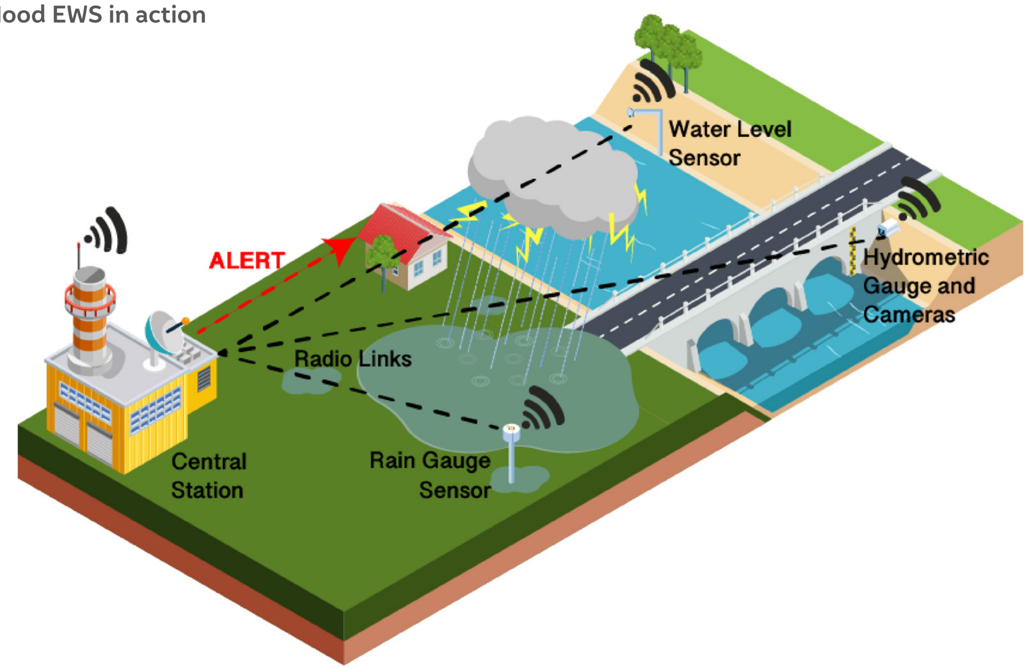
EWS use a variety of tools and methods, such as sensors, data analysis, and communication channels, to gather information to detect potential threats or hazards and provide advance information or warning to individuals or organisations that may be affected (Figure 1). According to the United Nations, the early warning system is

"an adaptive measure for climate change, using integrated communication systems to help communities prepare for hazardous climate-related events" (UN 2022).

Since there are different types of EWS available globally, various organisations have their own definitions of EWS. This has delayed the formulation of a globally accepted definition for EWS. In the context of DRR using weather EWS, the United Nations Office for Disaster Risk Reduction (UNDRR) defines an EWS as

"an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events."

Figure 1 A flood EWS in action



Source: Esposito, Marco, Lorenzo Palma, Alberto Belli, Luisiana Sabbatini, and Paola Pierleoni. 2022. "Recent Advances in Internet of Things Solutions for Early Warning Systems: A Review."

What are multi-hazard early warning systems?

MHEWS enable early warning dissemination, which helps increase preparedness and enables early action. The United Nations International Strategy for Disaster (UNISDR), UNDRR, and World Meteorological Organization (WMO) note that MHEWS are systems that use various technologies and information sources to provide early warnings of potential hazards or disasters that may affect a community or region. These systems are designed to detect, monitor, and forecast various natural hazards, such as floods, hurricanes, earthquakes, tsunamis, droughts, and wildfires, and provide timely and accurate information to people, authorities, and other stakeholders to take preventive measures to reduce loss of life, property, and economic assets. MHEWS often integrate different data sources and technologies, such as meteorological and hydrological monitoring systems, remote sensing, geospatial data, social media, and community-based observations. They use various communication channels, such as radio, SMS, mobile apps, social media, and sirens, to disseminate warnings to different segments of the population, including vulnerable groups. Therefore, MHEWS require close coordination between various government agencies, including meteorological services, emergency management agencies, and national disaster management organisations, as well as with the private sector, civil society organisations, and communities themselves.

The idea of MHEWS has recently gained international attention. According to the Sendai Framework Monitor, the share of countries with MHEWS in Asia and the Pacific has increased from 25 per cent in 2015 to 60 per cent in 2022 (Baker, et al. 2022, UNDRR 2022b). In situations where dangerous events may occur singularly, concurrently, in a cascade, or cumulatively over time, MHEWS address multiple risks and impacts while considering the potential connected effects.

Therefore, MHEWS are increasingly recognised as a crucial tool for DRR and are being developed and implemented in many countries worldwide. The United States has several MHEWS in place, including those developed by the National Oceanic and Atmospheric Administration (NOAA), Integrated Water Resources Science and Services (IWRSS) and National Integrated Drought Information System (NIDIS). Further, Germany's Federal Ministry for Economic Cooperation and Development (BMZ) has funded the development of several multi-hazard EWS in Africa, including African Risk Capacity (ARC) and the Global Risk Identification Program (GRIP). Meteoalarm is a joint effort by the Network of European Meteorological Services (EUMETNET) and provides alerts in Europe of extreme weather events, including heavy rainfall with risk of flooding and severe thunderstorms, amongst many others (Climate ADAPT 2019).

1.2 What are the different types of EWS/MHEWS?

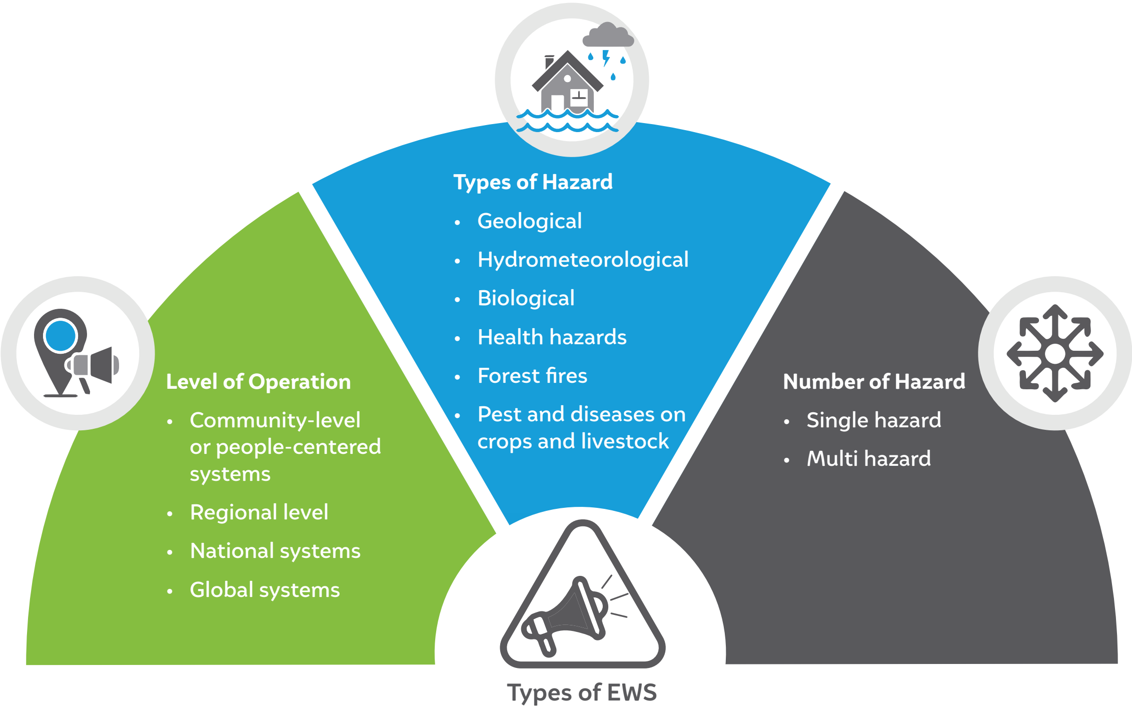
There are various ways of classifying EWS, such as by type of hazard, the level at which it is operated, and whether it is a single or multi-hazard system (UN-SPIDER 2021). Each system is designed to detect and alert people about different hazards, but they all share the common goal of reducing risks, saving lives, protecting property, and minimising economic losses. Some examples of the types of EWS available globally include:

- **Weather and climate EWS**: These systems are designed to provide advance notice of extreme weather events, such as hurricanes, tornadoes, and heat waves, as well as longer-term climate risks such as droughts and floods. They provide advance warning to local authorities and communities, allowing them to prepare and take necessary precautions.
- **Earthquake EWS**: These systems use seismometers to detect potential earthquakes and provide warnings to people in affected areas. This can give people time to take shelter and protect themselves from potential damage.
- **Tsunami EWS**: Similar to earthquake EWS, tsunami EWS use sensors to detect seismic activity in the ocean and provide alerts to coastal communities in the path of a potential tsunami.
- **Disease outbreak EWS**: These systems use data analysis and monitoring to detect and respond to potential disease outbreaks, such as those caused by emerging infectious diseases like COVID-19.
- **Wildfire EWS**: These systems use data on weather, vegetation, and other factors to estimate the risk of wildfires and provide alerts to nearby communities.
- **Volcano EWS**: Similar to earthquake and tsunami EWS, volcano EWS use sensors to detect changes in volcanic activity and provide alerts to people in affected areas.

- **Financial EWS**: These systems analyse financial data and market trends to detect potential economic risks or crises. They provide early warnings to policymakers, businesses, and investors, allowing them to take steps to mitigate potential losses.
- **Public health EWS**: These systems monitor patterns in disease outbreaks and provide alerts to public health officials and medical professionals. This can help contain the spread of infectious diseases and prevent epidemics.

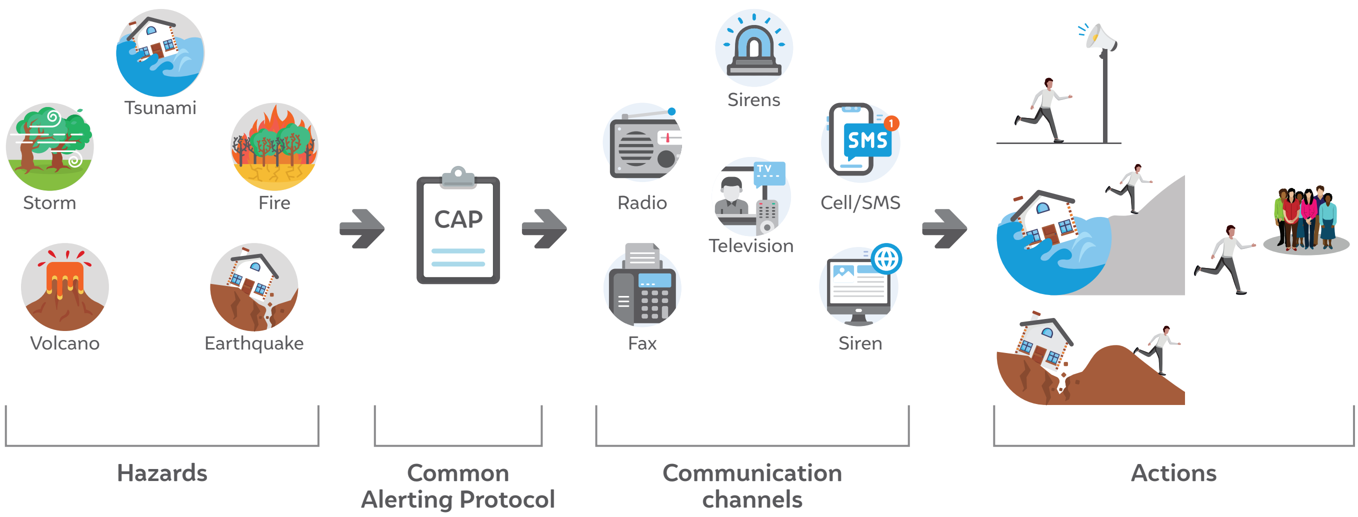
Our study focuses on the different types of weather EWS available in India. Figure 2 and 3 respectively, provides an overview of the different types of EWS and their functions.

Figure 2 Types of EWS and their functions



Source: Author's compilation based on UN-SPIDER 2021.

Figure 3 Functioning of MHEWS to alert at-risk communities to enable early action



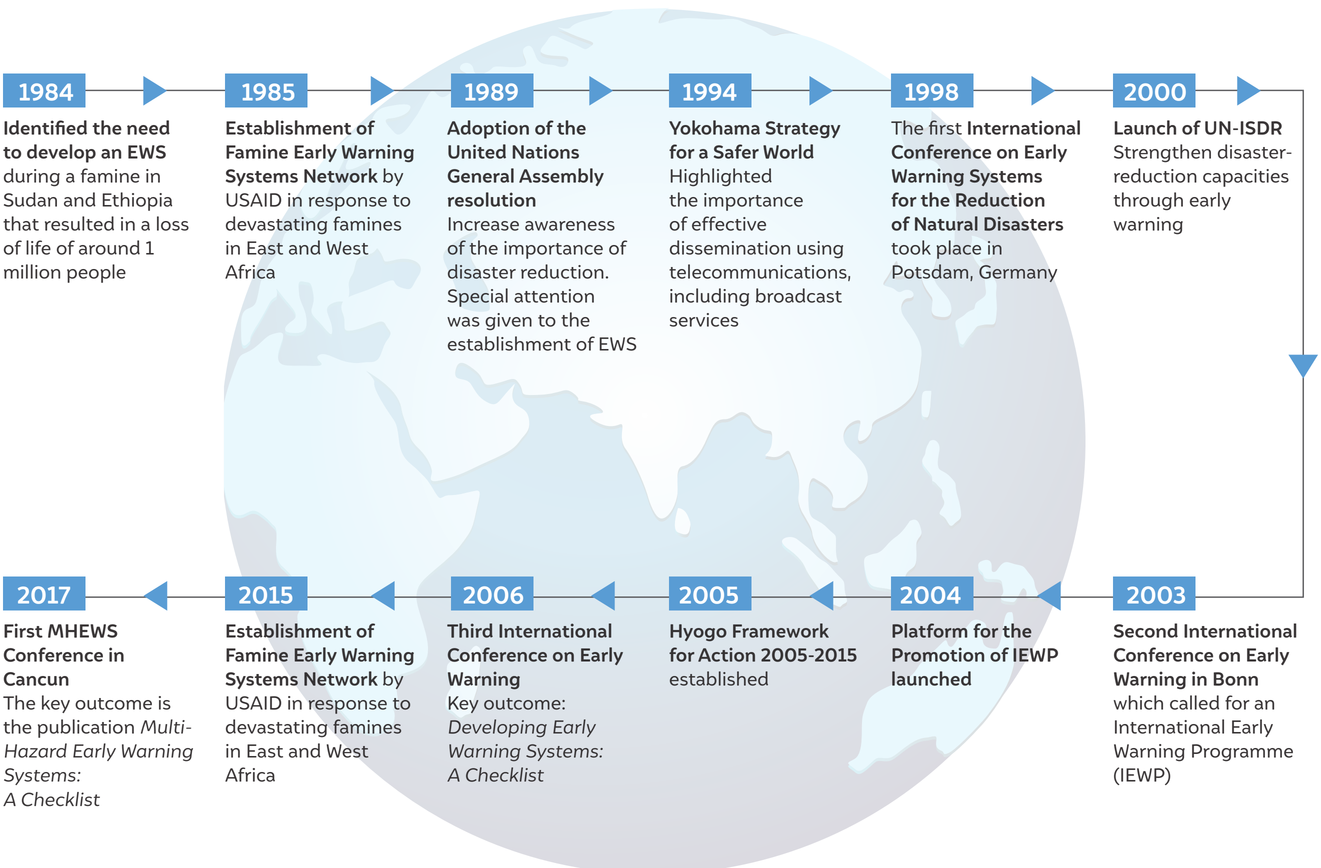
Source: Author's compilation based on WMO 2022c.

1.3 Why do we need MHEWS?

The need for EWS was realised decades ago. Bangladesh's journey towards developing a world-leading system can be traced back to 1970, when Cyclone Bhola caused immense devastation in the Bay of Bengal region, claiming the lives of approximately half a million people. To reduce the risk of further such tragedies, Bangladesh made substantial investments in weather forecasting technologies, set up cyclone shelters, and trained a dedicated network of volunteers in coastal areas (WMO 2020). In 1984, a famine in Sudan and Ethiopia resulted in one million deaths. In response, in 1985, the United States Agency for International Development (USAID) established the first famine EWS for African countries. However, EWS can save lives and protect livelihoods only if they incorporate clear roles, responsibilities, and coordination mechanisms for action. The overall success of an EWS ultimately depends on its ability to translate warnings, particularly, impact-based forecasts, into prevention and mitigation measures for all affected people, including hard-to-reach communities (WMO 2022).

On 26 December 2004, an earthquake in the Indian Ocean caused a devastating tsunami that killed more than 2 million people in 14 countries (WMO 2018). Many of these deaths could have been avoided if adequate warnings were provided, as people would have had time to seek safety. However, no effective EWS was in place. The scale of destruction pushed the international community to establish the Indian Ocean Tsunami Early Warning and Mitigation System to safeguard the lives and livelihoods of people and communities residing in some of the most vulnerable countries in the region. We have made significant leaps since 2004 in our understanding of how crucial EWS and MHEWS are for DRR. The combined mortalities resulting from extreme events such as floods, cyclones, lightning, and heatwaves have reduced by 45 per cent in the US as timely early warnings allowed people to take shelter (Teisberg and Weiher 2009). Similarly, due to timely and accurate warnings, the Bangladesh authorities and government were able to evacuate more than three million people successfully at the onset of Cyclone Sidr in 2007 (Rogers and Tsirkunov 2010). Figure 4 provides a brief overview of the evolution of EWS globally and the transition from early warning to MHEWS.

Figure 4 Overview of the evolution of EWS globally



Source: Author's compilation

However, with the impacts of climate change becoming more severe, experts, practitioners, policymakers, and environmentalists are shifting from emphasising the need to provide timely and accurate early warnings to **end-to-end, people-centred, and multi-hazard early warning systems (MHEWS)**. People-centred essentially means considering the inputs of affected communities when designing EWS and taking into consideration the needs of those most vulnerable to the impacts of climate change. During the 2008 Kosi River flood in Nepal, zero casualties were reported as the EWS had vaulted into action, alerting communities of the incoming danger well ahead of time (Davison 2022).

This shift to a people-centred MHEWS is the result of communities and countries recognising and realising the need to prepare better and adapt to the risks posed by extreme climate events. Further, the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030, the global blueprint for reducing disaster risk and losses, recognises the benefits of MHEWS and highlights them in one of its seven global targets (Target G):

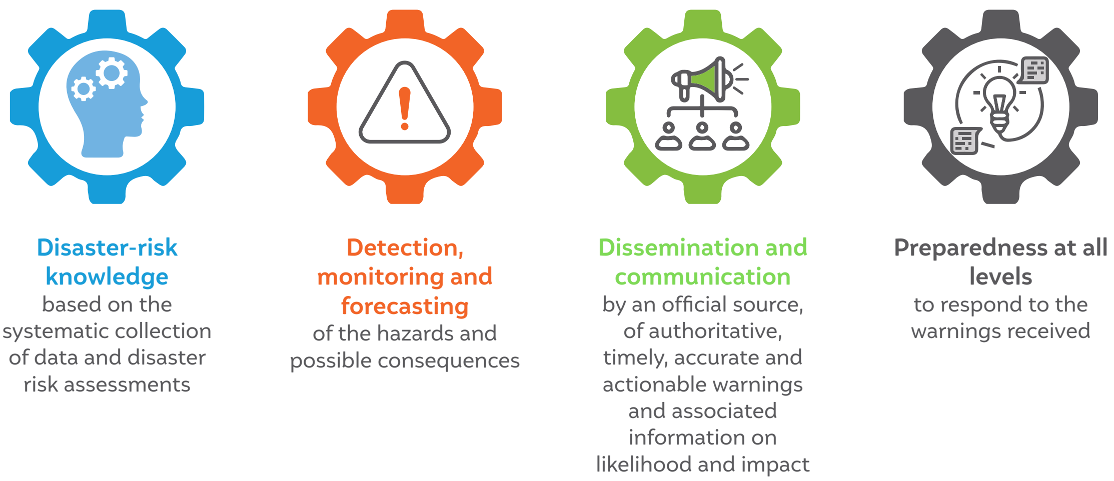
"Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030." (UNDRR 2021)

According to the World Meteorological Organization (WMO), SFDRR and UNISDR,[4] there are four key elements for effective, people-centred MHEWS, as highlighted in Figure 5.

An effective, accurate, and timely early warning provided through MHEWS allows communities and individuals exposed to disasters to take appropriate action in sufficient time to safeguard themselves from the impending impacts of hazardous weather or climate-related events. Figure 6 illustrates the three reasons why an effective, end-to-end, and people-centred early warning is essential for DRR and building resilience (NIDM 2014).

- **Safety for everyone.** People can act at the first sign of a crisis when they have access to reliable early warning information.
- **Preservation of the country's productive resources (infrastructure, private property, and investments).** EWS provide information that enables communities to protect their lives and property, thereby reducing economic losses, injuries, and fatalities.
- **Ensure long-term progress and economic expansion.** MHEWS have been acknowledged as a useful instrument to lessen vulnerabilities and enhance readiness and responses to natural hazards, resulting in the reduction of loss and damage and securing the nation's developmental trajectory.

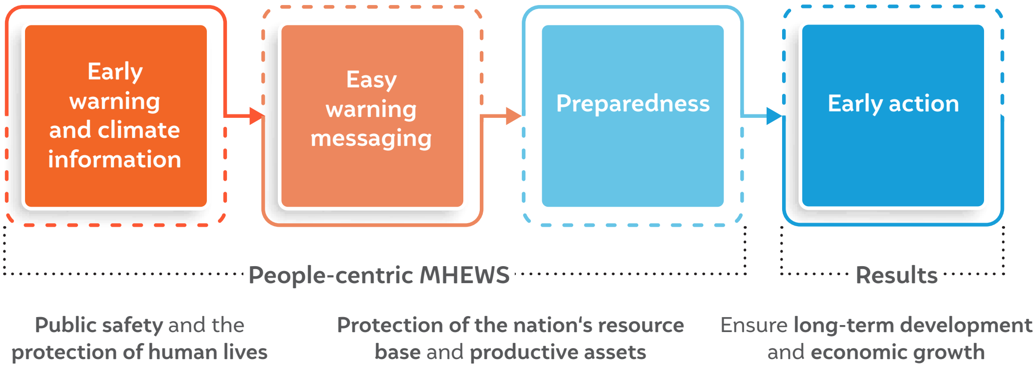
Figure 5 Elements of an effective MHEWS



Source: Author's compilation based on UNDRR Strategic Framework

4. United Nations Office for Disaster Risk Reduction Strategic Framework 2016-2021, which guides the organisation to achieve its vision, mandate and overarching objectives.

Figure 6 A people-centric MHEWS empowers individuals and communities to take timely action



Source: Author's compilation

1.4 What makes an EWS and MHEWS resilient?

A disaster might occur alone or with associated events; for example, tropical cyclones generally cause heavy rains, coastal flooding, and storm surges, leading to cascading and compounding impacts on communities. Hence, to actively adapt to the impacts of climate change, a resilient EWS cannot operate in silos; rather, it must address the full range of hazards, their associated events, and their impacts. Consequently, an MHEWS that includes a diversity of hazards enables an integrated approach to DRR, which helps communities understand the information easily and is highly resource-efficient. Further, a resilient and effective EWS and MHEWS must address the following four operational components:

These four components must be well-coordinated across agencies at the national, sub-national, and regional levels. Lack of coordination or failure to implement one or more components can lead to the failure of the entire system (CDEMA 2016).

Further, to be effective, EWS and MHEWS must recognise the importance of 'leaving no one behind' (Bond 2022) and focus on providing information to all the members of the community. This further necessitates that the system be **available** and **accessible** to all for it to become an **effective** tool in managing disaster risks and building resilience. Additionally, the **effectiveness of EWS or MHEWS** can be enhanced through the integration of **end-to-end early warning dissemination systems**, i.e., by achieving **last-mile connectivity** by providing climate information to each individual, as warnings must reach those at risk. However, accomplishing end-to-end dissemination is a continuous process, as the number of people vulnerable to climate extremes is constantly increasing due to the rising intensity and frequency of weather events, spurts in population growth in hazard-exposed areas (WMO 2021b), and the increasing displacement of communities due to the impacts of extreme events.

Availability of EWS or MHEWS. The presence of an EWS can ensure continuous monitoring of hazards and their precursors to facilitate timely action and evacuation strategies that allow sufficient time for the affected community or communities to follow disaster management plans appropriate for that hazard (WMO 2018).

Access to EWS or MHEWS. It is a measure of the number of people that have access to the information necessary to take immediate action. The key component of accessibility to early warning information is access to early warning dissemination systems (EWDS).

BOX 1 Leveraging mobile-based EWS to achieve last-mile connectivity

Mobile-based public EWS refer to systems that use mobile devices such as smartphones, tablets, or other wireless devices to alert people about potential hazards or disasters. These systems can be used to warn people about various types of hazards, including natural disasters such as earthquakes, hurricanes, and floods, as well as man-made disasters such as terrorist attacks or industrial accidents. The key advantage of mobile-based public EWS is that they are able to reach a large number of people quickly and effectively. Since many people have mobile devices, alerts can be sent directly to their phones or other wireless devices, ensuring that they receive the message in a timely manner.

Mobile-based public EWS can use various methods to alert people, including text messages, voice calls, push notifications, and mobile apps. These systems can also be integrated with social media platforms to spread information quickly and reach a wider audience. Cell-broadcast or location-based SMS (short message service) warnings can be targeted to reach only people located in an at-risk area or broadcast to all connected handsets within a designated target area which can be as large as an entire network or as small as a single cell *(ITU 2023)*. However, mobile-based EWS do have some limitations. One of the biggest challenges is ensuring that alerts are sent to the right people at the right time. There is also the risk that people may ignore or turn off alerts if they receive them too frequently, leading to a drop in effectiveness over time.

Overall, mobile-based public EWS can be a powerful tool for keeping people informed and safe during times of crisis. However, it is important to ensure that these systems are properly designed and implemented to ensure maximum effectiveness.

Source: Author's compilation

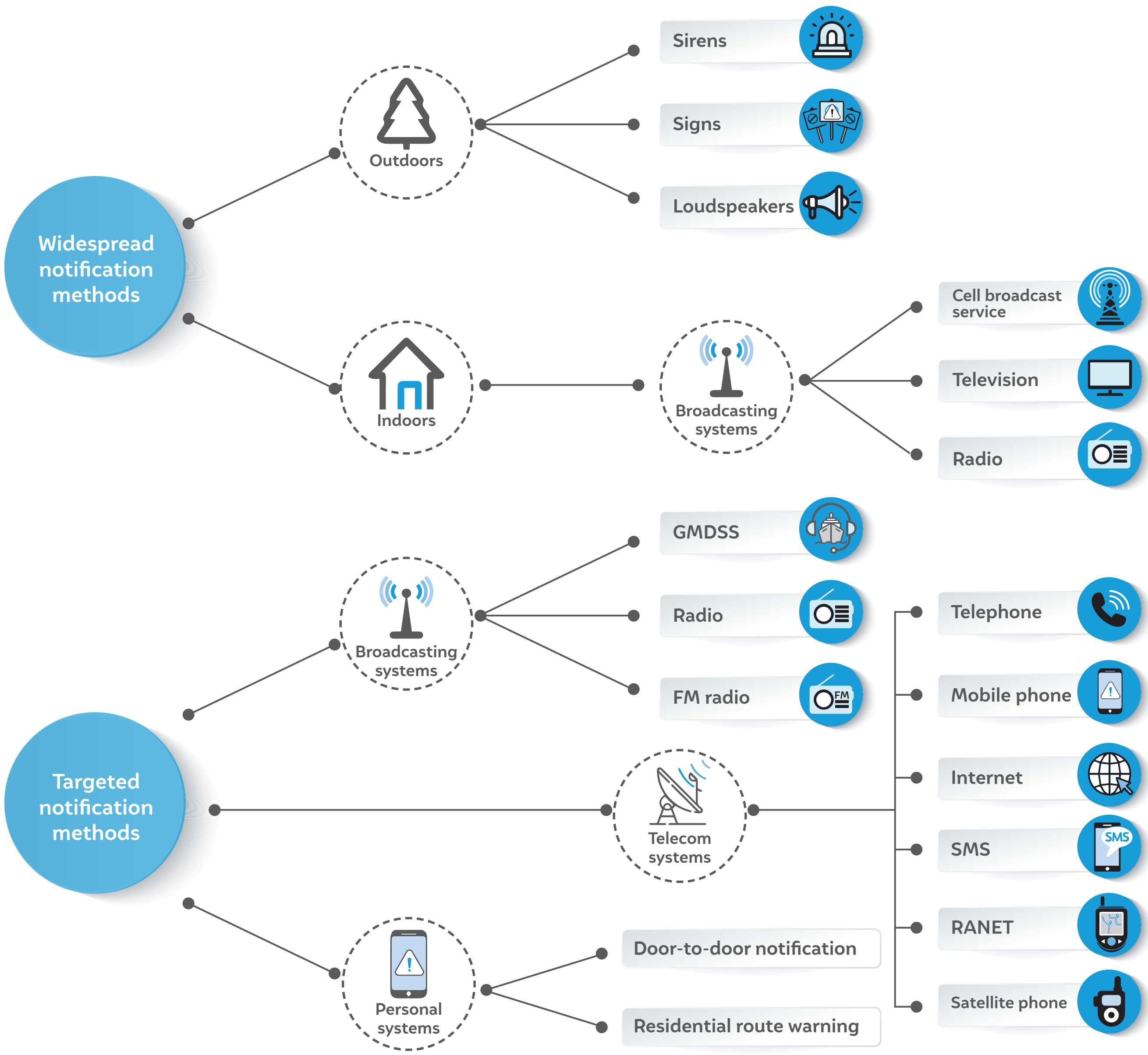
Hence, EWDS are an essential component of establishing a fool-proof communications system to address the existing gaps in disseminating disaster warnings up to the community level (OSDMA 2021). Maintaining access to EWDS is crucial to ensure information is relayed and disseminated from the state, district, and block levels to communities and vice versa so that the last person nearest to the sea is well informed about taking appropriate action in case a cyclone or any other disaster occurs.

At all societal levels, access to reliable, accurate, and timely disaster warnings is crucial. For people and communities to react appropriately, information needs to be easily gathered, processed, evaluated, and shared. Without accurate information, people are often forced to make crucial decisions based on unclear and conflicting reports. Therefore, there is an urgent need for speedy dissemination of disaster alerts to a maximum number of persons in order to ensure preparedness, both at the individual level as well as the responding institution level (NDMA 2021). Therefore, telecommunication services such as calls, messages, push messages, and other alerts are the most reliable and immediate way to relay early warning communication to the masses. Box 1 provides a brief overview of how mobile-based EWS can be leveraged to achieve last-mile connectivity and increase the effectiveness of EWS.

It is essential to identify the most suitable method for information dissemination based on the needs and level of comprehensibility of the community. Dissemination techniques can be further categorised into widespread and targeted dissemination techniques, depending on where they are used and applied. While targeted methods can provide warnings to individual users, families, persons, neighbourhoods, predefined groups, agencies, etc., widespread methods (mass dissemination techniques) are less targeted and are primarily via the mainstream media. Scaling both general and specialised warning techniques will help to ensure that the desired message reached the intended audience. The likelihood that the message will reach important stakeholders increases as the range of deployed distribution mechanisms increases. To ensure that as many people as possible are alerted, to anticipate and be prepared for the failure of any channel, and to reinforce the warning message, numerous communication channels must be used (WMO 2018). Thus, redundancies will come in handy if a certain technology or approach fails.

In order to ensure that people and communities receive warnings in advance of approaching hazard events, and to facilitate national and regional coordination and information exchange, communication and dissemination mechanisms must be developed to ensure last-mile connectivity. Further, there must be pre-identified regional, national, and community-level communication platforms to ensure a reliable flow of information. Figure 7 provides a brief overview of the available methods for information dissemination.

Figure 7 Available methods for information dissemination



Source: Author's compilation

1.5 About the study

Scope of the study

According to a WMO report, 80 per cent of the natural catastrophes that affected Asia in 2021 were caused by floods and storms; and floods had the largest impact in Asia in terms of fatalities and economic damage (WMO 2021a). Natural disasters caused an estimated loss and damage of USD 35.6 billion (approximately INR 2.9 lakh crore) to Asian nations in 2021. India alone suffered damages worth USD 7.6 billion (INR 62,000 crore) due to extreme flood and cyclone events as they are rapid onset events and cause widespread disruptions (WMO 2021a). Therefore, this study aims to assess the effectiveness of nationally operated EWS and MHEWS for hydrometeorological hazards with a special focus on floods and cyclones. For flood EWS, the focus was limited to the level forecast stations installed by CWC for forecasting riverine floods in India. Level forecast stations are primarily responsible for providing information to disaster management agencies in deciding mitigating measures for safeguarding lives and livelihoods.

Further, droughts have not been taken into consideration in this study, as they are generally classified as *'creeping disasters'*. Droughts are different from most other hazards as they develop slowly, sometimes even over years, and their onset is generally difficult to detect.

Given that droughts range in their characteristics and effects across different regions, especially in terms of rainfall patterns, societal responses, and resilience, it is challenging to offer a specific and widely accepted definition of what it is. All climatic regimes experience drought, which is a regular occurrence that is often classified by its spatial extension, intensity, and duration.

Learnings from literature

Through an in-depth review of the literature, different indicators were identified for evaluating how EWS contributes to building India's resilience against extreme hydrometeorological disasters. To conduct a robust assessment of EWS and MHEWS, the study adheres to the following global standards identified by the Global Partnership for Effective Development Cooperation (GPEDC 2022) for achieving effective information dissemination through EWS:

- **Timeliness and relevance of early warning information**. EWS must be able to provide timely and relevant information to people at risk of natural disasters, disease outbreaks, and other emergencies. This information should be based on accurate data and analysis and should be communicated in a way that is easily understandable to the target group.
- **Accessibility and inclusivity of EWS**. EWS should be designed to reach all segments of society, including marginalised and vulnerable populations such as women, children, and people with disabilities. This requires the use of multiple communication channels, including mobile phones, radio, television, and other media, to ensure that information reaches as many people as possible.
- **Coordination and cooperation among stakeholders**. Effective EWS require collaboration and coordination among multiple stakeholders, including government agencies, civil society organisations, the private sector, and the international community. This includes sharing information, resources, and expertise to ensure that EWS are effective and sustainable in the long term.

By adhering to these three global standards, countries and organisations can ensure that their EWS are effective in disseminating critical information to people at risk of emergencies and disasters.

An additional set of indicators can be taken into consideration. These include technologies involved in EWS; mode of collecting hazard-related information (geological hazards, hydrometeorological hazards, and disease risks); message content and appropriateness; service support and system maintenance to review the mode of collecting information related to hazard events; monitoring; and transmitting it to other agencies, particularly the municipal government and district administration.

This study aims to identify the indicators necessary to understanding how effective EWS are in building resilience and reducing vulnerability to extreme weather events. Therefore, a thorough assessment, including all the additional indicators mentioned for all the EWS at a national scale, is beyond the scope of this study. This limitation arises due to the lack of availability of data. Moreover, without a common framework, it would be difficult to assess these additional indicators due to the ambiguity that exists among current approaches.

1.6 EWS in India

India has a wide variety of EWS and MHEWS for different hazards. The Indian Tsunami Early Warning System was inaugurated on 15 October 2007 by the Ministry of Earth Sciences, Government of India, to provide early warnings of earthquakes and tsunamis in the Indian region. The Indian National Centre for Ocean Information Services (INCOIS), Hyderabad, and the National Centre for Seismology (NCS) are the nodal agencies for coordinating and operationalising the National Tsunami Early Warning Centre and receive support from the India Meteorological Department (IMD).

The Central Water Commission (CWC) is the nodal flood forecasting authority in India, which has installed 331 flood forecasting stations in the country until December 2021 (Ministry of Jal Shakti 2021). The IMD supports the flood warning services of the CWC by providing observed and forecasted rainfall data, which helps in making accurate and timely flood forecasts. Several states in India have also partnered with private companies to install flood EWS, specifically to disseminate early warning information at the regional level, for example, FLEWS in Assam, iFLOWS Mumbai in Maharashtra, and Flood Management Information System (FMIS) in Bihar. As a novel initiative, the Ministry of Earth Sciences and the Tamil Nadu state government have developed CFLOWS-Chennai, a web GIS-based decision-making support system, integrating data and outputs derived

> **Annually, ~10,000 flood forecasts are issued by CWC in India (PIB 2022).**

from weather forecast models and hydrologic, hydraulic, and hydrodynamic models. It is India's first integrated coastal flood warning system.

Flood forecasting comprises level forecasting and inflow forecasting. Level forecasts help disaster management agencies decide mitigating measures such as evacuation and shifting people and their movable property to safer locations. Inflow forecasting is used by various dam authorities to optimise the operation of reservoirs and ensure the safe passage of floodwaters downstream. It also helps ensure adequate storage in reservoirs to meet the water demand during the non-monsoon period.

Further, cyclone EWS in India function as multi-hazard EWS, providing critical information on cyclones and their intensity, likely point and time of landfall, associated heavy rainfall, strong winds and storm surges, along with their impact, and advice to the general public, media, fisherfolk, and disaster managers (IMD 2022). Currently, seven cyclone warning centres have been established by the IMD, which has developed state of art tools for cyclone warning services (Ministry of Earth Sciences 2021). Under the *National Cyclone Risk Mitigation Project* (NCRMP) Phase I and II, suitable structural and non-structural measures to mitigate the effects of cyclones in the coastal states and UTs of India are currently underway in collaboration with the NDMA (PIB 2021). The centre and several state governments have also developed several application programming interface (APIs), apps, and dashboards such as SATARK and TNSMART to transfer information to communities.

Figure 8 gives a brief overview of the availability of EWS in India for floods and cyclones.

Furthermore, different central authorities in India are responsible for disseminating early warnings regarding specific hazards such as the Ministry of Agriculture and Farmers Welfare (MoAFW) for droughts, the Ministry of Health and Family Welfare (MoHFH) for epidemics, and the Geological Survey of India for landslides. Given India's heterogeneous climate and the dynamism shown in heat extremes, the IMD also set up a forecast system under the *National Monsoon Mission* to issue early warnings and alerts for heat and cold waves.

1.7 Research questions

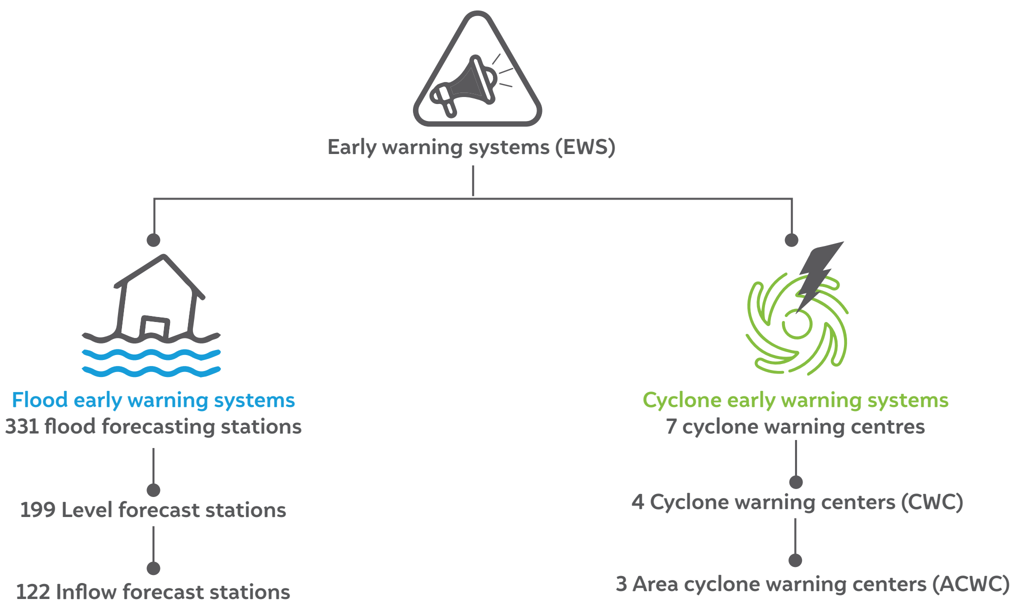
Early warning systems can improve resilience against climate-related hazards by providing information for early action. However, to be effective, EWS must incorporate aspects of resilient systems. Therefore, this study attempts to answer the following questions to assess the 'vulnerability to resilience' capacity of Indian states towards extreme climate events, especially with reference to floods and cyclones.

Q1. What is the status of the availability and accessibility of EWS in India?

Q2. What are the gaps and challenges in implementing people-centred MHEWS in India?

Q3. How effective and efficient are India's EWS and MHEWS?

Figure 8 Overview of the availability of flood and cyclone EWS in India



Source: Author's compilation

2. Approach and methodology

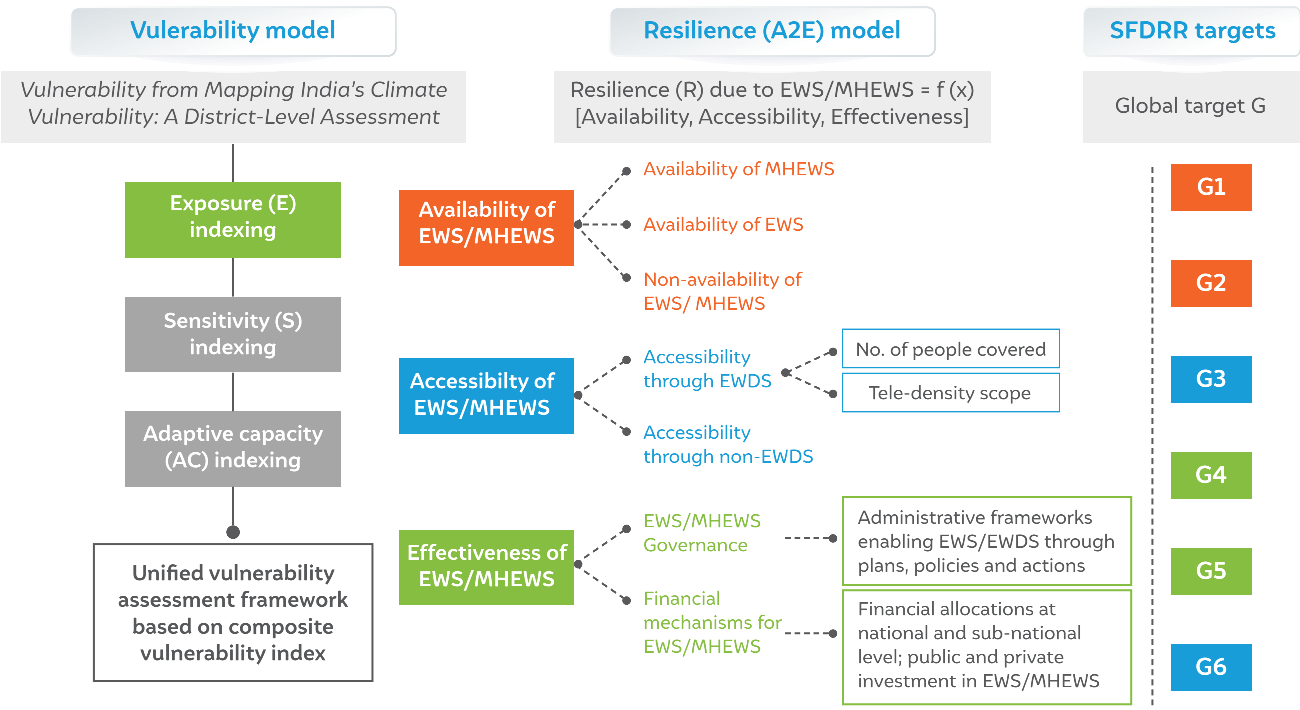
To assess the effectiveness of EWS in India, our study proposes a novel, strengthened, and sustainable **vulnerability to resilience model based on EWS**, integrating the four pillars of the Sendai Framework in convergence with the Sustainable Development Goals (SDGs)[5] to enhance disaster preparedness, reduce the impacts of climate risks, and build resilience at the national and sub-national level against extreme hydrometeorological disasters. This proposed model has two variables: **first, vulnerability**,[6] based on the integrated vulnerability assessment framework established in a previous CEEW report, *Mapping India's Climate Vulnerability: A District-Level Assessment* (2021), and **second, resilience**, based on the A2E framework, under which three components have been taken into consideration, i.e., **availability**, **accessibility**, and e**ffectiveness of EWS and MHEWS**.

2.1 Vulnerability-to-resilience model

Mapping India's Climate Vulnerability: A District-Level Assessment (a 2021 CEEW study) built a composite index for integrated vulnerability assessment, considering three components of vulnerability, i.e., exposure, sensitivity, and adaptive capacity.

To assess how EWS and MHEWS contribute to the resilience of a country at the sub-national level a comparative analysis was undertaken. Building on the vulnerability assessment and based on the Sendai Framework global Target G to assess how EWS contribute to building the resilience of Indian states, the **A2E framework** is proposed. The framework has three core components: availability, accessibility, and effectiveness of EWS and MHEWS. The schematic diagram in Figure 9 illustrates the interlinkages between vulnerability and resilience and how the selected indicators synchronise with the global target (g) established by the *Sendai Framework* and SDG 13.

Figure 9 The vulnerability to resilience (V2R) model



Source: Author's analysis

Note:
The indicators selected are in convergence with the global target 8 of Sendai Framework and SDGs (SDG13 – 13.1 and 13.3 specifically). Global target G: Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030. G1-G6: Indicators to measure global progress in the implementation of the Sendai Framework for Disaster Risk Reduction (UNDRR 2021).

5. The 17 Sustainable Development Goals (SDGs) are an urgent call for action by UN member states in 2015 – both developed and developing – to commit to a shared blueprint for peace and prosperity for people and the planet, now and into the future (UN 2022).
6. "Characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard" (UNDRR 2009).

Assessing the vulnerability of Indian states

When evaluating vulnerability, exposure is the key indicator that is taken into consideration. Exposure is "the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC 2014). It is a necessary condition for a hazard to become a disaster and pose a risk. Populations are often directly or indirectly affected due to exposure to a hazard. Injury, disease, health repercussions, evacuation and displacement, and economic, social, cultural, and environmental harm are examples of direct effects. Indirect impacts include additional long-term effects that result in unsafe or unhealthy conditions due to disruptions and changes in the economy, infrastructure, society, or people's physical and mental health (Saulnier et al. 2020). Therefore, to establish accurate and resilient EWS, it is essential to undertake exposure mapping to identify hotspot regions and the people most at risk of being impacted by the onset of a hazard.

The exposure index was used directly from the *Mapping India's Climate Vulnerability: A District-Level Assessment* report. Exposure was conceptualised as a particular event in a particular grid characterised by a district boundary (Mohanty and Wadhawan 2021). This was primarily done to identify districts that were extreme event hotspots. CEEW carried out district-level profiling of India's extreme climate events, including cyclones, floods, and droughts and their associated events, through a pentad decadal analysis (Mohanty 2020). The assessment examined the frequency and intensity of hydrometeorological disasters, the pattern of associated events, and how the impacts have compounded on a temporal scale of 50 years (1970–2019). We further aggregated the district-level hotspots to identify state-level exposure, as EWS is a matter of state-level governance. This assessment helped us identify the states and the degree of exposure of its population[7] to a particular extreme event, especially for floods and cyclones.

Assessing resilience using the A2E framework

The availability of EWS and MHEWS was assessed through secondary data collection. The availability of EWS and MHEWS in the hotspot districts was done by conducting a thorough literature review of the available gray literature and an in-depth analysis of government documents such as the state disaster management plans (SDMPs), district disaster management plans (DDMPs), and disaster response plans (DRPs) of particular hotspot districts considered. Further, the presence of EWS or MHEWS in a district was confirmed by accessing the official websites and documents released by nodal forecasting agencies such as the IMD or CWC, amongst others. The data was then aggregated at a state level to compare with state-level exposure data. Furthermore, the data was validated through stakeholder consultations with the nodal officers of the concerned agencies responsible for issuing early warnings.

The accessibility of EWS and MHEWS was assessed by considering the number of people covered through EWDS using the teledensity scope. The teledensity scope was quantified using the *Telecom Subscriptions Reports* – Telecom Regulatory authority of India (TRAI) subscribers' database for both wireline and wireless subscribers for all telecom companies. The data was available at a sub-national level and was used to identify the number of people who could be reached through telecommunication services such as calls, messages, push messages, and other alerts. Telephones play an important role in warning communities of an impending disaster. For example, simple phone warnings saved many lives during the 2004 Tsunami in the Indian Ocean. Telephone EWS are particularly effective in sending disaster warnings to individuals and communities (Global Alliance on Accessible Technologies and Environments 2014). Thus, teledensity scope is an accurate way to quantify the reach EWS can have in a state and to estimate the capacity of an EWS or MHEWS to achieve last-mile connectivity.

> **An effective early warning could save many lives and reduce damage by 30% if activated 24 hours before the event.**

7. Total population was based on Census 2011 (Office of the Registrar General & Census Commissioner 2011). The dataset was extrapolated using the Center for Geographic Analysis at Harvard University, Cambridge, MA (Wang 2021). State level population data is till the year 2022.

The effectiveness of the EWS was evaluated using a systematic flow for comprehending the governance of the EWS at the national, state, and district levels; institutional mechanisms and their roles within the elements of the EWS; a specified institutional mechanism for implementation with clearly defined roles and responsibilities; delivery of goods and services by technical and disaster management agencies; review of the already-existing EWS mechanisms in districts; and the role of agencies in the EWS and their integration into the disaster management institutions (district disaster management plans). Table 1 provides a brief overview of the selected indicators and their relation to each component under the EWS.

2.2 Scoring via the Criteria Development Matrix

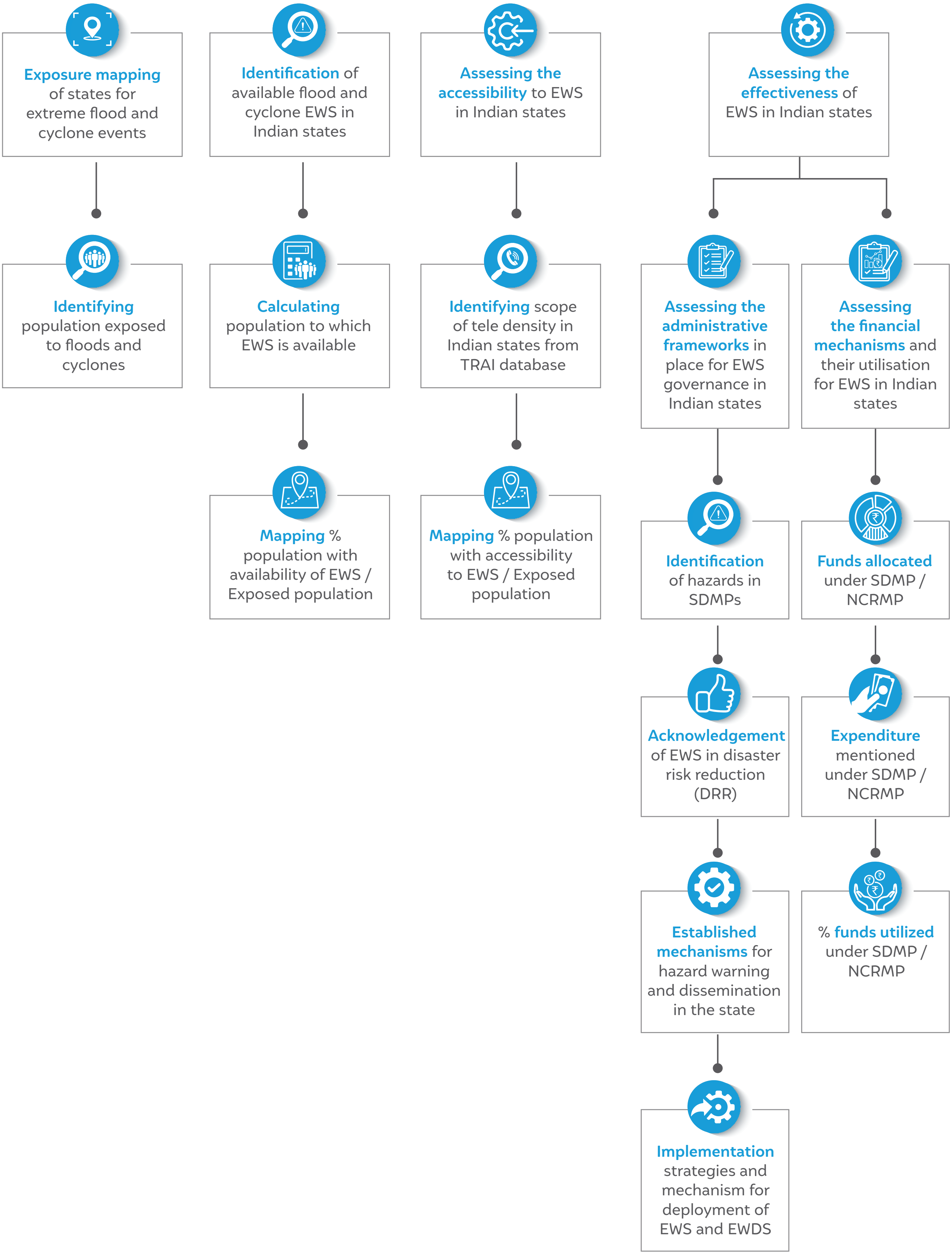
Based on past research and studies, a quantitative indicator–based Criteria Development Matrix was adopted for the analysis to score the indicators adopted under the 'vulnerability to resilience' model. Figure 10 provides an overview of the approach and the methodology adopted for developing the matrix and scoring the EWS in India on the developed criteria.

Table 1 Overview of the selected indicators

V2R Model	Components	Selected indicators	Source
Vulnerability	Exposure	a. Frequency and intensity of extreme events and their associated events b. State-wise total population c. Extrapolated population data	a. Mohanty and Wadhawan (2021) b. Census (2011) c. Center for Geographic Analysis at Harvard University, Cambridge, MA (2021)
Resilience	Availability	Availability of EWS, availability of MHEWS, non-availability of EWS/MHEWS	IMD, CWC, PIB, SDMPs, and DDMPs
	Accessibility	Accessibility through EWDS, accessibility through non-EWDS, teledensity scope	SDMPs, DDMPs, PIB, and TRAI subscribers' database 2021-2022
	Effectiveness	a. Financial mechanisms for EWS and MHEWS - Funds allocated under state disaster management plans (SDMPs) - Expenditure of the allocated funds under SDMPs - Percentage of funds utilised under SDMPs b. Governance of EWS and MHEWS - Identification of the hazards the state is exposed to - Acknowledgement of the role of EWS in DRR - Established mechanism for different hazard warnings and dissemination, explaining the roles and responsibilities of various agencies and early warning centres. - Implementation strategies and mechanisms for the deployment of EWS and EWDS for information dissemination; clear institutional mechanism for implementation, with well-defined roles and responsibilities to be enacted at the onset of a disaster.	a. SDMPs, DDMPs, PIB b. SDMPs, DDMPs

Source: Author's compilation

Figure 10 Approach and methodology for scoring EWS



Source: Author's compilation

The indicators were finalised based on an extensive literature review. Further, the indicators and sub-indicators were prioritised through a series of four stakeholder consultations with nodal officers from the CWC and IMD, and a total of ten indicators were selected to conduct the comparative analysis. The Criteria Development Matrix was built around the three components of the development model for EWS, namely availability, accessibility, and effectiveness of EWS in India, and was designed to indicate the level of EWS available and accessible to the population based on comparative scoring using the exposure data. Independent scoring was conducted for each of the three components and further normalised using the linear scaling method to reach a final cumulative score.

$$\text{Availability of EWS or MHEWS} = \frac{\text{Population with availability to EWS or MHEWS}}{\text{Population exposed}}$$

$$\text{Accessibility of EWS or MHEWS} = \frac{\text{Wireless and wired population TRAI subscribers database}}{\text{Population exposed}}$$

$$\text{Effectiveness of EWS or MHEWS} = \text{Total score for (administrative frameworks + financial mechanisms)}$$

% Availability/accessibility of EWS or MHEWS	Score
0–20	0
21–40	0.25
41–60	0.5
61–80	0.75
81–100	1

An overall score indicates the performance of the EWS in a particular state, contributing to the state's resilience. The following range of resilience was finalised based on the normalised scores:

Normalised score	Category
0–0.33	Low
0.34–0.66	Moderate
0.67–1.00	High

Finally, to assess how EWS are helping Indian states in building their resilience and reducing the impacts of disasters, the states were ranked from most to least resilient based on the aggregated scores obtained for the EWS. A relative indexing was used since it provides a unified comparison, making it an important addition to the sub-national early warning analysis. An integrated approach was used with absolute values to derive individual component scores and relative scoring for component-wise and comprehensive indexing (Mohanty and Wadhawan 2021). This can lead to targeted policies, actions, and financing for enhancing resilience capacity.

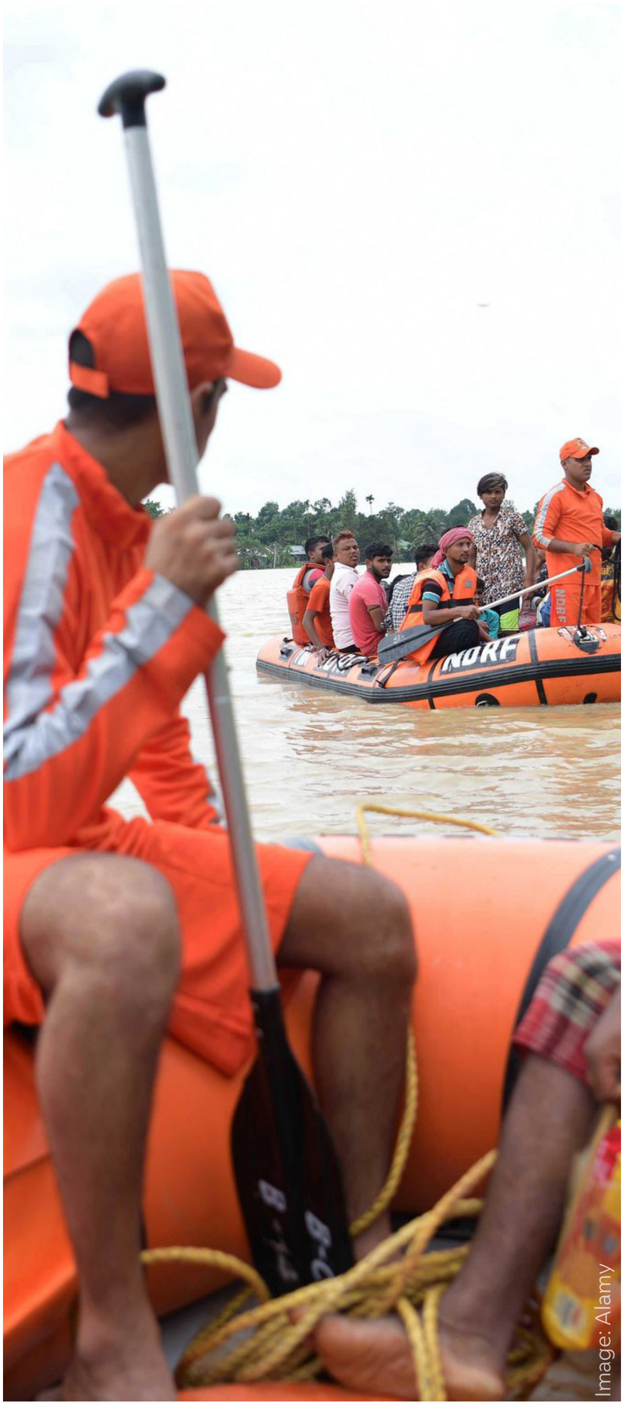


Image: Alamy

3. Results and discussion

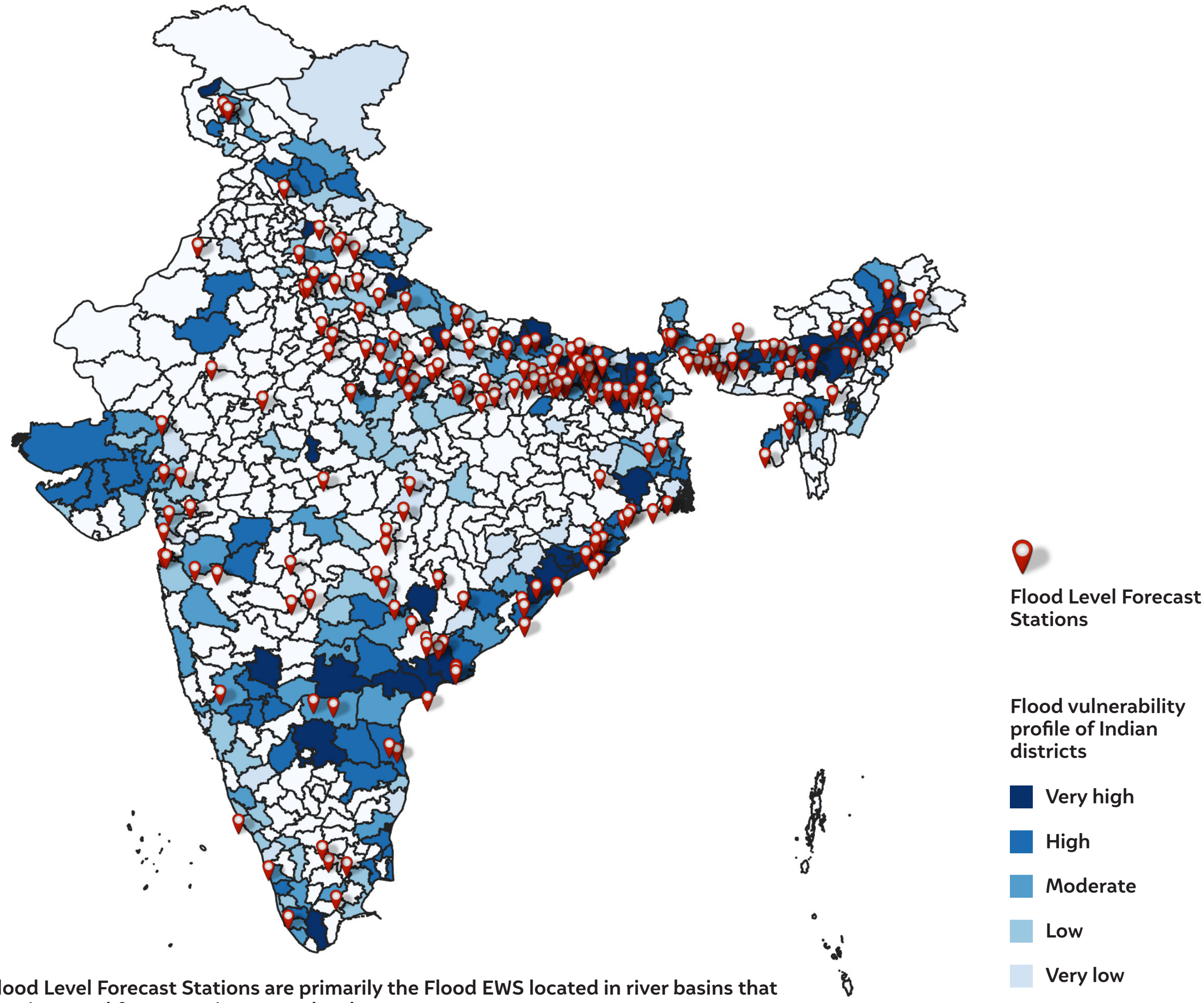
Recent advancements in EWS and an expansion in the hazards being monitored have been made possible through a better understanding of natural disaster triggers and the deployment of better sensors and communication systems to transmit data to observatories in various countries (UN-SPIDER 2021). Improved EWS have made significant progress in saving lives and reducing mortality; yet, the availability of these EWS remains a challenge (WMO & iN-MHEWS 2022). One-third of India's population lives in coastal areas and is highly vulnerable to extreme climate events such as floods and cyclones. An analysis by CEEW suggests that 75 per cent of districts in India are extreme event hotspots, with more than 80 per cent of India's population living in districts highly vulnerable to extreme hydrometeorological disasters (Mohanty and Wadhawan 2021). This makes it imperative for Indian states to step up climate action and build resilience by investing in EWS and MHEWS.

3.1 Availability of EWS and MHEWS in India

Availability of flood EWS

The district-level analysis revealed that while 72 per cent of districts in India were exposed to extreme flood events, merely 25 per cent of these exposed districts had level flood forecasting stations. This meant that two-thirds of individuals in India are exposed to extreme flood events, and only one-third of those exposed individuals have flood EWS. Figure 11 presents a spatial distribution of flood EWS across flood-prone districts in India.

Figure 11 Only 25% of flood-exposed districts have a level flood forecasting station in India



Flood Level Forecast Stations are primarily the Flood EWS located in river basins that monitors and forecasts river water levels

Source: Author's analysis

However, aggregating the district-level availability scores at a state level presents a more comprehensive picture of the availability of flood EWS in India. The analysis found that 12 states in India were highly exposed to extreme flood events, and only 3 of these exposed states have a high availability of flood EWS, and 8 such states have low availability of flood EWS indicating a gap in the planning for installing flood monitoring and forecasting stations. Figure 12 represents the distribution of flood EWS across states based on their exposure to extreme flood events.

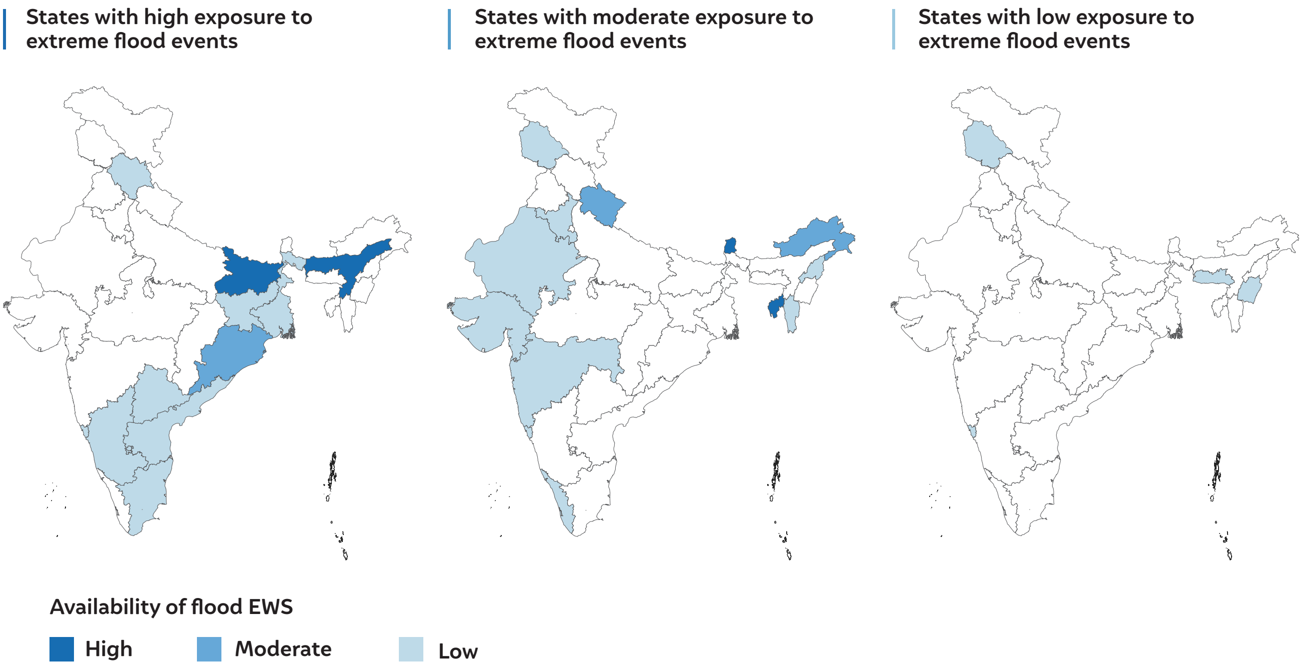
Further, the comparative analysis revealed that despite high exposure, the best-performing states were Assam, Bihar, Uttar Pradesh, Odisha, and Sikkim. In contrast, states such as Tamil Nadu, Himachal Pradesh, Karnataka, and Telangana had the lowest availability of flood EWS (Level flood forecasting stations).

Approximately 97.51 million people in India are exposed to extreme flood events in India (Mohanty 2020), and most districts are exposed to more than one extreme event. This highlights the importance of making EWS available to all in India, especially in the states and districts most exposed to its impacts. Annexure I (Table A1) presents the comparative analysis of states in terms of the availability of flood EWS and their respective exposure to extreme flood events.

Availability of cyclone EWS

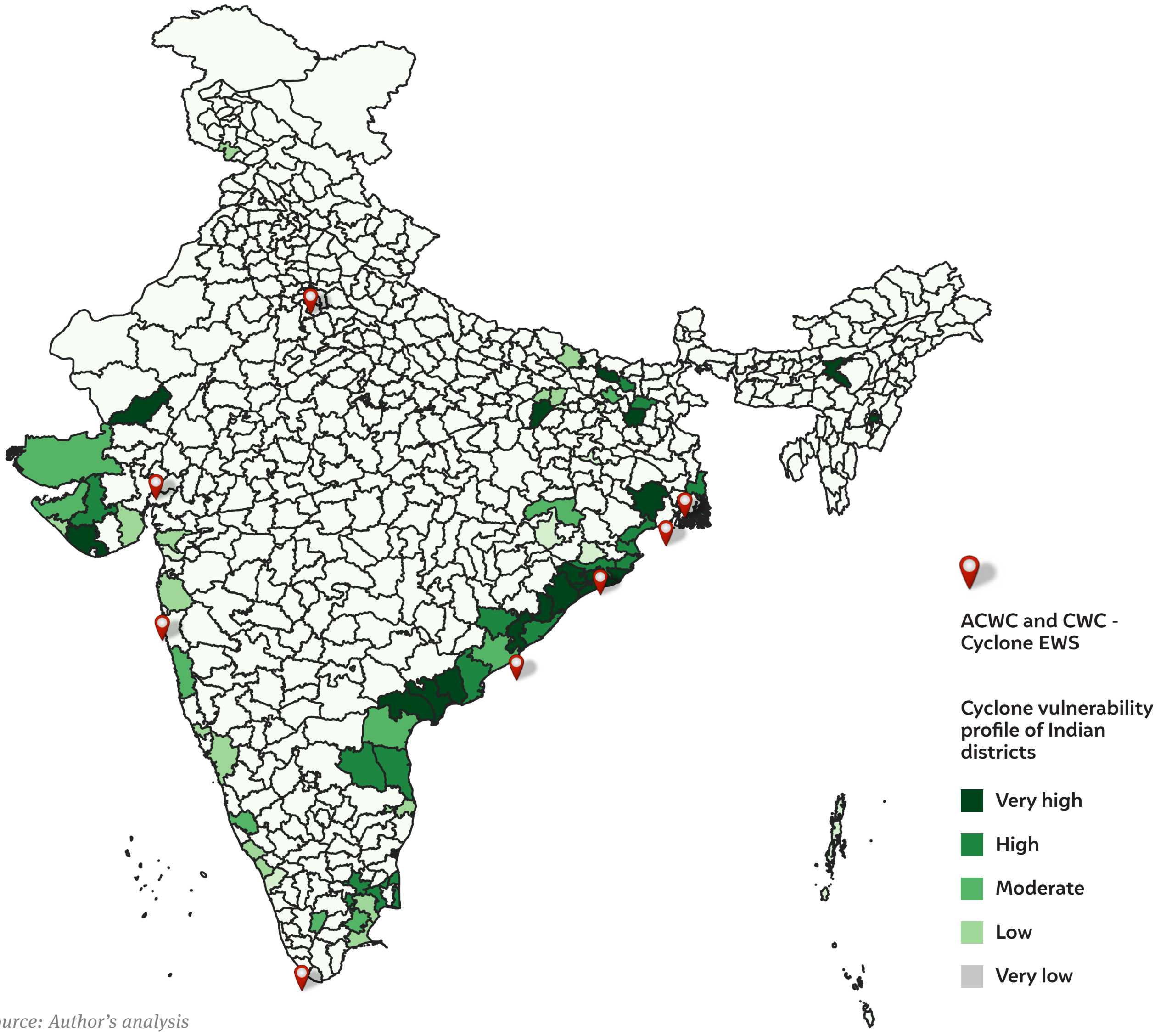
At present, Cyclone warning centres (CWCs) and Area cyclone warning centres (ACWCs) are installed across 11 states in India. However, as cyclone warning centres cover a larger area for information dissemination than flood forecasting stations, they can provide early warning to a larger population cluster. Our analysis found that the availability of the present cyclone EWS covers 100 per cent of the exposed population. In India, 25 per cent of the population is exposed to cyclones and their impacts, however, cyclone warnings are available to more than the exposed population. This makes the cyclone EWS highly impactful in India as they can provide information to all the exposed population. Figure 13 offers a spatial distribution of cyclone EWS across cyclone-prone districts in India.

Figure 12 Eight highly exposed states in India have low availability of flood EWS



Source: Author's analysis

Figure 13 Cyclone early warning stations are available to all exposed districts in India



Source: Author's analysis

The best-performing states, despite high exposure, are Andhra Pradesh, Goa, Karnataka, Kerala, Odisha, Tamil Nadu, and West Bengal. Whereas states such as Bihar, Assam, Jharkhand, and Rajasthan do not have direct availability of cyclone early warning stations. This highlights the importance of installing cyclone EWS across all the coastal states in India, especially in the states and districts most exposed to its impacts. Annexure I (Table A2) presents the comparative analysis of states in terms of the availability of cyclone EWS.

3.2 Accessibility to EWS

More than 88 per cent of Indian states that are exposed to floods, and 100 per cent of the states exposed to extreme cyclone events have a high teledensity ratio. This suggests that most of India's exposed population can access early warning information through a mobile or telephone connection. However, to access this information, EWS and EWDS must be available. Therefore, the possibility of making information accessible is quite high, i.e., if EWS is made available, the infrastructure to reach the masses already exists. Annexure I (Tables A3 and A4) presents the comparative analysis of states in terms of availability vs accessibility to floods and cyclone EWS, respectively.

3.3 Effectiveness of EWS

Effectiveness of flood EWS in India

This study found that 24 out of the 32 states exposed to extreme flood events mention institutional mechanisms and their roles within the elements of the EWS in their state disaster management plans. These plans identify and acknowledge the importance of flood monitoring stations in effective DRR. Further, the plans of these states establish mechanisms and frameworks for different hazard warnings and dissemination. They also explain the roles and responsibilities of various agencies and early warning centres. These states also cite implementation strategies for the deployment of EWS and EWDS for information dissemination in their administrative boundaries.

However, only 6 flood-exposed states have a moderate utilisation of funds allocated for establishing flood EWS and the remaining 26 states have a low utilisation of funds. This indicates a gap in various issues related to budgeting, implementation, and effectiveness of government spending towards building resilience through EWS.

An inefficient or ineffective government spending further indicates that the government has allocated funds for a particular purpose but is not using them. It may be an indication that the government is not efficient in its spending or that the funds are not being used effectively to achieve the intended goals. Low utilisation of funds may also indicate:

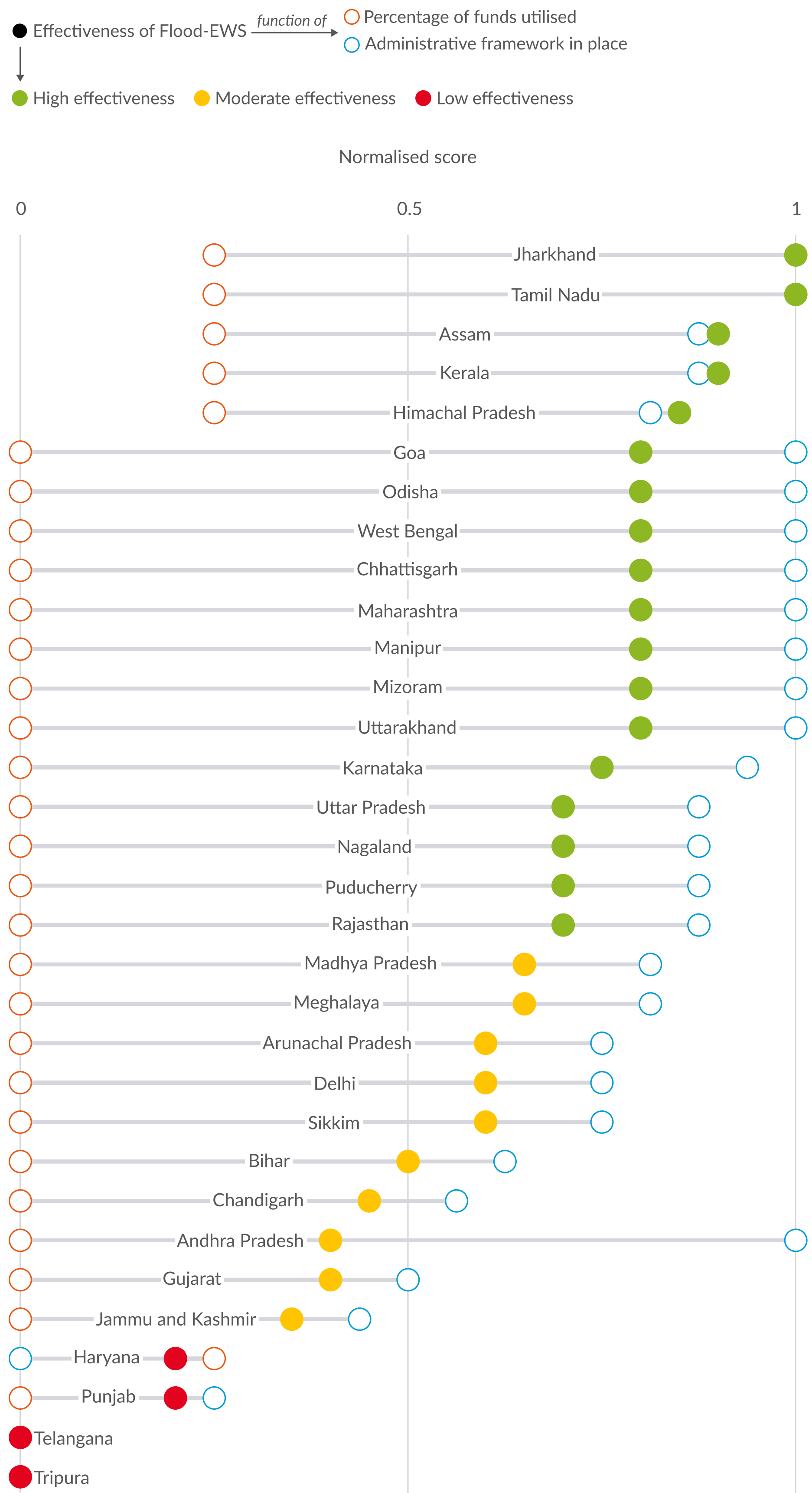
- A lack of demand for the services or programmes that the funds were intended to support;
- The programme is not meeting the needs of the population, or that there is a lack of awareness of the programme;
- Inadequate budgeting as the government may have allocated too little money for a particular programme or project, making it difficult to fully implement or achieve its goals;
- Delays in implementation, such as administrative delays.

After a thorough assessment of the financial and administrative frameworks in the Indian states for establishing flood EWS, we found that nine states with high exposure to extreme flood events also had a highly effective flood EWS in place. This indicates that nine highly exposed Indian states identified, acknowledged, established, and implemented a mechanism for installing flood monitoring and EWS stations. Annexure I (Table A5) provides an overview of the effectiveness of flood EWS in Indian states based on the financial and administrative frameworks established for their implementation. Figure 14 illustrates the administrative and financial effectiveness of flood EWS in Indian states.

Image: iStock

Emergency response by the community in the state of Kerala during the 2018 floods.

Figure 14 **Only six Indian states have moderate utilisation of funds allocated for flood EWS**



Source: Author's analysis

Effectiveness of cyclone EWS in India

This study found that 14 of the 17 states exposed to extreme cyclone events have effective administrative frameworks in place that mention institutional mechanisms and their roles within the elements of the EWS in their state disaster management plans. These plans identify and acknowledge the importance of cyclone monitoring stations in effective DRR. Further, the plans of these states also direct the establishment of mechanisms and frameworks for different hazard warnings and dissemination and explain the roles and responsibilities of various agencies and cyclone and area cyclone warning centres. These states also cite implementation strategies for the deployment of CWC and ACWC for information dissemination in their administrative boundaries.

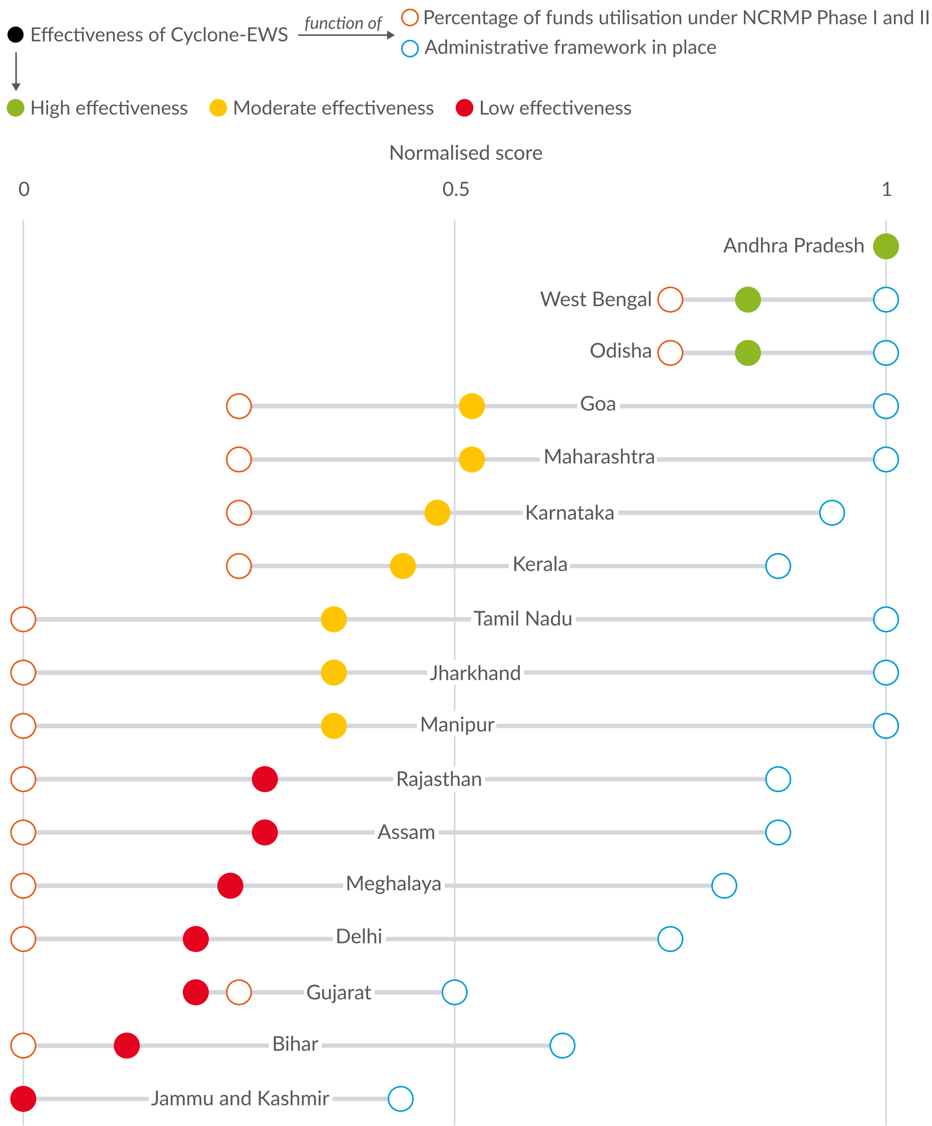
Odisha, Andhra Pradesh, and West Bengal have high utilisation of funds allocated for establishing cyclone early warning stations, and states such as Goa, Maharashtra, Karnataka, Kerala, and Gujarat have low utilisation of funds as reported under the *National Cyclone Risk Mitigation Project* (NCRMP) Phases I and II respectively. However, no data is available for states such as Tamil Nadu, Jharkhand, Manipur, Rajasthan, Assam, and others. Under the NCRMP Phase I, only Odisha and Andhra Pradesh were covered. In Phase II, funds have been released to establish cyclone warning stations in Maharashtra, Goa, Gujarat, West Bengal, Karnataka, and Kerala.

Ten states with moderate to high exposure to extreme cyclone events have a moderate to highly effective cyclone EWS in place. This suggests that ten Indian states have identified, acknowledged, established, and implemented a mechanism for installing CWCs and ACWCs in their administrative boundaries. Annexure I (Table A6) provides an overview of the effectiveness of cyclone EWS in Indian states based on the financial and administrative frameworks established for their implementation.

Furthermore, no data was available for union territories such as the Andaman and Nicobar Islands, Lakshadweep, and Daman and Diu. Therefore, they have not been taken into consideration for cyclone EWS analysis. Figure 15 illustrates the administrative and financial effectiveness of cyclone EWS in Indian states.

Boats being covered as a preparedness measure after receiving early warnings for an incoming cyclone.

Figure 15 **Ten cyclone-exposed states also have a moderate to high effectiveness of cyclone EWS**



Source: Author's analysis

Early warnings being provided to communities through sirens and loud speakers.

BOX 2 The crucial role of cell broadcasting technology in early warning systems

Cell broadcasting technology plays a crucial role in early warning systems, serving as a powerful tool for disseminating critical information to a wide population within seconds. Its significance lies in its ability to deliver urgent alerts, such as natural disasters, public safety threats, and emergency situations, directly to mobile devices in specific geographical areas. By leveraging the ubiquity of mobile networks, cell broadcasting ensures that vital notifications reach individuals regardless of their location or network provider, enhancing the effectiveness and reach of early warning systems. This technology aids swift evacuation, enables prompt response coordination, and empowers individuals to make informed decisions during crises, ultimately saving lives and mitigating the impact of climate extremes.

Further, a Gazette passed by the Ministry of Communications, Government of India on 6 April 2023 makes it mandatory for all manufacturers smart phones and feature phones to include the following services:

(a) mandatory support to receive cell broadcast messages in English & Hindi languages;

(b) storing received cell broadcast messages for at least twenty-four hours, subject to the memory of the feature phone;

(c) maintaining cell broadcast messages on the screen until acknowledged by the user;

(d) alert sound, vibration and light duration for at least thirty seconds; and

(e) mandatory mentioning of cell broadcast capability in feature lists and user manuals to increase customer awareness.

Additionally, the manufacturer of mobile phone handset and the mobile handset operating system developer shall explore that the smart phone, which have been sold in India within four years prior to such commencement, have the facility to receive cell broadcast messages and auto read out feature, in all Indian languages as per Eighth Schedule to the Constitution of India.

These guidelines will come into effect within six months from the commencement of these rules (Department of Telecommunications, Notification, April 2023).

Source: Author's compilation

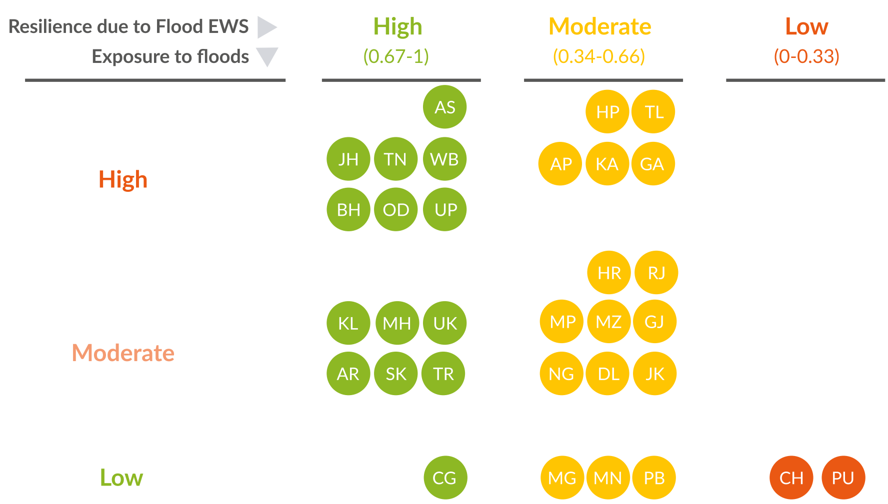
3.4 Vulnerability to resilience ratio

Resilience through flood EWS in India

This study found that 14 out of the 32 states exposed to floods have a high resilience. In comparison, 16 states have a moderate resilience owing to the availability, accessibility, and effectiveness of flood EWS. Figure 16 illustrates the resilience of exposed Indian states due to flood EWS.

Assam, Odisha, Sikkim, Uttar Pradesh, Uttarakhand, Jharkhand, and Kerala are leading in terms of building their resilience through flood EWS. Table 2 presents a comparative ranking of Indian states based on their exposure to floods and their resilience through flood EWS.

Figure 16 Fourteen Indian states exposed to floods have a high resilience due to flood EWS



Source: Author's analysis

Note: CG - Chhattisgarh; CH - Chandigarh

Table 2 Ranking of Indian states based on their exposure to floods and their resilience through flood EWS

S No.	State	Exposure	Final score (Resilience)	Level of resilience	Rank
1	Sikkim	Moderate	0.87	High	1
2	Uttar Pradesh	High	0.82	High	2
3	Assam	High	0.80	High	3
4	Odisha	High	0.77	High	4
5	Uttarakhand	Moderate	0.77	High	4
6	Jharkhand	High	0.75	High	5
7	Tamil Nadu	High	0.75	High	5
8	Kerala	Moderate	0.72	High	6
9	Arunachal Pradesh	Moderate	0.70	High	7
10	Chhattisgarh	Low	0.68	High	8
11	Maharashtra	Moderate	0.68	High	8
12	West Bengal	High	0.68	High	8
13	Bihar	High	0.67	High	9
14	Tripura	Moderate	0.67	High	9
15	Himachal Pradesh	High	0.62	Moderate	10
16	Goa	High	0.60	Moderate	11
17	Manipur	Low	0.60	Moderate	11
18	Mizoram	Moderate	0.60	Moderate	11
19	Karnataka	High	0.58	Moderate	12
20	Nagaland	Moderate	0.57	Moderate	13
21	Rajasthan	Moderate	0.57	Moderate	13
22	Madhya Pradesh	Moderate	0.55	Moderate	14
23	Meghalaya	Low	0.55	Moderate	14
24	Andhra Pradesh	High	0.55	Moderate	14
25	Gujarat	Moderate	0.55	Moderate	14
26	Delhi	Moderate	0.53	Moderate	15
27	J & K	Moderate	0.53	Moderate	15
28	Haryana	Moderate	0.40	Moderate	16
29	Punjab	Low	0.40	Moderate	16
30	Telangana	High	0.33	Moderate	17
31	Puducherry	Low	0.23	Low	18
32	Chandigarh	Low	0.15	Low	19

Source: Author's analysis

Resilience through cyclone EWS in India

The study found that 9 out of 17 states exposed to cyclones and their associated events have a high resilience, while the rest have a moderate resilience owing to the availability, accessibility, and effectiveness of cyclone and area cyclone EWS. Figure 17 illustrates the resilience of exposed states due to cyclone EWS.

Andhra Pradesh, Odisha, Goa, Karnataka, Kerala, and West Bengal are leading in terms of building their resilience through cyclone EWS. Table 3 presents a comparative ranking of Indian states based on their exposure to cyclones, their associated events, and resilience through cyclone EWS.

Figure 17 All states exposed to cyclones have moderate to high resilience due to cyclone EWS

Source: Author's analysis

Note: CG - Chhattisgarh; CH - Chandigarh

Table 3 Ranking of Indian states based on their exposure to cyclones and their resilience through cyclone EWS

S No.	State	Exposure	Final score (Resilience)	Level of resilience	Rank
1	Andhra Pradesh	High	1.00	High	1
2	Goa	High	0.95	High	2
3	Karnataka	High	0.95	High	2
4	Kerala	High	0.84	High	3
5	Odisha	High	0.84	High	3
6	Tamil Nadu	High	0.83	High	4
7	West Bengal	High	0.81	High	5
8	Maharashtra	Moderate	0.79	High	6
9	Gujarat	Moderate	0.79	High	6
10	Manipur	Low	0.45	Moderate	7
11	Meghalaya	Low	0.43	Moderate	8
12	Assam	Moderate	0.43	Moderate	8
13	Jharkhand	Moderate	0.41	Moderate	9
14	Rajasthan	Moderate	0.40	Moderate	10
15	Bihar	High	0.40	Moderate	10
16	Delhi	Moderate	0.37	Moderate	11
17	J & K	Moderate	0.33	Moderate	12

Source: Author's analysis

4. Recommendations to build resilience in India through EWS

To build an effective people-centred EWS at the national and sub-national levels, bridge gaps in global capacities, strengthen scientific and data foundations for early warning, and develop the institutional foundations for a robust and resilient EWS, the following measures are being recommended:

4.1 States should mainstream inclusive, impact-based, and community-led MHEWS

The success of any MHEWS relies on its close integration with communities (UNDRR 2022). Regular and inclusive engagement with communities will facilitate trust and positive relationships between programme implementers and community members. Community engagement is vital to enhancing the success of MHEWS initiatives. The more inclusive it is, the more likely initiatives will be sustainable and reflect the needs and priorities of all community members, including diverse groups of different ages, sexes, disabilities, literacy levels, languages, geographic locations, and socio-economic positions. Indian states can learn from Bangladesh, which has one of the most comprehensive MHEWS in the world, known as the Community-Based Early Warning System (CBEWS). The system provides weather and flood forecasting as well as warnings for landslides, earthquakes, and tsunamis. Using community connections and networks that already exist can also enhance community cohesion. Leveraging self-help groups and identifying youth volunteers within communities could also help achieve last-mile connectivity.

Further, for any early warning to reach the last mile or the most remote and vulnerable individuals of a community, it is crucial to **establish effective and innovative IEC** (information, education, and communication). Spreading scientific alerts and warnings in vernacular languages using simple, colour-coded messages can be lifesaving. Further, socialising dos and don'ts in an understandable, simple, and user-friendly format can help spread awareness among varying age groups. Such initiatives can be easily promoted through social media channels, emails, radio, bulk text messages, mobile applications, and other similar channels. The information must be easy

> **The benefit-cost ratio is between USD 24 and 73 for investing in community-based flood EWS (Rai, et al. 2020).**

to understand and relatable. For example, instead of telling people what the weather might be like, explain what the weather could do to them. The existing system is well established, but the information provided by warning stations is too technical for ordinary people to understand.

4.2 States should strengthen EWDS by leveraging new-age technologies

The primary purpose of any EWDS is to establish a fool-proof communication system to address gaps in disseminating disaster warnings by strengthening the state emergency operation centre (SEOC), district emergency operation centre (DEOC), and block emergency operation centre (BEOC), thereby ensuring information dissemination from the state, district, and block levels to communities and vice versa, so that the last person living nearest to the sea is well informed to take appropriate action in case of a cyclone or any other disaster (OSDMA 2021). However, to safeguard lives and reduce vulnerability, it is essential to strengthen the telecommunication systems that deliver warning messages to exposed populations. Hence, leveraging the existing high scope of teledensity, mobile connectivity, sirens, and other means to communicate information form a key component of effective DRR and robust end-to-end information dissemination.

Utilising advanced information and communication technologies has the potential to make MHEWS available across national borders. These technologies offer several advantages, including low deployment costs and smart and efficient alert and information dissemination. Notably, technologies such as the Internet of Things (IoT) and artificial intelligence can greatly aid in monitoring, forecasting, and generating alarms for EWS. They provide the necessary tools for processing and analysing environmental data (Rangra 2022). IoT systems generate data that can be instantly accessed by real-time warning applications. There are also infrastructures that support communication between interconnected objects, making their management, data mining, and access to data that much easier (Dorsemaine 2015). In the context of early warning, IoT solutions can prove highly effective in data collection, transmission, and disaster prediction, while still being highly cost-effective. Therefore, it is advisable to incorporate wireless sensor networks, cloud solutions, machine learning, and other elements of the Internet of Things when implementing EWS or integrating them into existing systems.

4.3 States and the centre should invest in regional real-time flood monitoring microsensors

India has a proposed outlay of INR 15,000 crore for the *Flood Management and Border Area Programme* (FMBAP) for 2021–26 (Niti Aayog 2021). However, the lack of impact-based forecasts that identify risks, the lack of scientific data on the effectiveness of warning systems, and the lack of localised action plans limit the effectiveness of India's flood EWS (Deshpande 2022). A more integrated effort is needed to build a robust system that can accurately forecast floods at least 48–72 hours before the event occurs.

To do so, India needs to invest in real-time flood monitoring sensors at the regional level. Low-cost microsensors installed at a regional level based on the regions' exposure to flood events will enable accurate and real-time collection of data. This can be shared with the CWC and combined with their flood monitoring data to make flood forecasts more targeted and accurate.

For example, the Karnataka State Natural Disaster Management Centre (KSNDMC) has installed 132 water-level sensors in highly vulnerable and vulnerable areas prone to flooding in the state to find a technology-driven solution to urban flooding (*The Hindu* 2022). The decentralised sensors can be financed following a similar model to the NCRMP, where the centre and states pool funds to establish regional real-time flood monitoring sensors. Further, establishing data standardisation protocols for easy data sharing across state and central agencies will make the system even more efficient.

4.4 States and the centre should promote public–private partnerships to enhance MHEWS efficiency

Improving the quality of services and related infrastructures, especially in LDC and SIDS countries, requires investments worth USD 1.5 billion in 2022–2027 (WMO 2022). Thus, to increase the availability and accessibility of EWS and MHEWS, nations need to

> **95% of the world's population has access to mobile broadband networks (ITU 2023).**

acknowledge the role of private-sector companies in mobilising funds, bringing more transparency and accountability to the flow of finance towards EWS.

Data analysis and modelling, combined with the effective use of technology, contribute to resilience and preparedness by providing data-driven insights that can be communicated to the population and authorities on time. To ensure maximum effectiveness, it is important to choose alerting technologies based on their global adoption, reputation, experience, implementation history, global footprint, and capacity for insights. Collaboration with private companies with expertise in EWS and MHEWS can help in identifying the best technologies to adopt and maximise resilience against climate and other hazards. Private companies also have a significant role to play in developing innovative technologies and platforms for effective DRR and can play a crucial role in achieving last-mile connectivity. They will further encourage inter-agency cooperation and will assist government organisations by avoiding duplication of efforts related to the establishment of MHEWS and enable easy replication of best practices across states and regions.

4.5 Leveraging knowledge transfer through international collaboration

India has the potential to greatly benefit from knowledge transfer through international collaborations such as the Conference of Parties (COP) and the Group of Twenty (G20). By actively participating in these global platforms, India can tap into the expertise and experiences of other countries in effectively establishing and operating EWS. These collaborations can provide an opportunity for India to learn from the best practices, technological advancements, and innovative approaches adopted by other nations to strengthen their resilience against various hazards, including natural disasters, climate change impacts, and pandemics.

Through knowledge transfer, countries can acquire valuable insights on the design, implementation, and maintenance of EWS and MHEWS. Enabling channels of inter-country collaboration can enhance the understanding of the key components required for an effective EWS. This can be achieved by providing knowledge about data collection and analysis, risk assessment, information dissemination mechanisms, and community engagement strategies. This knowledge exchange can also facilitate the adoption of cutting-edge technologies and tools for the early detection and monitoring of potential threats, enabling India and other countries to respond more proactively and mitigate the impacts of disasters. Additionally, international collaborations can assist India in capacity building and providing training opportunities for experts and officials involved in managing EWS, thereby strengthening the nation's overall preparedness and response capabilities. Further, such collaboration presents an opportunity to share knowledge and experiences from diverse Indian landscapes.

5. Conclusion and the way forward

India's cyclone EWS fare much better in reducing impacts and building resilience as compared to its flood EWS. This can be due to the pioneering work by the IMD and NDMA under India's NCRMP, which covers six coastal states and has an outlay of INR 2,059 crore. Of this, INR 126 crore has been set aside for creating and operating early warning dissemination systems (Rajya Sabha 2022). Further, to improve on existing models of cyclone early warning and forecasting, INCOIS also set up a Storm Surge Early Warning System (SSEWS) for the Indian coasts, in collaboration with the IMD, to forecast cyclone-induced storm surges and inundation extent. Still in its second phase, the National Disaster Management Authority (NDMA) and the IMD have developed a web-based tool for forecasting the expected damage associated with the land falling cyclones over coastal districts. This is a step ahead to developing impact-based EWS.

The 1999 super cyclone that hit the coast of Odisha caused more than 10,000 fatalities. Many cyclones of similar intensity, such as Phailin (2014), Titli (2018), Amphan (2020), and Biparjoy (2023), have hit coastal states; however, casualties have been limited to double digits, suggesting that the cyclone EWS in India is highly effective. However, one lacuna that still exists is the gaps in providing timely communication of disaster warnings. According to data from the Rajya Sabha, deaths due to cyclonic storms increased between 2010 and 2021 (Rajya Sabha 2022), which can also be attributed to an increase in the population density of many districts in India. However, the government is also taking initiatives to strengthen EWDS. The NDMA has conceived a national-level project, Common Alerting Protocol Based Integrated Alert System (SACHET), aimed at integrating alert-generating agencies (IMD, CWC, INCOIS, DGRE, FSI), alert disseminating agencies (TSPs, TV, radio, cable TV, social media, Indian Railways, coastal sirens, GAGAN, and NavIC, etc) and the state disaster management authorities (SDMAs) on a Common Alerting Protocol (CAP) based platform. After successfully implementing its pilot project in Tamil Nadu, the government has sanctioned the pan-India implementation of Phase I of the CAP. The efficient workflow of this chain is monitored by disaster management authorities at the national as well as state levels (NDMA 2021).

India needs to invest more in comprehensive and community-based disaster risk management to ensure that climate change adaptation is incorporated into national and local DRR policies. EWS are saving more lives than ever before, but it is also true that more people are vulnerable to disasters because of the population increase in hazard-prone areas and the increasing intensity and frequency of hydrometeorological disasters. Despite the significant progress seen in strengthening EWS worldwide, often by making use of advances in science and technology, unmet needs remain. Significant gaps exist, especially in reaching the last mile – the most remote and vulnerable populations who require timely, understandable, and actionable warning information, but lack capacities to make use of the information (WMO & iN-MHEWS 2021). The resulting societal benefits of EWS have thus far been spread unevenly across regions, countries, and communities.

Ultimately, EWS is only one of the components of disaster preparedness. We need to also focus on climate-proofing infrastructure that might reduce disaster risk due to climatic extremes. Given the increasing frequency and intensity of climatic extremes, boosting EWS plays a crucial role in enhancing the climate resilience of people and infrastructure in high-exposure areas in India.

> **SACHET provides a converged platform for dissemination of targeted alerts to people in vernacular languages through SMS.**

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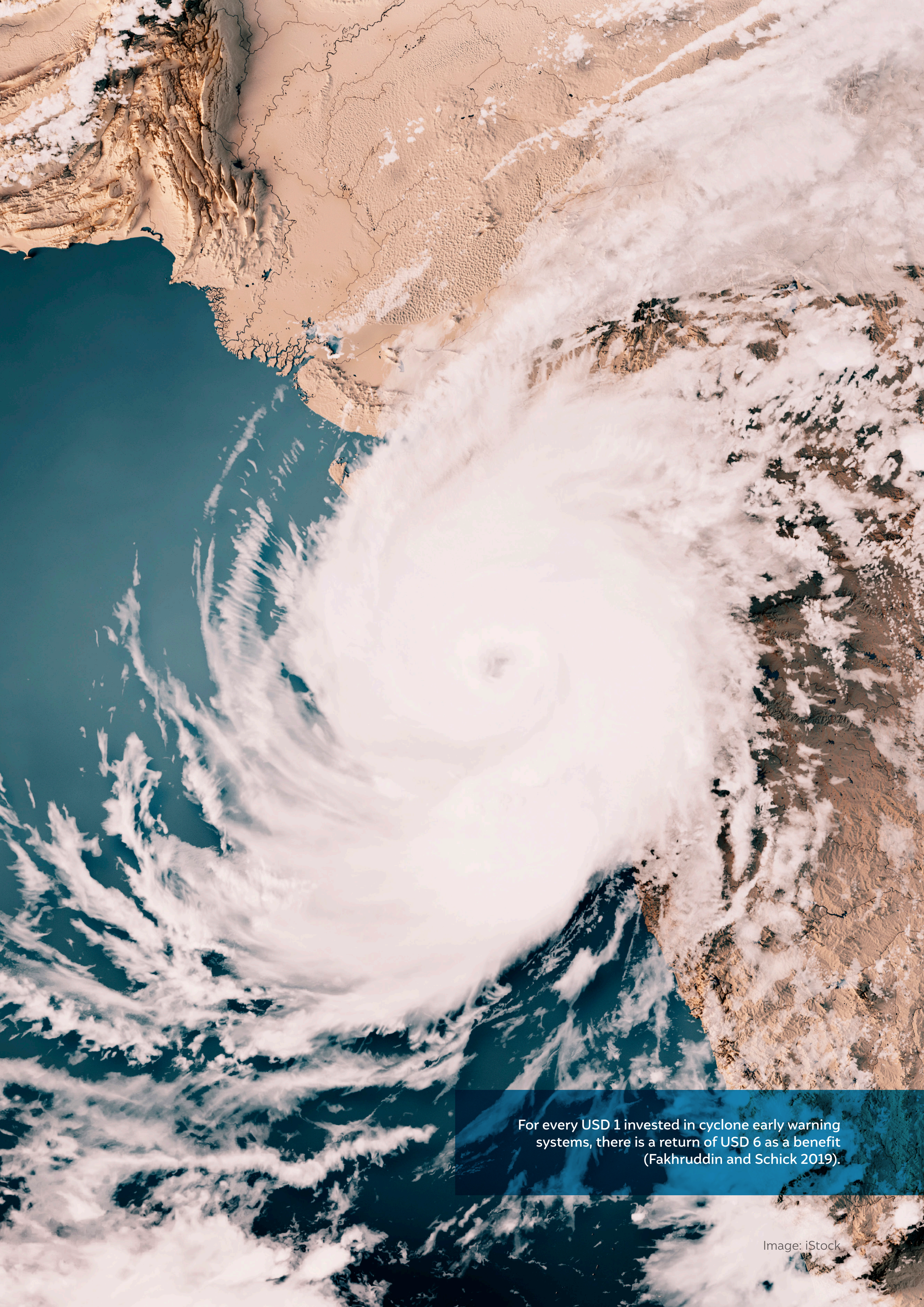
Acronyms

A2E	Availability, Accessibility, and Effectiveness of EWS/MHEWS
CAP	Common Alerting Protocol
CBEWS	community-based early warning system
CWC	Central Water Commission
DDMPs	district disaster management plans
DM	disaster management
DRPs	disaster response plans
DRR	disaster risk reduction
DST	Department of Science and Technology
EUMETNET	The Network of European Meteorological Services
EWDS	early warning dissemination systems
EWS	early warning systems
FMIS	Flood Management Information System
GRIP	Global Risk Identification Program
IEC	information, education, and communication
IMD	India Meteorological Department
INCOIS	Indian National Centre for Ocean Information Services
IPCC	Intergovernmental Panel on Climate Change
IWRSS	Integrated Water Resources Science and Services
LDCs	least developed countries
MHEWS	multi-hazard early warning systems
NCRMP	National Cyclone Risk Mitigation Project
NCS	National Centre for Seismology
NDMA	National Disaster Management Authority
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic Atmospheric Administration
NRSC	National Remote Sensing Centre, Indian Space Research Organisation
PIB	Press Information Bureau
SDGs	Sustainable Development Goals
SDMA	state disaster management authority
SDMP	state disaster management plan
SFDRR	Sendai Framework for Disaster Risk Reduction
SHGs	self-help groups
SIDS	small island developing states
SSEWS	Storm Surge Early Warning System
TRAI	Telecom Regulatory Authority of India
UNDRR	United Nations Office for Disaster Risk Reduction
V2R Model	Vulnerability to Resilience Model
WHO	World Health Organization
WMO	World Meteorological Organization

The author

Shreya Wadhawan
shreya.wadhawan@ceew.in I @Shreya_Wadhawan

Shreya is a Programme Associate with the Climate Resilience team at the Council. Her work focuses on spatio-temporal analysis that helps in designing decision-making tools for effective policymaking on the intricacies of climate change risks, sustainability, and environmental resources management. As part of her research projects, she has worked on air quality models, satellite data analysis, and spatial mapping at IIRS, ISRO.



For every USD 1 invested in cyclone early warning systems, there is a return of USD 6 as a benefit (Fakhruddin and Schick 2019).

Image: iStock

COUNCIL ON ENERGY, ENVIRONMENT AND WATER (CEEW)

ISID Campus, 4 Vasant Kunj Institutional Area
New Delhi - 110070, India
T: +91 (0) 11 4073 3300

info@ceew.in | ceew.in | @CEEWIndia | ceewindia