Making India's Healthcare Infrastructure Climate Resilient

A District-level Risk Assessment Framework

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By 2100, 1 in 12 hospitals in the world are at risk of shutting down due to extreme weather events (XDI 2023).

Image: Alamy

About CEEW

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top 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 is a strategic/ knowledge partner to 11 ministries for India's G20 presidency.

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The Council's major contributions include: Informing India's net-zero goals; work for the PMO on accelerated targets for renewables, power sector reforms, environmental clearances, *Swachh Bharat*; pathbreaking work for India's G20 presidency, the Paris Agreement, the HFC deal, the aviation emissions agreement, and international climate technology cooperation; the first independent evaluation of the *National Solar Mission*; India's first report on global governance, submitted to the National Security Advisor; support to the National Green Hydrogen and Green Steel Missions; the 584-page *National Water Resources Framework Study* for India's 12th Five Year Plan; irrigation reform for Bihar; the birth of the Clean Energy Access Network; the concept and strategy for the International Solar Alliance (ISA); the Common Risk Mitigation Mechanism (CRMM); India's largest multidimensional energy access survey (ACCESS); critical minerals for Make in India; India's climate geoengineering governance; analysing energy transition in emerging economies, including Indonesia, South Africa, Sri Lanka, and Viet Nam. CEEW published Jobs, Growth and Sustainability: A New Social Contract for India's Recovery, the first economic recovery report by a think tank during the COVID-19 pandemic.

The Council's current initiatives include: State-level modelling for energy and climate policies; consumer-centric smart metering transition and wholesale power market reforms; modelling carbon markets; piloting business models for solar rooftop adoption; fleet electrification and developing low-emission zones across cities; assessing green jobs potential at the state-level, circular economy of solar supply chains and wastewater; assessing carbon pricing mechanisms and India's carbon capture, usage and storage (CCUS) potential; developing a first-of-its-kind Climate Risk Atlas for India; sustainable cooling solutions; developing state-specific dairy sector roadmaps; supporting India's electric vehicle and battery ambitions; and enhancing global action for clean air via a global commission 'Our Common Air'.

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Every USD 1 invested in adaptation against extreme events could reduce India's annual disaster losses by USD 5.5 (UNESCAP 2022).

Image: Alamy

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Foreword

India is uniquely positioned at the confluence of rapid urbanization and increasing climate impacts. As its large population resides in districts susceptible to hydro-meteorological disasters such as floods, droughts, and cyclones, there is a pressing need to safeguard public health. Future projections of climate variables indicate that the frequency and intensity of extreme weather events and rainfall variability will continue to increase in both the short and long term. Consequently, the country's health infrastructure must be resilient enough to withstand climate shocks and cater to the growing healthcare demand to protect vulnerable populations. Therefore, there is an urgent need to focus on climate-proofing health infrastructure assets.

The National Programme on Climate Change and Human Health (NPCCHH), launched in 2019, strives to support State and District Health Departments in integrating green and climate-resilient measures into healthcare facilities. Given the extensive health infrastructure, prioritizing facility assessments and improvements requires careful planning and resource allocation.

I appreciate CEEW for their research and the development of a scalable assessment framework aimed at climate-proofing healthcare facilities. Drawing on the IPCC's AR5 Risk Assessment Framework, the report builds on with a focus on healthcare facility relevant indicators. The comprehensive study piloted in Maharashtra holds the potential to deliver crucial insights into the underlying strengths and vulnerabilities of healthcare facilities in India in the face of climate change.

Awareness of possible risks and developing a shared understanding of health facility resilience are key steps toward ensuring effective implementation of structural and operational measures. By sharing our experiences, expertise, and research outcomes, India has the potential to lead by example, thus contributing to the global discourse on building resilient healthcare systems. I am confident that this study will offer much-needed foresight and be instrumental in shaping future policies and practices for climate-resilient health facilities in India. I extend my best wishes for its optimal utilization.

Aakash Shrivastava

(Aakash Shrivastava)

National Programme on Climate Change and Human Health

55% of the amount allocated to the healthcare budget is spent through the *National Health Mission* (MoHFW 2024).

Image: iStock

Contents

In 2023 alone, a total of 79 hydro-meteorological hazard events were reported in Asia that directly affected nine million people (WMO 2024)

Image: Alamy

Executive summary

According to the World Meteorological Organization (WMO), Asia suffered more than 81 climate- and water-related – or hydro-meteorological – disasters in 2022, which caused economic damage of more than USD 36 billion (INR 2.9 trillion) (WMO 2022). India ranks as the seventh-most vulnerable country in the world with respect to climate extremes (Germanwatch 2020). Further, 80 per cent of its population resides in districts that are highly vulnerable to the impacts of extreme hydro-meteorological disasters such as floods, droughts, and cyclones (Mohanty and Wadhawan 2021). The occurrence of such disasters can trigger a series of cascading and compounding impacts. Rapid-onset disasters such as floods and cyclones can cause substantial physical damage to infrastructure assets, severely impacting critical[1] assets such as road networks, power systems, and healthcare facilities, magnifying disaster risks. According to the State Bank of India (SBI) ECOWRAP report, India suffered economic losses of INR 12 trillion due to floods and storms between 1900 and 2023 (State Bank of India 2023). Further, India's transport and power infrastructure sectors are estimated to suffer annual losses of INR 1.5 trillion due to extreme weather events such as floods and cyclones (World Bank 2019).

1 in 5 hospitals in Southeast Asia could be at risk of shutdown by century's end (XDI 2023)

Additionally, like in most countries in the Global South, India's disaster management framework primarily focuses on response, recovery, and relief rather than anticipatory action to reduce future losses (UNDRR 2023). Following the implementation of the *National Disaster Management Act, 2005*, India's disaster management plans, policies, and guidelines emphasise preparedness and recovery over mitigation and adaptation. Furthermore, departmental silos and the associated governance complexities further pose challenges for realising infrastructural resilience. The development of the most critical infrastructure assets such as healthcare, transportation, and water fall under the purview of the states, while disaster risk reduction and climate adaptation largely remain under the purview of the central government. This hinders the adoption of a holistic approach to resilient infrastructure development.

To develop context-specific adaptation solutions, India must identify and quantify physical risk at a granular level. This calls for a comprehensive risk assessment across critical infrastructure sectors, which will enable administrators, policymakers, and investors to make informed decisions and prioritise adaptation planning. Such a risk assessment will help policymakers prioritise spending on critical assets and streamline the implementation of adaptation measures, thus safeguarding current and future infrastructure investments. To help support this risk assessment exercise, we have developed a **first-of-its-kind, unified, and scalable risk assessment framework for climate-proofing critical infrastructure against extreme floods and cyclones**.

1 Critical infrastructures refer to the physical structures, facilities, networks, and other assets that provide services indispensable to the social and economic functioning of society and are necessary for managing disaster risk (CDRI 2023).

Building on the Intergovernmental Panel on Climate Change (IPCC) definition of risk, the framework has been designed to serve a dual purpose: (a) First, it quantifies and maps the risk to critical infrastructure geospatially at the district level; (b) Second, drawing insights from the risk assessment, it identifies risk drivers that can help decision-makers design and implement context-specific adaptation solutions at varying scales. This is crucial for prioritising infrastructure at risk, streamlining adaptation solutions through a needs-based approach, and minimising redundant investments.

A scientific risk assessment is the first step in climate-proofing. Risk mapping helps strengthen climate resilience by assessing the overall climate change risk at a granular scale. Therefore, the framework provides empirical data that can aid in selecting the most suitable adaptation measures for sustainable infrastructure development and prioritising the implementation of adaptation actions.

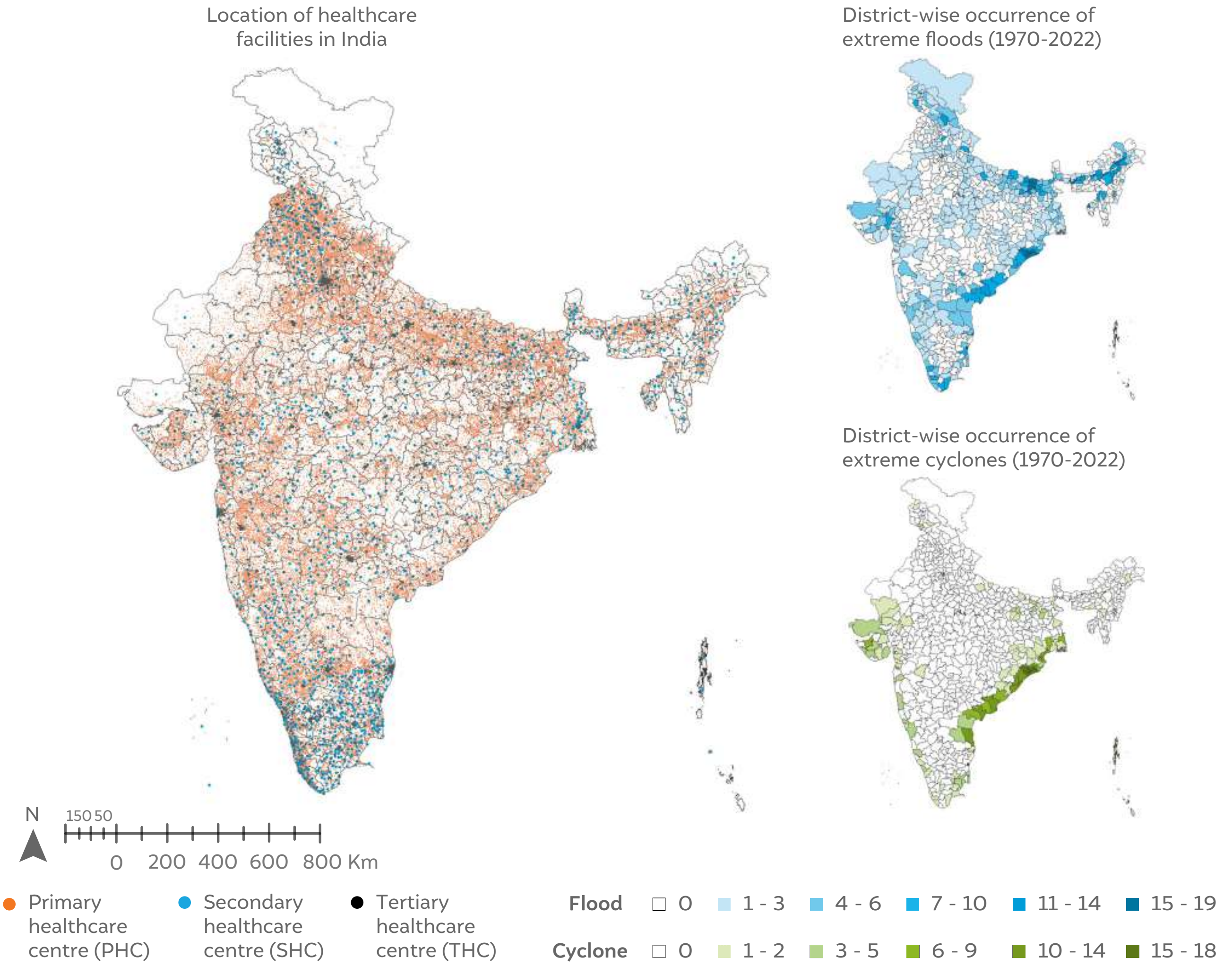
This report illustrates a case study on healthcare facilities, which play a pivotal role in safeguarding public health, bolstering economic resilience, and enabling efficient disaster response. India has more than 200,000 healthcare facilities (see Fig ES1). These comprise government facilities (primary, secondary and tertiary healthcare facilities) as well as private ones that are empanelled under government schemes or programmes such as *Ayushman Bharat*, *Pradhan Manti Jan Arogya Yojana* (PMJAY), and *Central Government Health Scheme* (CGHS). Therefore, a significant share of the Indian population depends on these healthcare facilities, many of which face risks due to extreme weather events or are likely to face them in the foreseeable future.

Further, the healthcare sector in India has witnessed a 14 per cent increase in expenditure over the past year underscoring the government's prioritisation of public healthcare and social security (PIB 2024). This underlines the need for a granular risk assessment of healthcare infrastructure to ensure that these investments are channelled wisely into establishing sustainable, efficient, and resilient healthcare services.

The Ministry of Health and Family Welfare launched the *National Programme on Climate Change and Human Health* (NPCCHH) in 2019

Image: iStock

Figure ES1 **India has more than 200,000 healthcare facilities, many of which are at risk due to extreme weather events***



Source: Authors' analysis

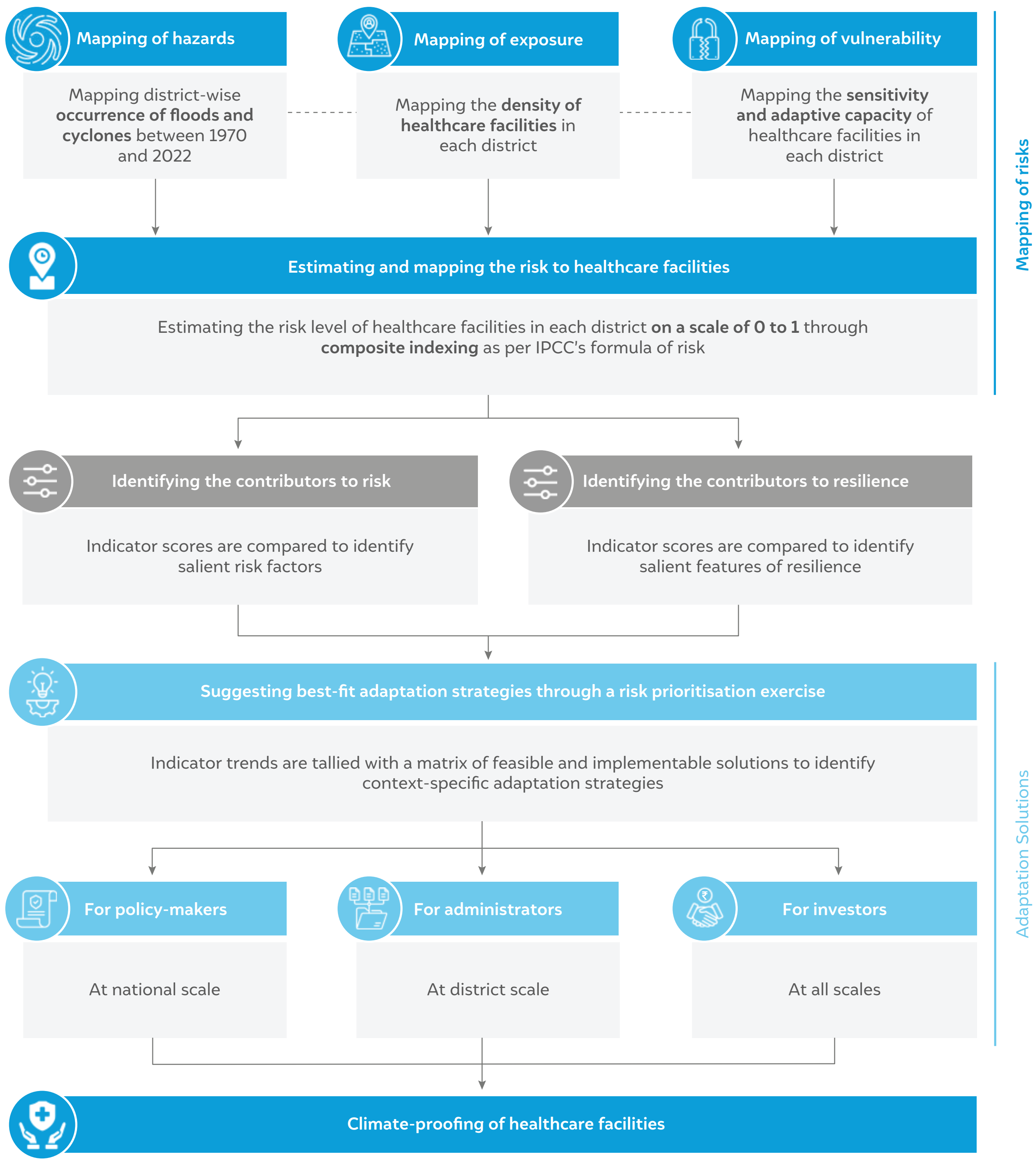
Addressing this need, the devised framework for climate-proofing healthcare facilities evaluates multiple indicators to assess each risk component and collates the risk score at a district level. In alignment with the IPCC formula, the framework defines risk to critical infrastructure as a function of three variables:

- **Hazard**: The historical or projected occurrence of floods and cyclones in a district;
- **Exposure**: The density of critical infrastructure assets in the district;
- **Vulnerability**: The likelihood of critical infrastructure assets in the district being adversely affected by extreme floods or cyclones.

The risk score, represented on a scale from 0 to 1, is estimated using a composite index-based methodology that combines the scores of each indicator in alignment with the IPCC risk formula. ES Figure 2 provides a snapshot of the risk-assessment framework.

* Please note: Healthcare facility locations are not unavailable for Pakistan Occupied Kashmir (POK).

Figure ES2 **Framework for climate-proofing healthcare facilities**



Source: Authors' analysis

The proposed framework was further tested through a pilot study in Maharashtra, which ranks third among the Indian states in terms of vulnerability to extreme hydro-meteorological disasters (Mohanty and Wadhawan 2021). The state houses more than 17,000 public healthcare facilities, which might face significant impacts due to the increasing occurrence and intensity of extreme weather events (EWEs) (PMGSY n.d.). This poses a substantial risk to the functioning of healthcare facilities during disasters. Maharashtra also houses one of the largest economies among the states in India, highlighting a need to protect its current and future infrastructural investments to safeguard the Indian economy as a whole (Government of Maharashtra 2023). Further, the Interim Budget 2024–25 has proposed allocating nearly INR 10,000 crore to improving healthcare facilities in the state presenting a unique opportunity to risk-proof its existing health infrastructure as well as incorporate risk-proofing in new facilities. This underscores the need to safeguard the state's economy and upcoming investments, which must be protected from disaster-induced losses to ensure maximum utilisation (TERI 2024).

India's healthcare budget increased by 12.9% in 2025, as funds for the *National Health Mission* increased by INR 4000 crore (PIB 2024)

Maharashtra has adopted exemplary steps to enhance the adaptive capacity of its healthcare system against the growing threats posed by climate change. The state ranks fourth as per Niti Aayog's Health Index, which tracks state-level improvements in key health outcomes improvements in key health outcomes (Niti Aayog 2022). Maharashtra has also submitted a revised version of its *State Action Plan on Climate Change and Human Health* (SAPCCHH) for 2022–2027, laying out a comprehensive roadmap to tackle climate-induced health risks. Additionally, regional initiatives such as the *Maharashtra Tertiary Care and Medical Education Sector Development Programme* in Raigad and Sindhudurg districts aim to strengthen tertiary healthcare services and ensure improved access to quality care (ADB 2023). These initiatives are especially timely as the state faces more frequent and intense extreme weather events, such as heavy rainfall, heatwaves, and cold waves, heightening the risks of vector-borne diseases (ADB 2023).

However, our key findings suggest that further action is necessary to safeguard healthcare facilities in the state, especially to reduce physical risks posed by increased extreme weather events such as floods and cyclones.

A. Key findings from Maharashtra

Risk level of healthcare facilities in Maharashtra

- **About 89 per cent of healthcare facilities in Maharashtra are not at immediate risk from floods and cyclones**. However, over **1,700** healthcare facilities in Maharashtra, representing **approximately 11 per cent of the total healthcare facilities in the state, are currently at high risk from floods and cyclones and require immediate action** (ES Figure 3). The at-risk facilities are concentrated in four districts: **Raigad, Mumbai Suburban, Mumbai, and Nagpur**. These facilities were identified by mapping historical trends of flood and cyclone occurrence (1990 and 2022), the exposure level of healthcare facilities in each district, as well as their level of vulnerability.
- **Over 5,500** healthcare facilities in Maharashtra, representing **33 per cent of the total healthcare facilities in the state (across 14 districts), are likely to experience high risk from floods and/or cyclones by 2050**, given the increasing occurrence of hazards and the adaptive capacity of the state's existing healthcare infrastructure. Healthcare facilities in these districts have underlying vulnerabilities stemming from low structural and functional capacities and low expenditure on maintenance and upgradation. Such vulnerabilities can magnify disaster risk, as annual heavy rainfall days are projected to increase by an average of 15 per cent between 2023 and 2050[2] (CEEW 2024).

2 Based on an RCP 4.5 scenario

Adaptive capacity of healthcare facilities in Maharashtra

- **Approximately 52 per cent of healthcare facilities in Maharashtra have moderate to high adaptive capacity**. The adaptive capacity score is representative of factors such as the adequacy of the healthcare system in the district, the preparedness of facilities against extreme weather events, and expenditure on structural upgradation. Mumbai, Sindhudurg, and Ratnagiri recorded the highest administrative capacity, indicating that healthcare facilities in these districts are better prepared for anticipatory action. Nashik, Aurangabad, Gadchiroli, and Pune have robust district disaster management plans (DDMPs) that contain relevant structural and non-structural strategies for improving healthcare resilience in the face of extreme climate events. These districts also recorded higher annual expenditures on strengthening the healthcare system (NHM PIP Budget 2023). Additionally, Pune and Kolhapur house the maximum number of hospitals in the state that have been accredited by the National Quality Assurance Standards (NQAS) and National Accreditation Board for Hospitals and Healthcare Providers (NABH), indicating their higher operational efficiency. Healthcare facilities in these districts can serve as leading examples for increasing adaptive capacity across the state.
- Despite exemplary efforts, healthcare facilities across 19 districts in the state observe low adaptive capacity. This comprises **approximately 8,400** healthcare facilities, representing **48 per cent** of the total. Facilities in these districts can improve their structural resilience by increasing their expenditure on structural upgradation. This can be achieved by utilising funds under the *National Health Mission*. Inspiration can be drawn from Nashik and Thane districts, where more than INR 10 crore was spent on structural upgrades in each district in the last financial year (NHM PIP Budget 2023). Districts can also improve the functional capacity of their healthcare facilities by increasing the number of NABH and NQAS-accredited hospitals. Additionally, preparing hospital disaster management plans that focus on managing the impacts of extreme weather events can improve administrative preparedness.

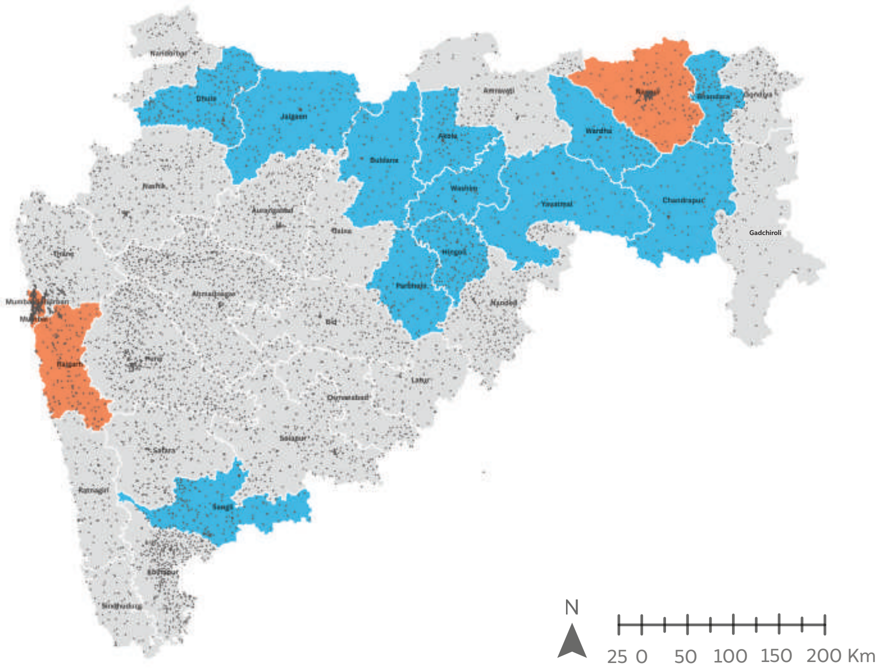
Figure ES3 **11% of healthcare facilities across four districts in Maharashtra are currently at high risk of floods and cyclones**

2022	**11%** of healthcare facilities are at **immediate risk** across	**4/35** districts in Maharashtra	The at-risk facilities are concentrated in four districts: **Raigad, Mumbai Suburban, Mumbai, and Nagpur**. These districts experience **frequent extreme floods and cyclones**, and **70–80 per cent** of their healthcare facilities are located in highly flood and/or cyclone-prone geographical locations, magnifying their risk.
	89% of healthcare facilities are **not at immediate risk** across	**31/35** districts in Maharashtra	Healthcare facilities in districts that observe a **low adaptive capacity and a growing trend in hazard** occurrence should undertake planned action by conducting **asset-level risk assessments** and identifying infrastructure corridors in safe locations.
2050	**33%** of healthcare facilities might be at **immediate risk** across	**14/35** districts in Maharashtra	**Annual heavy rainfall days are projected to increase by an average of 15 per cent between 2023 and 2050** (CEEW 2024). The projected increase in hazard occurrence and the adaptive capacity of the state's existing healthcare infrastructure leads to the projected risk scenario.

Source: Authors' analysis

- Healthcare facilities located in districts with a low adaptive capacity and high prevalence of floods and cyclones must take immediate action. These short-term actions can include structural audits of healthcare facilities, capacity-building of the healthcare workforce, and increasing investments in the operation and maintenance of facilities. Facilities in districts with a low adaptive capacity and increasing hazard occurrence should undertake planned action by conducting asset-level risk assessments and identifying infrastructure corridors in safe locations (see Figure ES4).

Figure ES4 Healthcare facilities across districts must undertake immediate actions, invest in long-term planning or sustain actions based on their risk profile



- Represents one healthcare facility
- Districts with healthcare facilities at moderate to high risk, requiring immediate action
- Districts with healthcare facilities having underlying vulnerabilities, requiring planned action to reduce future risk
- Districts with healthcare facilities observing increasing risk, requiring sustained action

Source: Authors' analysis

It is important to note that even healthcare facilities in well-performing districts can observe increasing risk levels, owing to the increasing frequency and intensity of extreme weather events. Therefore, sustained action is necessary to ensure that the adaptive capacity of the healthcare facilities in these districts also steadily increases over time. Maharashtra can thus secure the resilience of the state's healthcare facilities and safeguard crucial investments in healthcare infrastructure. The framework can accelerate states' efforts by helping identify risk drivers, streamline investments, and reduce damage and losses. By implementing the framework, Maharashtra can become a leading example for other states. Using insights from the Maharashtra use case, the study suggests national-, state-, and district-level recommendations to reduce risk for healthcare facilities across the country.

B. Key recommendations

- **The *National Programme on Climate Change and Human Health* (NPCCHH) should identify characteristics of healthcare infrastructure resilience:** Currently, the guidelines of the NPCCHH on *Green and Climate Resilient Healthcare* (MoHFW 2023) focus more on climate change mitigation than adaptation. The NPCCHH guidelines must be revised to include specific adaptation measures, to align with the objectives of the *National Health Policy*, which emphasises the importance of resilient healthcare infrastructure, especially during extreme climate events such as floods and cyclones. This report presents a checklist to assess asset-level preparedness and quantify healthcare facility resilience, which can be directly incorporated into the existing NPCCHH guidelines.

- **District health departments must assess risk and enhance the resilience of healthcare facilities at the local level:** A quantitative risk assessment helps identify healthcare facility vulnerabilities, aiding the section of risk-informed solutions. However, such an assessment must be conducted at the district scale, as local administrators will be aware of limiting factors such as cost, time, and resource availability, which will enable them to identify the most feasible solutions. Therefore, district-level health departments and local administrators should prioritise adaptation solutions based on on-ground realities to enhance solution specificity and optimise resource utilisation. An expert opinion survey was conducted to explore the influence of such parameters on the feasibility and impact of the selected adaptation strategies.
- **State health departments should mandate all the districts to assess risks at the asset level:** To accelerate action, state health departments should coordinate with stakeholders to define roles, set yearly targets, and monitor progress against key performance indicators (KPIs). By creating an inventory of data on climate-proofing healthcare infrastructure, they can track progress, realign objectives, and allocate funds based on priorities and the state healthcare budget.
- **The *Indian Public Health Standards* (IPHS) should be expanded to monitor the resilience of healthcare facilities:** The IPHS (MoHFW 2022), under the *National Health Mission* (NHM), can be expanded to include other factors that capture healthcare facilities' adaptive capacity. Mapping hospital locations will enhance the existing hospital database and complement the *IPHS Hospital Infrastructure Layouts* released in 2022 (MoHFW 2022). Additional data on building height, storeys, area, age, and maintenance records from district administrators should be used to conduct asset-level risk assessments to determine whether healthcare facilities are built and maintained in compliance with IPHS. This geospatial dataset can complement the IPHS. The Ministry of Health and Family Welfare (MoHFW) should invest in an online portal to enhance the management of healthcare infrastructure by using data-driven decision-making. District health administrators should be able to upload real-time status data to this portal, which in turn would enable continuous monitoring of healthcare facility resilience in line with the IPHS standards. By integrating these functions into a unified national platform, the system would support more efficient and effective oversight of healthcare facilities.
- **The *National Health Mission* should channel climate finance for healthcare infrastructure resilience.** The financial sector needs to be provided incentives to invest in climate-resilient infrastructure. The NHM offers financial assistance to states to improve the structural integrity of healthcare infrastructure. However, increased investments are needed to accelerate risk-informed decision-making and enhance the resilience of healthcare systems. Therefore, it is imperative to utilise innovative finance mechanisms to boost the volume of funds available.

Strengthening the resilience of healthcare infrastructure is a crucial step to building India's resilience to climate risks and safeguard future investments. Mainstreaming district-level risk assessments into national and state-level policies will be key to ensuring long-term preparedness against future climate-induced disasters. The pilot risk assessment in Maharashtra serves as an example for how states can adopt and operationalise risk-informed decision-making through a granular approach.

Only 20% of assessed facilities met the required benchmarks for healthcare infrastructure as per a survey by Indian Public Health Standards in 2024

1. Introduction

Image: iStock

India is experiencing varying impacts of climate change including rising temperatures, rainfall anomalies, and a surge in extreme weather events, affecting developmental outputs such as infrastructure, capital costs, labour productivity, and supply chains. The year 2023 served as a stark reminder of India's vulnerability to climate-induced disasters, as states such as Sikkim, Himachal Pradesh, and Rajasthan grappled with extreme floods. Many parts of the country are simultaneously experiencing heatwaves and deteriorating air quality (WMO 2022). Climate impacts can have significant economic costs – the northern Indian floods in 2023 are estimated to have resulted in economic losses in the range of INR 10,000 to 15,000 crore (SBI 2023). Such events not only cause short-term, high-impact destruction but also trigger long-term repercussions for the country's socio-economic landscape.

Being one of the fastest-growing economies globally, India's developmental trajectory stands in stark contrast to its on-ground reality. India is pursuing ambitious plans to invest in infrastructure projects, having pledged to invest INR 116.2 trillion in the sector from 2019 to 2023. In the 2023–24 Union Budget, the government announced a 33 per cent increase in capital investment for infrastructure development in India, amounting to INR 10000 billion (USD 122 billion), equivalent to 3.3 per cent of the country's GDP (Ministry of Finance 2023). In 2024, the central government further announced an increase of 11 per cent in capital expenditure on infrastructure development, with a particular emphasis on the road and power sectors (Ministry of Finance 2024). In addition, policies such as the *National Infrastructure Pipeline* (NIP) outline a strategic vision to boost the country's economic development through robust infrastructure, with projects worth INR 108 trillion (USD 1.3 trillion) at various stages of implementation. This investment is crucial for achieving India's economic growth target of INR 116.2 trillion by 2025 (PIB 2023).

India's healthcare sector is booming, with private equity and venture capital investments exceeding USD 1 billion in early 2024, up by 220% (IBEF 2024)

This surge in infrastructure projects has been catalysed by rapid urbanisation supported by large-scale investments. India's urban population is expected to grow up to 814 million by 2050, and half of the country's population would thus be living in cities (World Migration Report 2015). This is in line with the global megatrend, as 70 per cent of the global population is expected to reside in urban areas by 2050 (United Nations Statistics Division 2015) leading to a steep rise in the demand for infrastructure.

In 2023, the Coalition for Disaster Resilient Infrastructure (CDRI) estimated that an annual investment of USD 9.2 trillion will be needed to address the world's infrastructure deficit, realise the SDG targets, achieve net-zero emissions, and strengthen resilience by 2050 (McKinsey & Company 2022). Of this amount, up to USD 2.90 trillion must be invested in low- and middle-income countries (LMICs), which host nearly 84 per cent of the world's fastest-growing cities (UNDRR 2018) and therefore experience a surge in infrastructure demand. Thus, recognising the significance of infrastructure, the Indian government has made it one of its priority areas.

However, as India aspires to fortify its infrastructure, it grapples with the escalating impact of extreme weather and climate events. Natural disasters and climate change have dented India's infrastructure and buildings by causing huge annual average losses (AAL) worth INR 58 trillion (USD 700 billion) (CDRI 2023), which implies an urgent need to safeguard these investments against the growing impacts of climate change. The destruction of these crucial sectors not only hampers day-to-day operations but also places a substantial financial burden on the nation, necessitating climate-proofing our critical infrastructures.

1.1 Why should India invest in climate-proofing critical infrastructures?

As the world reaches the midpoint of the agreed timeframe for achieving the Sendai Framework for Disaster Risk Reduction (SFDRR) targets, progress towards all targets is being assessed. India, like many other nations, has grappled with its implementation. India's mid-term review shows that only a fraction of these goals have been achieved. In particular, progress has been slow under Target D[3], as an average of 142,582 critical infrastructure units and facilities have been destroyed or damaged by disasters annually between 2015 and 2021 (NDMA 2023). The Disaster Risk Reduction Working Group (DRRWG), an initiative led by India during its G20 presidency, indicates the global commitment towards making critical infrastructure systems resilient to disaster and climate change impacts. The DRRWG was formed as G20 countries face high exposure to disaster risks, with a combined estimated AAL of USD 218 billion (G20 India n.d.). This initiative also aligns with the prime minister's ten-point agenda, which emphasises incorporating disaster risk management principles in all development sectors (G20 India 2023).

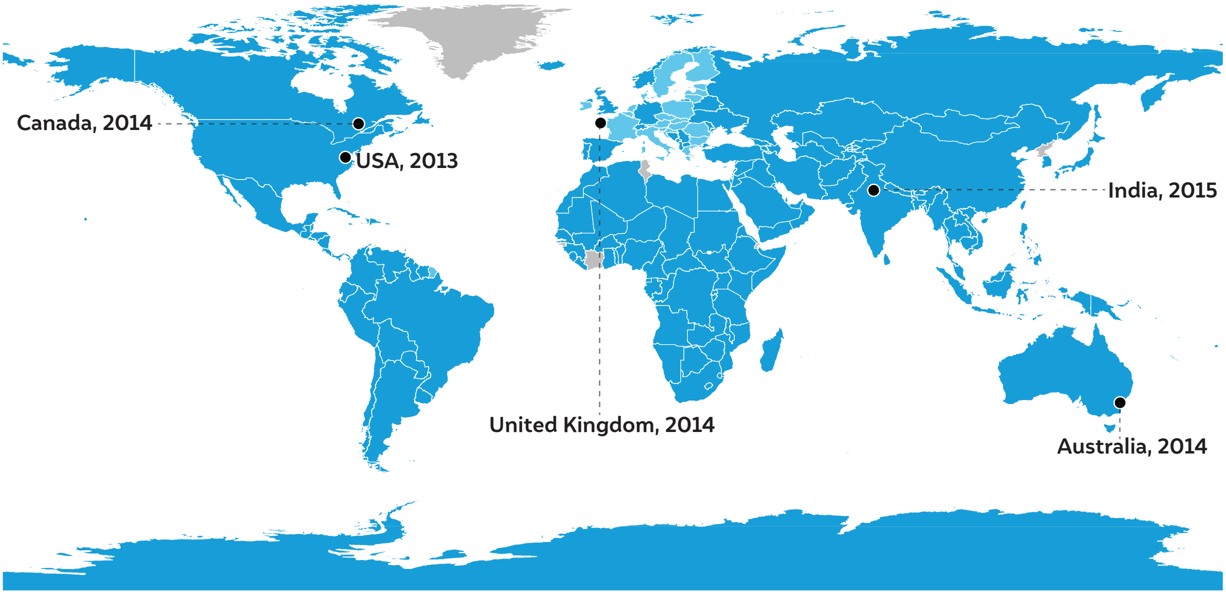
India's Union Budget 2024-25 has allocated INR 89.2 Crore, prioritising digital infrastructure for healthcare transformation

What are critical infrastructures? Even though the SFDRR focuses on "critical infrastructure", it refrains from establishing a definition, leaving it to national governments to decide which elements to include when reporting on progress. However, the SFDRR does identify some types of infrastructure as critical: water, transportation, and telecommunications infrastructure; educational facilities; hospitals; and other health facilities (UNDRR 2016).

While there is no universally agreed-upon definition of critical infrastructure, most definitions have a few common elements. However, as depicted in Figure 1, the term has gradually moved towards a unified global definition. As per the latest definition by CDRI, critical infrastructure refers to the **"physical structures, facilities, networks, and other assets that provide services that are indispensable to the social and economic functioning of society and are necessary for managing disaster risk"** (CDRI 2023). Further, critical infrastructures are identified as systems with heightened vulnerability to disruptions, which can lead to cascading and compounding effects in cases of failure. Therefore, to maintain the continuity of essential services, especially during extreme events and disasters, it is paramount to enhance the resilience of critical infrastructures.

3 Global Target D seeks to substantially reduce disaster-related damage to critical infrastructure and disruption of basic services, including healthcare and education, by developing their resilience by 2030 (UNDRR n.d.).

Figure 1 Local understanding of critical infrastructure moved towards a global definition with the conceptualisation of the Sendai Framework for Disaster Risk Reduction in 2015, comprising 187 UN member states



Local Definitions

2013

US Department of Homeland Security

The physical or virtual assets, systems, networks, and functions are so vital that their disruption would have a debilitating impact on security, the economy, public health and safety, or any combination of those matters.

2014

Australia, Canada, New Zealand, United Kingdom, United States

Critical infrastructure, also referred to as nationally significant infrastructure, can be broadly defined as the systems, assets, facilities, and networks that provide essential services and are necessary for the national security, economic security, prosperity, and health and safety of their respective nations.

2015

NCIIPC, India

Critical infrastructure comprises those facilities, systems, or functions, whose incapacity or destruction would cause a debilitating impact on national security, governance, economy, and social well-being of a nation.

Global Definitions

Sendai Framework, 2015

"Critical infrastructure, including water, transportation and telecommunications infrastructure, educational facilities, hospitals and other health facilities, to ensure that they remain safe, effective and operational during and after disasters in order to provide live-saving and essential services."

European Union, 2020

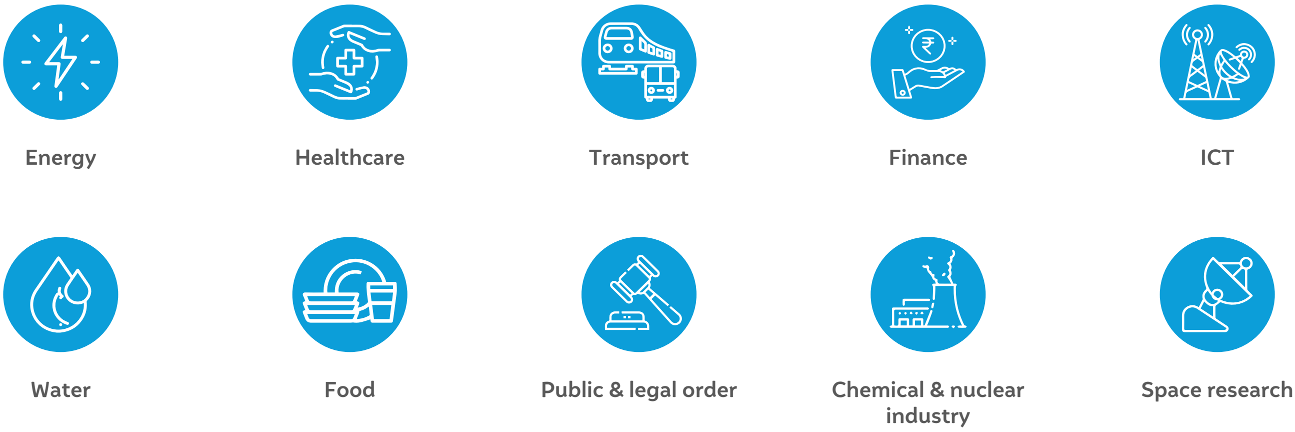
Critical infrastructure is the "physical and information technology facilities, networks, services and assets that, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic wellbeing of citizens or the effective functioning of governments in (EU) States"

Do not yet align with either definition

Source: Authors' compilation based on global definitions of critical infrastructure

In a recent training programme conducted by the National Institute of Disaster Management (NIDM) on "Critical Infrastructure Resilience to the Disasters" (2022), *critical infrastructures* were defined as **"the primary physical structures, technical facilities, and systems which are socially, economically, or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency"** (NIDM 2019). They further state that "critical facilities are elements of the infrastructure that support essential services in a society" and have identified the following sectors as critical (refer to Figure 2).

Figure 2 Critical infrastructure in India, as identified by the National Institute of Disaster Management in 2022

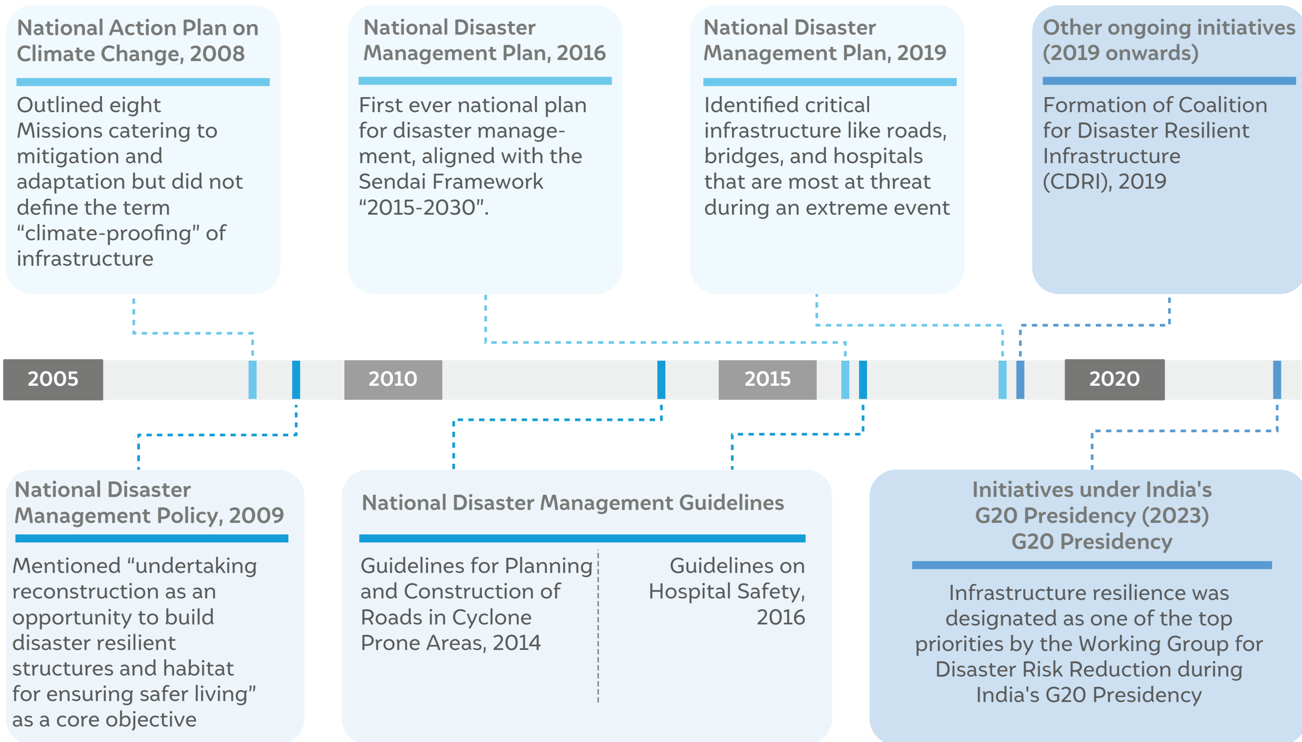


Source: Authors' compilation based on NIDM (2022)

1.2 India's journey towards climate-proofing its critical infrastructure

India's consistent efforts portray its attempts to incorporate resilience into infrastructure development. However, the complex and ambiguous nature of governance in this cross-cutting sector poses significant challenges (CDRI and The Resilience Shift 2021). As detailed by the Constitution of India, the development of most critical infrastructure falls under the purview of the states, while disaster risk reduction and climate adaptation remain the responsibility of the central government. Over the last two decades, several initiatives have been undertaken at every scale to improve the resilience of critical infrastructure (see Figure 3).

Figure 3 Over the last two decades, India has steadily progressed towards infrastructure resilience



Source: Authors' compilation

In 2005, the *National Disaster Management Act* introduced India's first legal mandate for building disaster resilience. In 2009, the *National Disaster Management Policy* cited "building disaster resilient structures and habitats to ensure safer living" as one of its core objectives, while the *National Disaster Management Plan* (2019) delineated critical infrastructure sectors and highlighted the need to review and maintain them during disasters. Although these documents provided the needed direction, the policy and the plan lacked actionable strategies to build the resilience of infrastructure systems on the ground (Jain and Bazaz 2017).

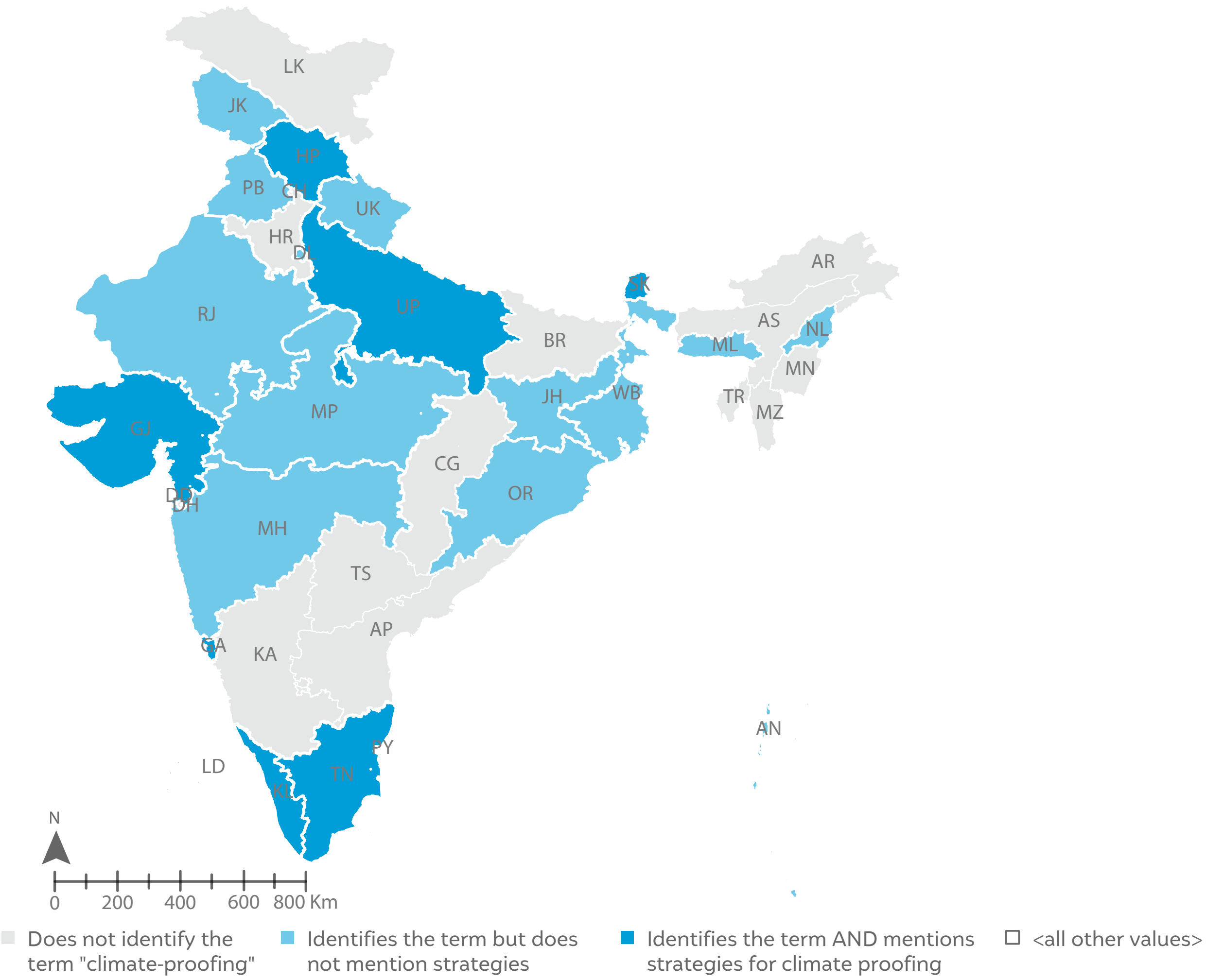
In contrast, the National Disaster Management Authority (NDMA) and the National Institute of Disaster Management (NIDM) developed the *National Disaster Management Guidelines* (National Disaster Management Act 2005). Some of these guidelines focus on critical infrastructure resilience such as ensuring hospital safety and road construction in disaster-prone areas, highlighting the ideal standards for infrastructure design, operation, maintenance, monitoring, and evaluation. However, in alignment with the objectives of the *National Disaster Management Act*, their approach leans towards disaster preparedness, response, and recovery rather than mitigation and adaptation, which are essential for preventing redundant investments amidst India's fast-urbanising landscape.

In 2008, the *National Action Plan for Climate Change* outlined a national strategy to adapt to climate change (PIB 2021). It contained eight National missions addressing mitigation and adaptation across sectors, which touch upon infrastructure resilience but do not identify it as a key priority. However, as states revise their state action plans for climate change (SAPCCs) and state disaster management plans (SDMPs), many subnational plans now refer to 'climate-proofing', while some also provide relevant strategies to climate-proof critical infrastructure assets (see Figure 4 and Box 1). Still, as the scope of these plans remains primarily restricted to state jurisdictions, they fail to delineate the role of decentralised government systems such as districts and cities or include other line departments (CSE 2019).

Moreover, as disaster management and climate action plans approach the infrastructure domain differently, their strategies lack the granularity required to address ground-level issues in infrastructure management. Additionally, infrastructure standards developed by industry-specific regulatory authorities do not follow a standardised approach and are not streamlined to adhere to international guidelines (Sapatnekar, Patnaik, and Kishore 2018). The lack of common standards and guidelines makes it difficult to mainstream risk reduction and resilience building in the infrastructure life cycle (CDRI 2021). Additionally, much of India's infrastructure had already been built by the time most standards and regulations came into force, creating systemic implementation issues, such as deciding how much of the existing infrastructure should be retrofitted (Sapatnekar, Patnaik, and Kishore 2018).

Annually, USD 9.2 trillion is required to close the global infrastructure gap, meet SDG targets, and achieve net-zero emissions by 2050 (CDRI 2023)

Figure 4 **Six out of thirty-six states in India have outlined strategies to climate-proof their infrastructure in their respective state climate action plans or state disaster management plans**



Source: Authors' analysis based on SAPCCs and SDMPs (published till December 2023)

In spite of such challenges, recent years have witnessed several fragmented efforts as national, state, and sector-specific authorities have attempted to address the risks posed to their respective infrastructure systems. For example, the Ministry of Power's *Disaster Management Plan 2021* serves as a blueprint for building resilience in the power sector (CEA 2022). It provides a hazard, risk, and vulnerability analysis for the power sector, identifying common risk drivers and characteristics of resilience. It also covers adaptation and mitigation solutions, including structural design standards and standard operating procedures. Similarly, the *Guidelines for Green and Climate-Resilient Healthcare Facilities* by the National Centre for Disease Control (NCDC) represent a positive step towards climate-proofing India's healthcare sector (MoHFW 2023). At the same time, state-level initiatives such as Kerala's *Hospital Disaster Management Guidelines* (DHS Kerala 2018) illustrate how state-level authorities can take coordinated steps towards increasing the resilience of critical systems.

However, these plans still lack hyperlocal risk assessments, which prevents the development of context-specific solutions and hinders the implementation of planned solutions at the local level.

As India continues to urbanise rapidly and faces a continued surge in infrastructure demand, governments must assess and invest in infrastructure prioritisation as they decide how to allocate limited resources (CDRI 2021). There is, therefore, a pressing need to mainstream granular risk assessment in the infrastructure life cycle and standardise the process across sectors and scales.

In 2023, the Working Group on Disaster Risk Reduction (WGDRR) under India's G20 presidency identified climate-resilient infrastructure development as a key priority area. As India leads the CDRI with the aim of enhancing global infrastructure resilience, it holds the potential to mainstream risk assessment in infrastructure development. Relevant legislation, policies, and plans must follow suit to define the process, introduce mandates where necessary, and simplify governance structures to ensure smooth interdepartmental coordination.

1.3 Scope of the study

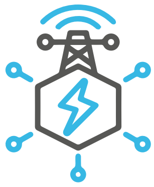
Since several different infrastructure sectors are considered 'critical' by various countries and global organisations, we developed criteria to shortlist three sectors for in-depth research. The criteria were based on the following three factors:

- Recognition as 'critical' by several global organisations in their formal communications
- Amount of global and national investments flowing into the sector
- Availability of uniform data at the district level on a pan-Indian scale

Based on these criteria, 12 sectors were identified, and subsequently, three sectors were shortlisted. Table A1 in Annexure I provides an overview of the criteria matrix with the sectors, subsectors, and classes identified. The research builds on previous global publications in this domain such as the biennial report by CDRI, *Global Infrastructure Resilience*, the World Bank report on the *Global Facility for Disaster Reduction and Recovery*, and white papers such as "Analysis of Critical Infrastructure Dependencies and Interdependencies" (Petit et al. 2015) to support indicator development. Thus, our research, through a series of publications, focuses on three critical infrastructure sectors, namely

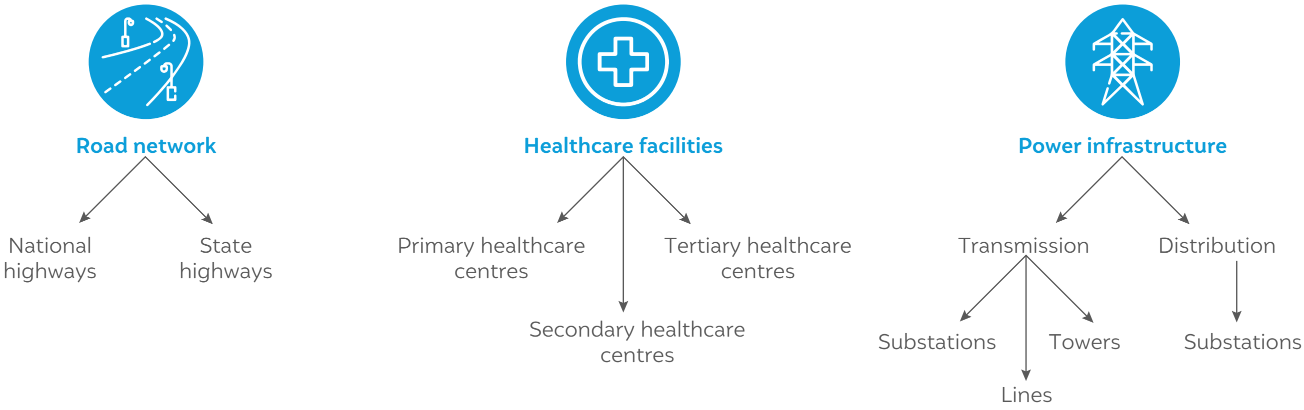
- Healthcare facilities: primary, secondary, and tertiary healthcare centres
- Road network: state highways, national highways, major district roads, other district roads, arterial roads, etc.
- Power transmission and distribution network: substations, transmission lines, and transmission towers

Moreover, recognising their pivotal role in safeguarding public health, bolstering economic resilience, and enabling efficient disaster response, we have identified these three key sectors as critical infrastructures (Figure 5). This designation aligns with the sectors' significance, as emphasised by the Task Force on Climate-related Financial Disclosures (TCFD), and also addresses the growing importance of financial considerations and reporting requirements in these sectors. These sectors also face the maximum immediate direct and indirect impacts of floods and cyclones. Direct damages amounting to USD 18 billion due to extreme events are observed annually for transport and power infrastructure in developing countries like India (GFDPR 2021).



In the 2018 Kerala floods, medicines and equipment worth INR 4 crore were destroyed in a 125-year-old hospital (NDTV 2018)

Figure 5 Critical infrastructures in focus



Source: Authors' analysis

Box 1	What does climate-proofing infrastructure mean?

Climate-proofing infrastructure involves adapting to climate change through a comprehensive climate change risk assessment of critical infrastructure as the initial step. While the concept of climate-proofing infrastructure has been previously introduced, it is imperative to address various challenges associated with its implementation. The term climate proofing has evolved over the years, and many global organisations have provided different interpretations and definitions for this term. In 2005, Asian Development Bank (ADB) provided the first definition for climate proofing infrastructure as "A process for identifying risks to a development project, or any other specified natural or human asset, as a result of climate change and variability, and ensuring that those risks are reduced to acceptable levels through long-lasting and environmentally sounds, economically viable, and socially acceptable changes" (ADB 2005). ADB further revised their definition in 2015 as "Climate proofing is meant as (i) a process that aims to identify risks that an investment project may face as a result of climate change, and to reduce those risks to levels considered to be acceptable, and (ii) a measure aimed at mitigating the climate risk to which a project is exposed" (ADB 2015).

Source: Authors' compilation

Now, the first phase of the research through this report focuses on assessing the risks and identifying pathways to build resilience of for the healthcare infrastructure sector, with a key focus on primary, secondary, and tertiary healthcare centres in India. India's healthcare sector has seen a notable increase in public spending, rising by 12.9 per cent in FY 2024–25 compared to the previous year's allocation, which amounted to 2.1 per cent of GDP in FY 2023 (PIB 2024). In the Union Budget for 2023–24, the Ministry of Health and Family Welfare (MoHFW) received a significant allocation of INR 8.92 trillion (USD 10.76 billion). Additionally, INR 720 billion (USD 870 million) was designated for the newly introduced *Pradhan Mantri–Ayushman Bharat Health Infrastructure Mission* (PM-ABHIM), aimed at fortifying India's healthcare infrastructure and enhancing primary, secondary, and tertiary care services (PIB 2023). India is anticipated to invest over INR 41 trillion (USD 500 billion) in medical infrastructure by 2030 (Indian Brand Equity Foundation 2023). Hence, it is imperative to ensure that new and existing infrastructure systems are climate- and disaster-resilient (Ministry of Finance 2020).

So, in this report, we explore the multifaceted impacts of climate change on India's healthcare infrastructure and the imperative to enhance resilience in the face of these challenges.

1.4 Limitations of the study

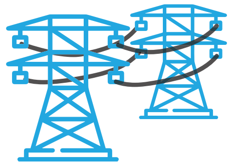
The framework developed in this study aims to assist authorities and stakeholders in identifying risks posed by floods and cyclones at a granular level for infrastructure facilities. However, several limitations could affect the accuracy and comprehensiveness of the results. These limitations include the following:

- **Lack of uniform asset-level dataset**
  The framework relies on broader datasets compiled at the block or district levels due to the unavailability of uniform and accessible asset-level data. This can lead to less precise risk assessments, as the granular data is crucial for accurately identifying vulnerabilities at the infrastructure or facility level.

- **Regional challenges**
  The framework does not adequately account for regional challenges. For instance, hilly regions may face different infrastructure challenges compared to coastal areas. Since the data has been collected using a unified scale, there is a risk of overlooking regional nuances that are critical for accurate risk assessment.

- **Time versus distance considerations**
  While the study considers the distance needed for relief and rescue operations, as well as the maintenance of critical infrastructure service delivery, it lacks concrete data on time disruptions. These disruptions, which can be highly variable depending on the event and location, are not directly accounted for due to their unpredictable nature. However, they have been indirectly captured through indicators like population density and the percentage of all-weather roads, which provide a derivative indication of such disruptions.

These limitations highlight the need for more detailed, region-specific data to improve the accuracy and reliability of the framework in assessing risks and vulnerabilities in critical infrastructure.



Power companies in Gujarat suffered an estimated loss of more than INR 1,013 crore due to Cyclone Biparjoy in 2023, which damaged power lines, towers, and transformers across 10 districts in the state (Economic Times 2023)

1.5 Research questions

The study undertaken explores and addresses the following research questions:

- How can healthcare facilities be mapped and identified in the wake of hydro-meteorological disasters such as floods and cyclones in India?
- What is the level of risk to healthcare facilities due to extreme hydro-meteorological disasters?
- How can we build the climate resilience of India's healthcare facilities against extreme hydro-meteorological disasters?

2. Methodology: Mapping the climate risk to healthcare facilities across India

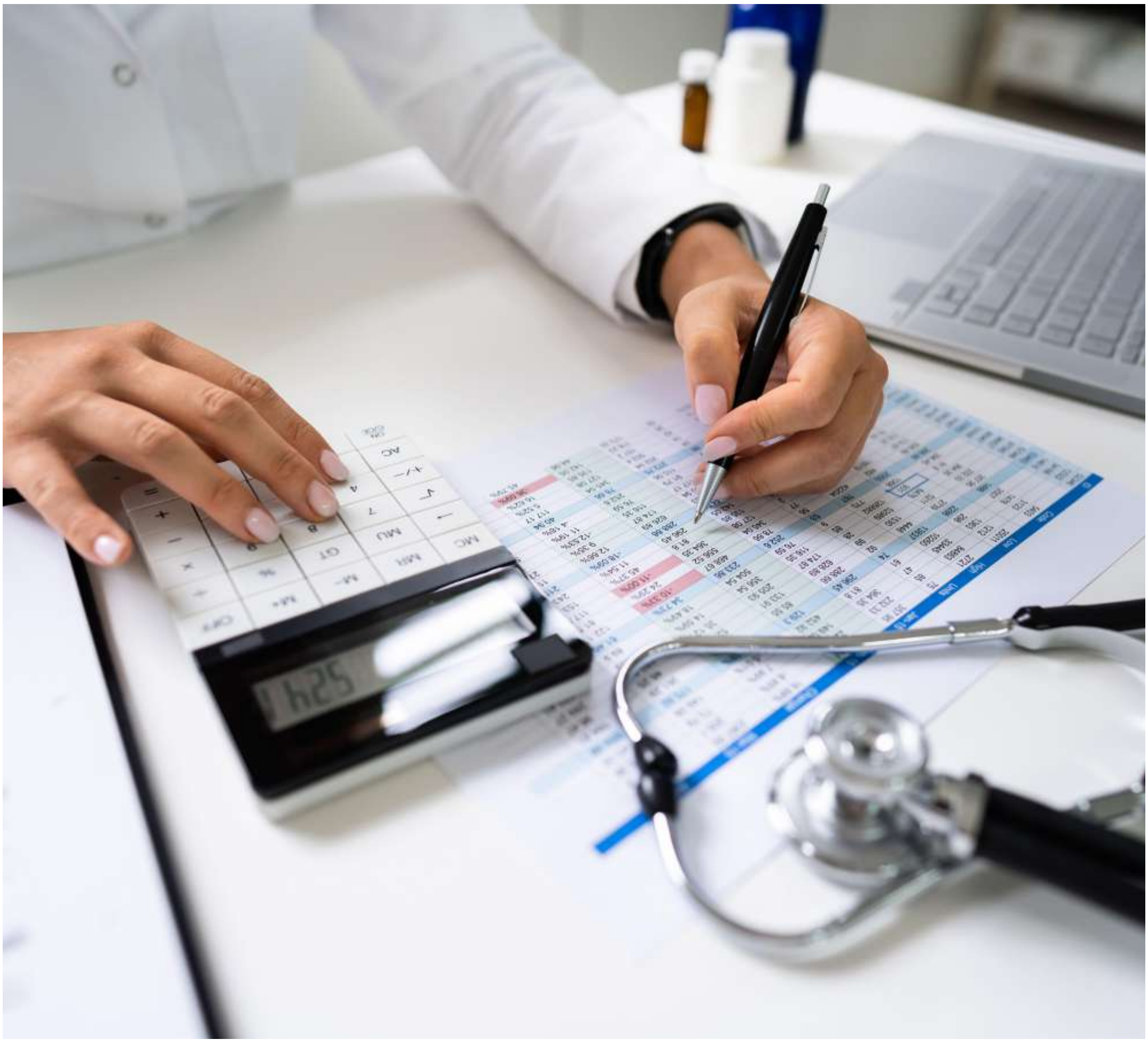


Image: Alamy

Healthcare facilities are classified as critical infrastructure because they provide vital services during extreme climate events. Primary healthcare facilities act as first responders, while secondary and tertiary facilities provide specialised care. However, extreme climate events can put healthcare facilities at risk of several adverse impacts. Physical damage to hospital structures and medical equipment can disrupt service delivery and hospital functioning, leading to a higher number of casualties during a disaster. Further, repair and restoration entail additional financial costs. Therefore, it is imperative to safeguard healthcare facilities from current and future climate risks.

The solution lies in building climate-resilient healthcare facilities that can withstand such impacts. However, to build this resilience, the following three questions must first be answered:

- **What** puts healthcare facilities at risk?
- **How many** such facilities are at risk?
- **Where** are the at-risk healthcare facilities located?

Estimating climate risk and mapping it geospatially can address all three questions. Implementing a unified multi-hazard climate risk assessment framework is, therefore, a prerequisite for enhancing infrastructure resilience. Such a framework can enable informed investments, optimise adaptation finance, and help identify tailored adaptation solutions to improve resilience.

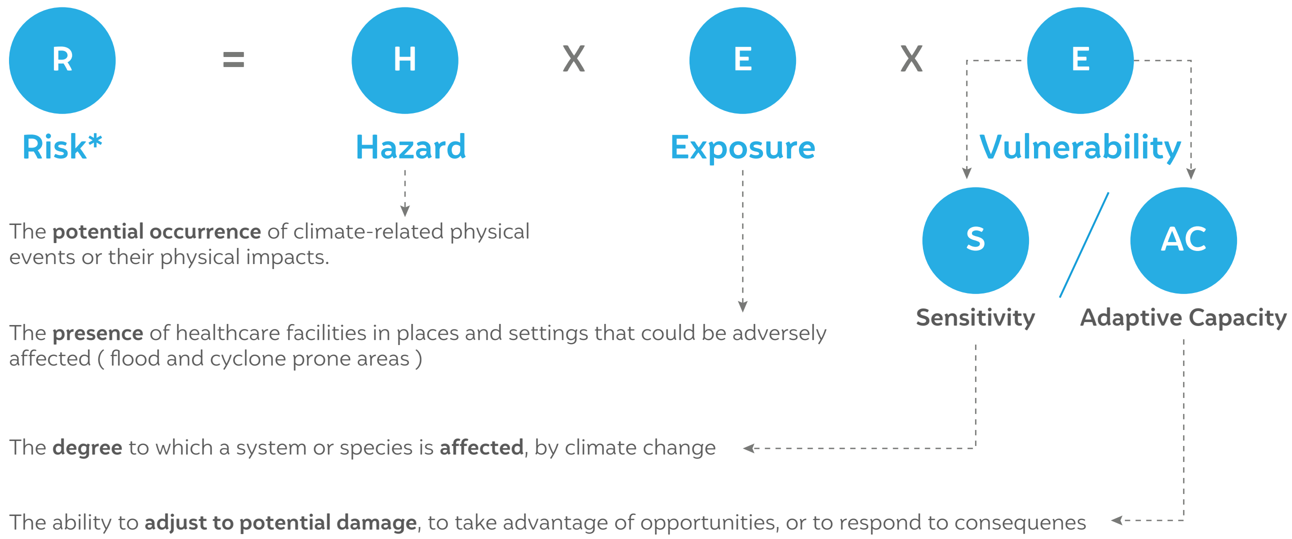
The Council on Energy, Environment and Water (CEEW) has developed this framework in alignment with the scientific definition of climate risk, as depicted in ES Figure 1. The following sections in this chapter elucidate how each risk component can be estimated using the devised framework and the kinds of results this exercise could yield when applied to a case study area.

2.1 How to estimate risk?

Quantifying the climate risks to healthcare facilities is the first step in incorporating characteristics of resilience into the infrastructure life cycle.

The term **risk** refers to "the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social, and cultural assets, services, and infrastructure" (IPCC 2014). The IPCC *Fifth Assessment Report* further defines risk as a function of three components (IPCC 2014): **hazard, exposure, and vulnerability** (Figure 6).

Figure 6 The IPCC AR5 definition of risk

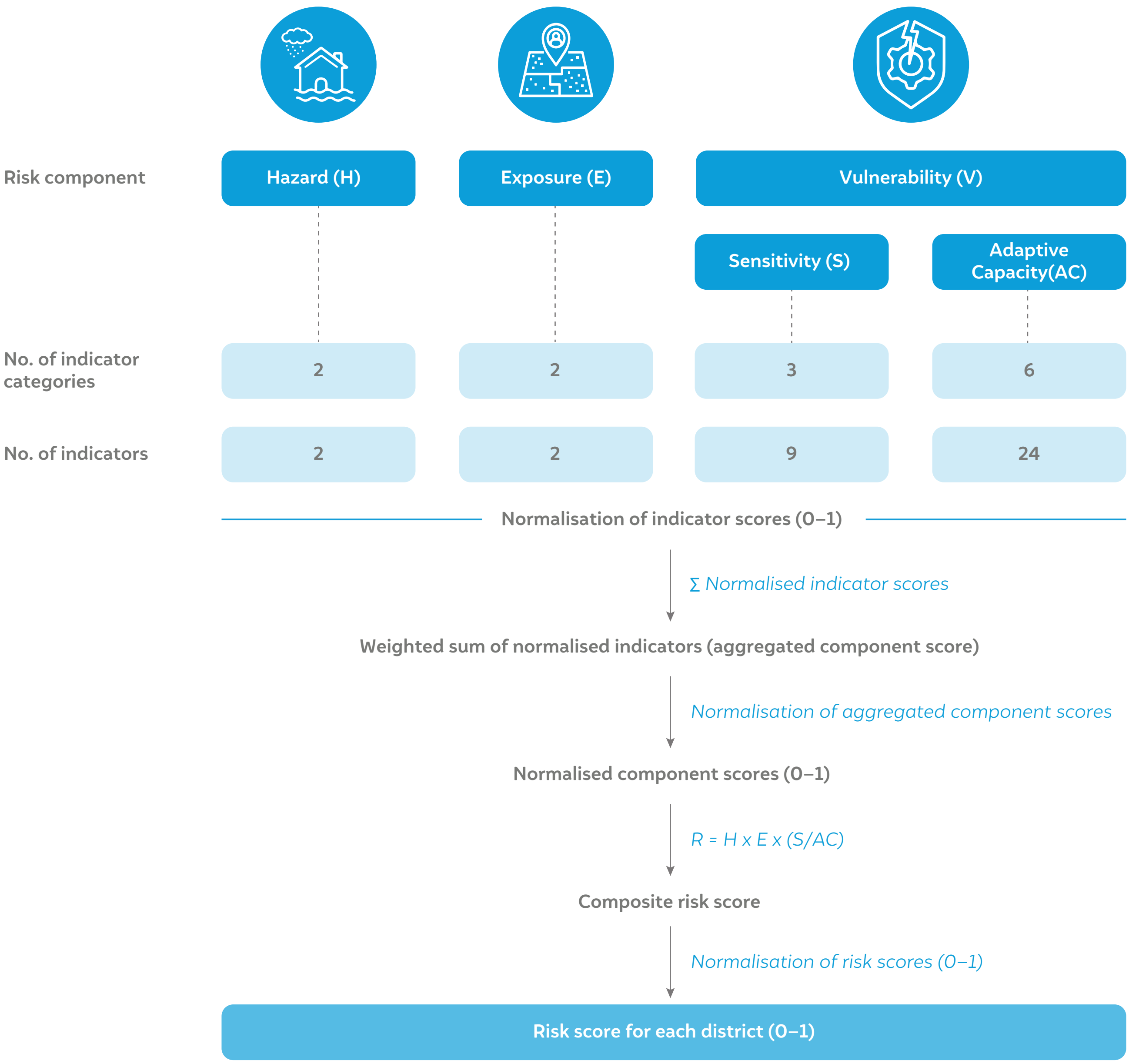


Source: IPCC Assessment Report V, 2014

In our study, we evaluate multiple indicators to assess each component of risk to healthcare facilities in each district. The risk score, represented on a scale from 0 to 1, is estimated using a composite index-based methodology (see Figure 7) that combines the scores of each indicator in alignment with the IPCC formula for risk. The risk level of healthcare facilities in every district is then mapped into the following categories: very low (0–0.2), low (0.2–0.4), moderate (0.4–0.6), high (0.6–0.8), and very high (0.8–1).

The composite index-based assessment reveals each indicator's importance, identifies vulnerability patterns, and guides context-specific adaptation strategies. However, as depicted in Box 2, min–max normalisation has been used to unify the indicator values into one measurement system.

Figure 7 A composite index-based method is used to obtain the risk scores for each district on a scale of 0–1



Source: Authors' analysis

Box 2 **Standardisation of indicator scores through min–max normalisation**

Since each indicator across the three risk components assesses different criteria with varied units, they need to be unified into one measurement system. Therefore, min–max normalisation or min–max scaling has been used to place indicator scores in the fixed range of 0–1.

The equation used is as follows:

$$I^s = \frac{I - \min^*(I)}{\max(I) - \min^*(I)}$$

where I is the value of an indicator with any unit, max (I) is the maximum value of I, the indicator, min*(I) is the minimum value of I, the indicator, and I^S is the computed standardised value of I and will satisfy $0 < I^S \leq I$.

Using the same formula, the total weighted sum of each risk component (aggregated component score) has been normalised on a scale from 0 to 1 to arrive at the final risk value.

Source: Authors' compilation based on the IPCC Fifth Assessment Report (2021)

The risk level informs decision-making by administrators, policymakers, and investors regarding climate-proofing healthcare facilities. By prioritising at-risk facilities, allocating more funds, and implementing upgrades, risk levels can be reduced. The following sections elucidate how each risk component has been estimated in the study.

2.2 Component 1 – Hazards: Mapping the occurrence of extreme floods and cyclones in India

In the context of climate change, the term **hazard** usually refers to "climate-related physical events or trends or their physical impacts" (IPCC 2014). Therefore, regardless of the type of critical infrastructure being assessed, the district's hazard score remains consistent.

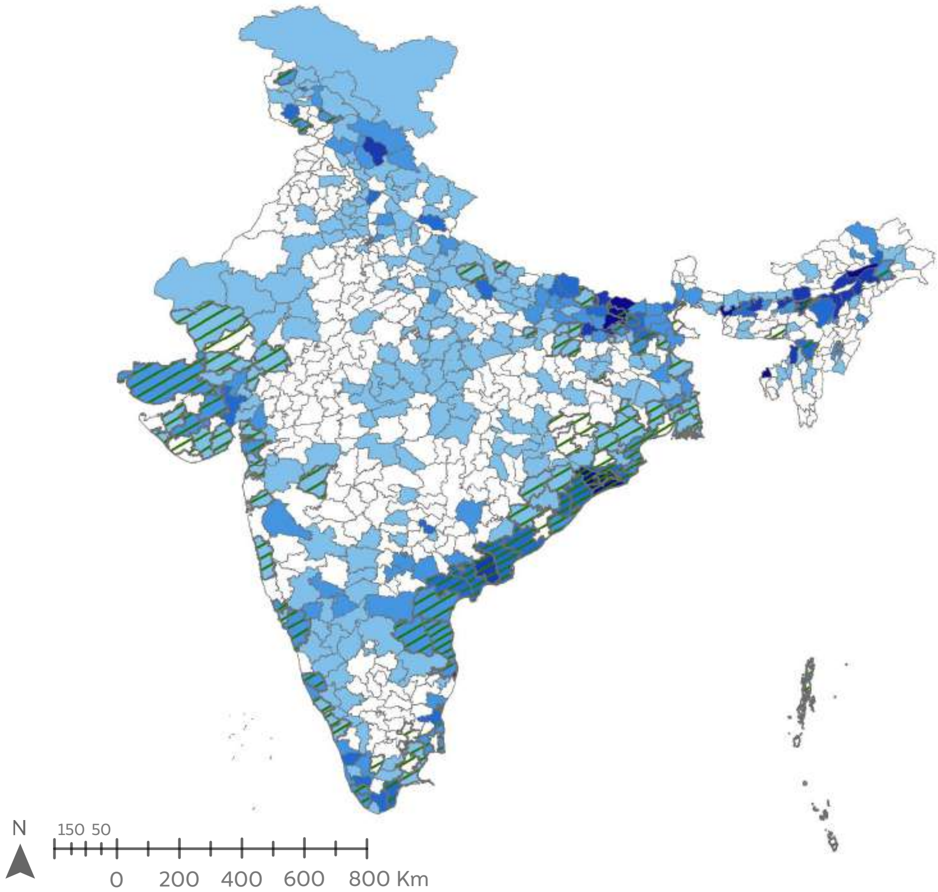
As per the defined scope of the study, *hazard* refers to extreme floods and cyclones and their compounding impacts. The historical occurrence of floods and cyclones is mapped based on the number of occurrences over the last 50 years, as recorded by the International Disaster Database or the Emergency Events Database (EM-DAT)[4] and the respective district or state disaster management plans (EM-DAT n.d.). The total number of extreme events in each district is, therefore, equal to the combined recorded number of flood and cyclone events. It must be noted that, although parameters such as rainfall intensity and cyclone wind speeds can possibly be used to assess the intensity of extreme climate events, they have not been used in this framework to reduce the chances of data unavailability across regions.

Figure 8 highlights that 370 and 111 out of 640 districts[5] in India have experienced an extreme flood or cyclone, respectively, at least once in the last 50 years (Mohanty and Wadhawan 2021). A recent study by CEEW also found that 55 per cent of *tehsils* or sub-districts witnessed a significant increase in monsoon rainfall of more than 10 per cent over the last decade (CEEW 2024). Additionally, the study found that the increased rainfall in these tehsils was frequently in the form of short-duration, heavy rainfall, often leading to flash flooding, and resulting in extreme events that overwhelm communities and infrastructure systems. Therefore, it is imperative that critical infrastructure assets, such as healthcare facilities, prepare for these extremes by building long-term resilience.

4 For a disaster to be entered into EM-DAT, it must fulfil at least one of the following criteria: (a) 10 or more people reported killed; (b) 100 or more people reported affected; (c) declaration of a state of emergency; and (d) call for international assistance.

5 According to the Census 2011, India had 640 districts, spread over 28 states and 8 union territories.

Figure 8 Occurrence of flood and cyclone events in Indian districts (1970–2022)



Flood ☐ 0 1 - 3 4 - 6 7 - 10 11 - 14 15 - 19

Cyclone ☐ 0 1 - 2 3 - 5 6 - 9 10 - 14 15 - 18

Source: Authors' analysis using data from the International Disaster Database (EM-DAT 2023)

2.3 Component 2 – Exposure: Mapping healthcare facilities across India

"Exposure" refers to "the presence of people, livelihoods, species, or ecosystems, as well as environmental functions, services, resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC 2014). In simple terms, a hazard-prone area (i.e., an area with a history of floods and/or cyclones) will have higher exposure if it has a high concentration of people, resources, or infrastructure at risk.

Our study estimates exposure based on the **density of healthcare facilities** in the districts where floods or cyclones are observed. However, it is important to note that the hazard component is a precondition for exposure to exist. If a district has not experienced floods or cyclones in the past, it would have nil exposure, regardless of the number of assets that may be located there.

Mapping India's healthcare facilities

To estimate exposure, the location of each healthcare facility was mapped to create a geospatial database. The geographic coordinates of over 200,000 healthcare facilities in India were compiled through geocoding from multiple government and open-source datasets, as outlined in Table 1.

Table 1 Data sources for mapping healthcare facilities

Type of healthcare facility	Primary data source	Other sources	Temporal resolution
PHCs and SHCs in rural districts	PMGSY rural dataset	Open Government Data (OGD) Platform India	2019
PHCs and SHCs in urban districts	Open Government Data (OGD) Platform India	Respective state health department websites	2019
THCs – PMJAY empanelled hospitals	PMJAY website		2022
THCs – CGHS empanelled hospitals	Central Government Health Scheme		2020
THCs – medical colleges	National Medical Commission		2022
THCs – railway-empanelled hospitals	Railway Authority of India		2016

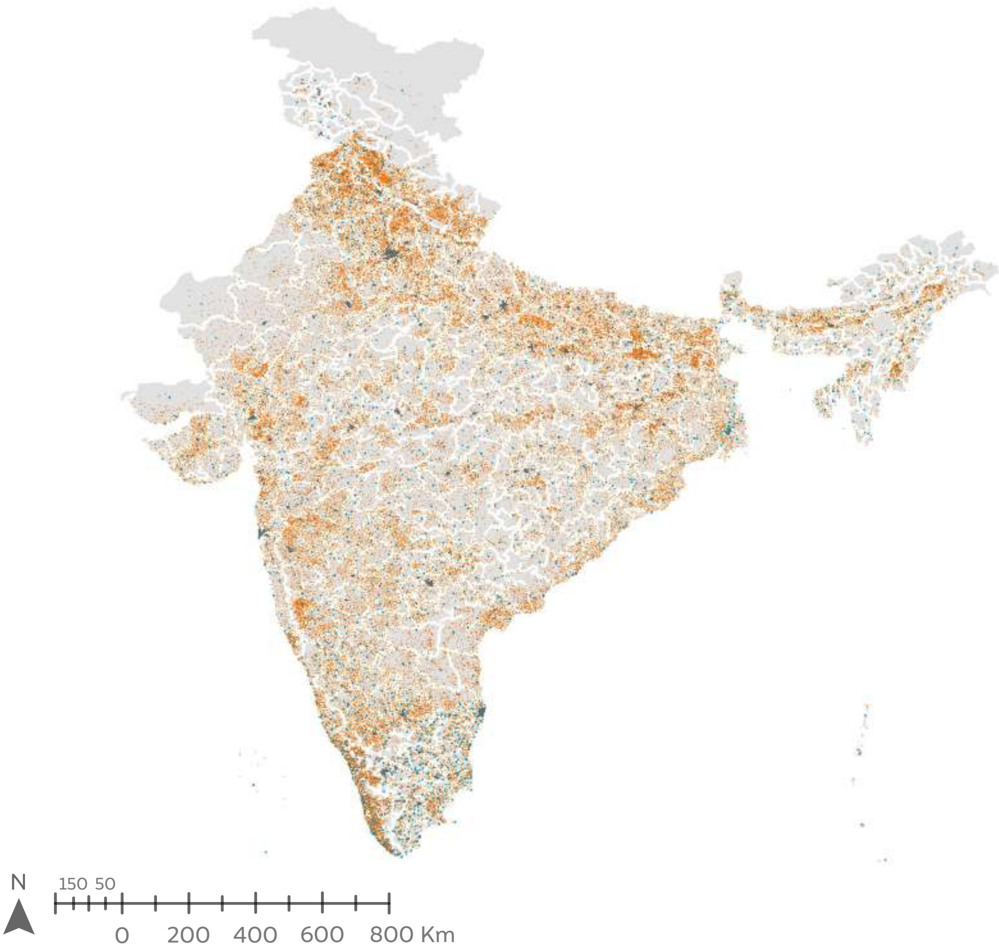
Source: Authors' compilation

Note: PHCs: primary health centres; SHCs: secondary health centres; THCs: tertiary health centres; PMJAY: Pradhan Mantri Jan Arogya Yojana; CGHS: Central Government Health Scheme; PMGSY: Pradhan Mantri Gram Sadak Yojana

Step 1: Creating a geospatial database of healthcare infrastructure assets

India has **over 200,000 (two hundred thousand) healthcare facilities** across three categories: primary, secondary, and tertiary healthcare. Each category of healthcare facility is designed to serve a specific population size according to the *Indian Public Health Standards* (IPHS) and is, therefore, strategically located. This strategic placement puts urban areas, which are highly concentrated in terms of both population and infrastructure, at a disadvantage, as a larger number of healthcare infrastructure assets can get impacted by a single extreme event. Since healthcare facilities provide critical services during disasters, districts with high exposure must take extra steps to climate-proof their healthcare systems. The compiled data was visualised in an ArcGIS desktop environment. The distribution of healthcare centres across districts is shown in Figure 9.

Figure 9 Primary and secondary healthcare facilities are distributed within districts, while tertiary healthcare facilities are concentrated in urban areas



● Primary Healthcare Centres ● Secondary Healthcare Centres ● Tertiary Healthcare Centres

Source: Authors' compilation using geospatial data from datasets as listed in Table 2.1

Step 2: Estimating the exposure score

The geospatial mapping of healthcare facilities is used to calculate the density of healthcare infrastructure assets in each district using the following formula:

Exposure = (No. of PHCs + No. of SHCs + No. of THCs in the district) / Area of the district

The normalised score thus obtained represents each district's exposure level – that is, the presence of healthcare infrastructure in areas prone to hazards such as floods and cyclones.

2.4 Component 3 – Vulnerability: Mapping the predisposition of healthcare facilities

Vulnerability refers to the "propensity or predisposition to be adversely affected." Vulnerability encompasses two subcomponents: (a) sensitivity or susceptibility to harm and (b) adaptive capacity or the capacity to cope and adapt (IPCC 2014). Therefore, the vulnerability of a healthcare facility can be determined using a composite score of its sensitivity and adaptive capacity.

Between 2000 and 2019, India experienced an annual average of 17 floods, making it the second most flood affected country in the world (CRED and UNDRR 2020)

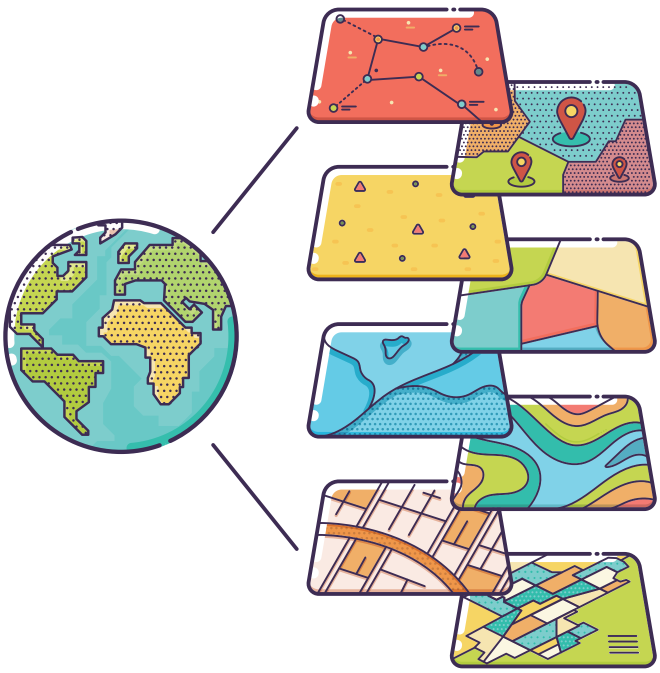
Mapping sensitivity

Sensitivity is the "degree to which a system is affected, either adversely or beneficially, by climate variability or change" (IPCC 2014). Therefore, sensitivity determines the **degree** to which an extreme event would affect the infrastructure asset.

An exhaustive list of over 50 parameters was reviewed, which directly and indirectly contribute to making a healthcare facility 'sensitive' to flood or cyclone events. Based on the literature review, multiple elimination rounds were conducted to shortlist three final indicator categories with a total of eight indicators. These indicators are as follows.

Indicator category 1: Landscape-based susceptibility to floods and cyclones

Category 1 indicators assess the susceptibility of healthcare facility locations to floods and cyclones. Flood susceptibility depends on factors such as topography, hydrology, and soil type, which influence water retention or infiltration (Das S. 2020). Geospatial susceptibility maps for floods and cyclones were created through a weighted overlay of these layers, as listed in Table 2. Using expert knowledge to determine the relative importance of each flood or cyclone susceptibility criterion, they were prioritised through the analytical hierarchy process[6] (AHP) to assign criteria weights.



A total of 12 parameters were mapped in an ArcGIS desktop environment to create landscape-based susceptibility maps. The flood or cyclone susceptibility of each infrastructure asset was then evaluated based on its geographical location.

6 AHP is a decision-making method based on qualitative and quantitative analyses of multi-attribute decision analysis methods for managing problems, criteria, and alternatives smoothly. It is used widely to make objective pairwise judgements to obtain the overall prioritisation for the attributes (Hoque 2019).

Table 2 Criteria weights for landscape-based susceptibility parameters through prioritisation based on the analytical hierarchy process

	Rank	CW (%)	Sample[7] 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average
Elevation	1	13.00	14.80	14.28	14.60	13.42	12.52	9.10	13.12
Slope	2	12.00	13.56	11.42	13.14	13.42	14.08	9.10	12.45
Land use land cover	3	11.00	13.43	11.54	11.59	13.86	9.39	8.00	11.30
Proximity to rivers	4	10.00	10.45	12.85	11.68	10.43	7.82	7.83	10.18
Drainage density	5	10.00	10.45	9.99	7.90	10.17	9.95	9.00	9.58
TWI	6	9.00	8.96	9.99	7.73	7.70	7.82	9.00	8.53
Soil type	7	8.00	5.97	5.71	8.81	8.94	9.95	8.00	7.90
Stream Power Index	8	7.00	8.96	8.57	7.73	7.45	3.13	9.00	7.47
Soil moisture level	9	6.00	2.99	2.86	5.25	3.08	12.52	8.00	5.78
NDVI	10	6.00	4.48	7.07	4.24	6.16	4.69	7.00	5.61
Profile curvature	11	5.00	4.48	4.28	5.15	3.58	4.69	8.00	5.03
Groundwater level	12	3.00	1.49	1.43	2.17	1.79	3.42	8.00	3.05
Consistency ratio			*0.06*	*0.05*	*0.07*	*0.08*	*0.06*	*0.05*	

Source: Author's analysis

Susceptibility maps rank areas from low to high, thus helping guide preparedness efforts. These maps were then overlaid with the exposure layer to determine whether or not a healthcare facility is located in a high-risk area where it may be susceptible to floods or cyclones. The percentage of such facilities in a district was then estimated for each type of extreme event to arrive at indicator category 1 scores.

Note: The high-resolution susceptibility map can serve as a decision-making tool for identifying whether a particular location is optimal and unsuitable for new infrastructure corridors or the relocation of key assets. Considering redundant investments during infrastructure development is vital for effective socio-spatial planning, which can be guided by a susceptibility map during the land-use planning phase.

Indicator category 2: Mapping compliance with zoning regulations

The second indicator category – sensitivity – evaluates compliance with zoning regulations, and examines whether healthcare facilities are located within designated flood-risk or no-development zones. National regulations control development density in hazard-prone areas; however, non-compliance may occur due to reasons such as malpractice or older infrastructure constructed before newer guidelines were established. Non-compliance implies greater sensitivity to hazards, as the infrastructure is located in government-identified risk zones.

7 One sample in this study represents an independent researcher with expertise in geographic information system (GIS)–based flood susceptibility analysis and an understanding of the analytical hierarchy process.

Government regulations mandate that critical infrastructures such as hospitals be built above flood levels corresponding to a 100-year frequency. Following this, the concerned department in the state, for example, the Maharashtra Water Resources Department, has prepared maps demarcating the flood line on both sides of major water bodies in each district. The flood line map was overlaid with the geospatial layer to identify non-compliance zones and estimate the percentage of healthcare facilities in each district located in such no-development zones. Similarly, for cyclones, compliance with coastal regulation zones has been assessed based on state notifications. Zones CRZ-II and CRZ-IB, designated as no-development zones, were checked for compliance by overlaying the healthcare facilities' locations.

330+ healthcare facilities were fully or partly damaged in the 2018 Kerala floods (Lancet 2022)

Indicator category 3: Mapping sectoral interdependencies

The third indicator category assesses system interdependencies that can amplify the sensitivity of healthcare facilities. Interdependencies between critical infrastructure components increase disaster risk by causing cascading and compounding failures. For instance, hospitals that rely on only one source of uninterrupted power supply face heightened risk if events like cyclones or floods compromise the power source. For example, during the 2015 Chennai floods, 18 casualties were reported at a renowned multi-speciality hospital as floodwaters interrupted road access, communication lines, and food supply (Johnson 2015).

To quantify such interdependencies, we analysed the relationships between susceptible assets (e.g., healthcare facilities, power, and roads) in each district. We added buffers around susceptible assets using ArcGIS to determine the percentage of healthcare infrastructure within their areas of interaction.

Calculating the sensitivity score

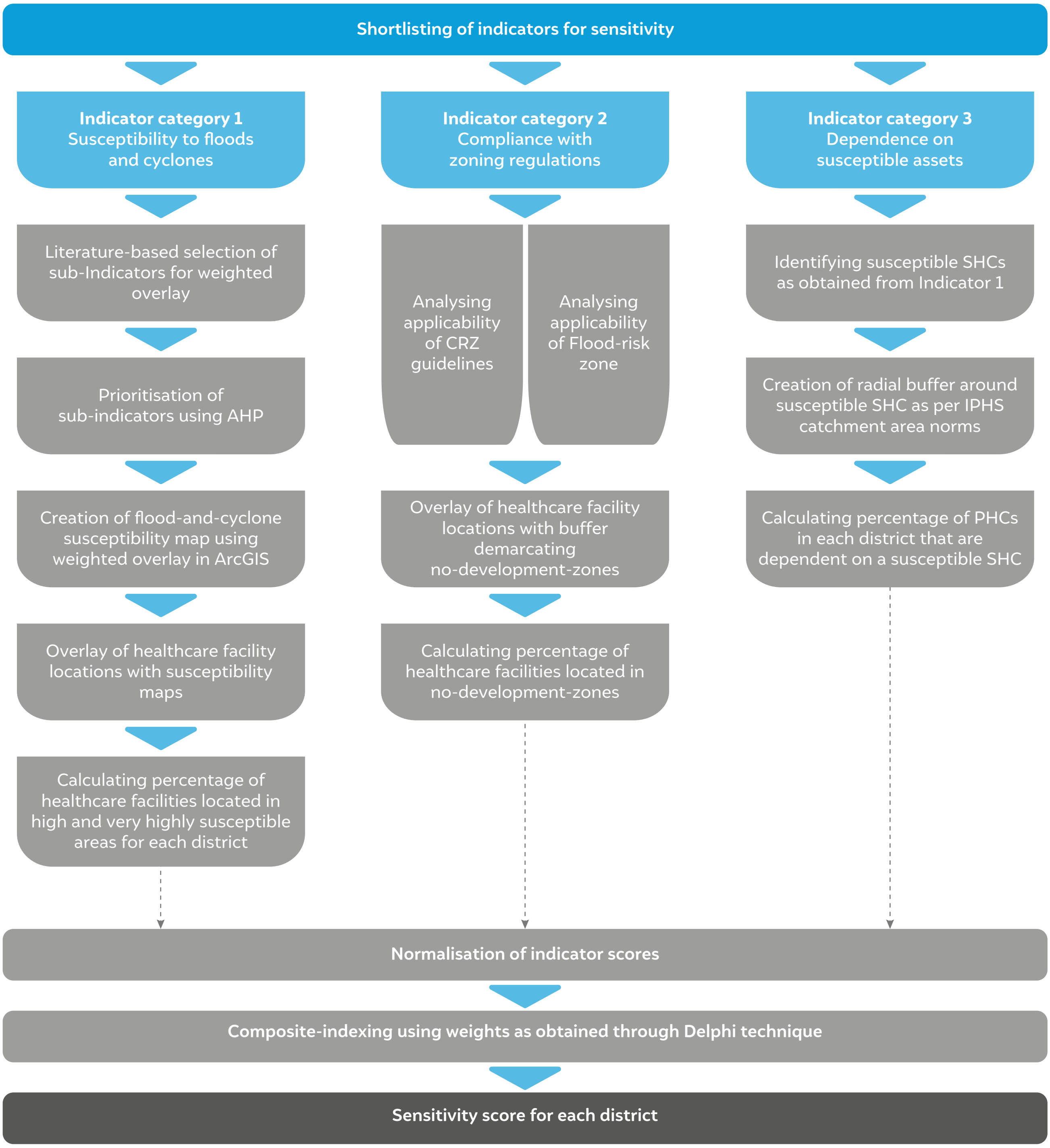
The selected indicators were discussed and prioritised using the Delphi technique[8]. We convened a discussion with over 15 climate change and health-sector experts who debated the nature and importance of each sensitivity indicator. The order of priority, thus obtained, was converted into weights for each indicator using the rank sum method[9]. The weighted average of each sensitivity indicator score produces the aggregate sensitivity score for each district, which was then mapped in an ArcGIS desktop environment to display the sensitivity at a district scale.

The sensitivity score compares the districts in terms of potential impacts on the healthcare facility due to their geographical location. It helps pinpoint assets located in highly susceptible areas and prioritise those assets that may require measures such as relocation (Figure 10).

8 The Delphi method is a systematic process used to arrive at a common consensus or decision by surveying a panel of experts. The process leverages collective intelligence to develop best practice guidance where research is limited or evidence is conflicting. Experts respond to several rounds of questionnaires, and the responses are aggregated and shared with the group after each round and discussed until a consensus is achieved (Nasa, Jain, Juneja 2021).

9 The rank sum method is used to convert ranks assigned to a set of parameters into corresponding numerical weights. With n number of criteria, rank r receives the weight $n - r + 1$.

Figure 10 **A multi-step normalisation-based process is used to estimate the sensitivity score for each indicator**



Source: Authors' analysis

Mapping the adaptive capacity

The **adaptive capacity** of a system refers to “the ability of the system to adjust to potential damage, take advantage of opportunities, or respond to consequences” (IPCC 2014). Adaptive capacity is indirectly related to vulnerability. Therefore, as the adaptive capacity of a healthcare facility increases, its vulnerability to extreme events decreases, thereby reducing overall risk and increasing resilience.

Climate-proofing the health sector is essential for achieving SDG Targets 3, 4, 5, 6, 13, 14, and 15, ensuring universal access to adequate health services

The adaptive capacity of critical infrastructure depends on its preparedness, redundancy, replaceability, and robustness (Lenz 2009). Conversely, inadequate infrastructure governance, marked by deficient planning, poor quality, ineffective regulation, and low investment in maintenance, hinders resilience (Hallegate et al. 2019). To capture the spectrum of characteristics that contribute to the adaptive capacity of a healthcare facility, a total of 24 indicators were selected from a list of 50 parameters based on factors such as data availability, scalability, and/or the presence of proxy indicators.

Indicators for adaptive capacity were derived by synthesising and extracting relevant measures outlined in the *National Guidelines for Disaster Management* by the NDMA. Particular guidelines for flood- and cyclone-resistant construction, such as the *National Disaster Management Guidelines on Management of Floods* by the NIDM (2008) and the *National Disaster Management Guidelines on Hospital Safety* (2016), have also been followed. The final set of indicators can be grouped into six broad categories based on the component of adaptive capacity they aim to assess. These categories are detailed in Table A5 in Annexure II.

Indicator category 1: Network capacity

Network capacity indicators are designed to measure the systemic capacity of the healthcare infrastructure network during an extreme flood or cyclone. These include (a) measuring the adequacy of healthcare facilities in terms of the number of operational facilities in the district and (b) measuring their accessibility in terms of factors such as road network density.

Indicator category 2: Structural capacity

The structural capacity of hospital infrastructure pertains to the stability of the hospital building, influenced by factors such as its age, design, and materials. Although asset-level assessments fall beyond the study’s scope, the structural capacity is quantified using two methods: (a) by examining the district disaster management plan (DDMP) to determine if it mandates hospital compliance with relevant building codes for structural safety and (b) assessing the annual expenditure on hospital structural upgrades in accordance with IPHS norms under the *National Health Mission* (NHM) for each district.

Indicator category 3: Administrative capacity

Administrative capacity refers to the hospital administration’s preparedness in case of an extreme flood or cyclone. The organisational or facility preparedness aspect assesses whether designated authorities are able to manage the excess stress caused by an extreme climate event and are informed and trained on hospital functioning during such an event (Krings, Geibprasert, Terbrugge 2010). Factors such as the presence of a hospital disaster management plan, demarcated emergency operation centres, and an alternate power supply increase the preparedness of a healthcare facility.

Indicator category 4: Functional capacity

When disasters impact health facilities, they trigger cascading effects caused by structural and functional damages (Yadav, Sood, and Gupta 2023). The efficiency of the healthcare services in a district correlates with its ability to function fully during disasters. To gauge healthcare service quality, two national accreditation systems are utilised: The National Quality Assurance Standards (NQAS) and the National Accreditation Board for Hospitals (NABH). Both systems conduct on-ground surveys to evaluate healthcare facilities based on specially designed criteria for each type of healthcare facility, revolving around factors such as service provision, quality management, support services, and outcomes. Quantifying the number of accredited facilities in each district allows for a comparison of healthcare facilities' functioning and capacity for service delivery.

Indicator category 5: Operation and maintenance expenditure

Insufficient annual spending on operations and maintenance leads to poor infrastructure and services, early deterioration, and increased construction costs (CDRI 2023). A portion of the funds under the NHM is allocated for upgrading healthcare systems in the country. Comparing expenditures on healthcare infrastructure in each district provides an estimate of their operations and maintenance performance. Table A5 in Annexure II outlines an extensive list of adaptive capacity indicators, and their rationales, nature of correlation, and data sources.

Indicator category 6: Evaluation of respective district disaster management plans

The overall adaptive capacity of the district can also be captured by quantitatively scoring the DDMP in terms of its approach to climate-proofing the district's healthcare facilities. This indicator category assesses the comprehensiveness of each plan based on whether it contains a data catalogue identifying the distribution of healthcare infrastructure assets in the district, as well as the comprehensiveness of its structural and non-structural strategies for climate-proofing healthcare.

Calculating the adaptive capacity score

Each indicator of adaptive capacity is measured using one of three methods: (a) data mining, extraction, and consolidation for quantitative indicators; (b) keyword-based systematic evaluation and scoring of DDMPs for qualitative indicators; and (c) GIS-based scoring for spatial indicators.

To assign weights to individual indicators, an expert opinion survey was conducted via the Delphi technique. Over 15 experts on climate change and/or healthcare participated in a closed-door multi-stakeholder consultation to discuss, validate, and prioritise indicators for assessing the adaptive capacity of healthcare facilities at the district scale (Figure 11). The ranks assigned to each indicator were then converted into weights. However, each of the six indicator categories was assigned equal weightage. The rationale behind indicator prioritisation is detailed in Table A6 in Annexure II.

Severe flooding in Assam in 2022 forced a 150 bed cancer hospital to administer chemotherapy on the streets due to waterlogging at the facility

Image: CEEW

15+ experts on climate change and health participated in a multi-stakeholder consultation to discuss and prioritise indicators for risk assessment at CEEW.

Figure 11 Estimating adaptive capacity through a weighted sum of 24 indicators

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1			AH1 - Network strength							AH2 - Structural		AH3 - Institutional preparedness				AH5 - Functional		AH5 - Ex	A0 - DDMP Evaluation								Total Weighted Score (Out of 24)	Normalised Score
2			AH1.1	AH1.2	AH1.3	AH1.4	AH1.5	AH1.6	AH1.7	AH2.1	AH2.2	AH3.1	AH3.2	AH3.3	AH3.4	AH4.1	AH4.2	AH5	A0.1	A0.2	A0.3	A0.4	A0.5	A0.6	A0.7	A0.8		
3	District Code	District Name	0.86	0.71	1.00	0.29	0.57	0.43	0.14	2.67	1.33	1.60	0.40	0.80	1.20	2.00	2.00	4.00	0.33	0.11	0.56	0.89	0.78	0.67	0.22	0.44		
4	519	Mumbai	0.58	0.57	0.18	0.59	1.00	0.00	1.00	1.00	1.00	1.00	0.90	1.00	0.50	0.00	0.23	1.00	0.50	1.00	1.00	0.25	0.00	0.75	0.25	1.00	15.84	1.00
5	521	Pune	0.00	0.34	0.24	0.60	0.22	1.00	0.00	0.75	0.62	1.00	0.90	0.39	0.41	1.00	1.00	0.28	0.50	1.00	0.75	0.25	0.50	0.50	1.00	1.00	14.25	0.85
6	529	Sindhudurg	0.63	0.70	0.82	1.00	0.48	1.00	0.00	0.75	0.65	1.00	1.00	0.45	0.17	0.00	0.00	1.00	0.50	1.00	0.75	0.25	0.50	0.75	1.00	1.00	13.95	0.82
7	516	Nashik	0.53	0.53	0.71	0.62	0.44	1.00	1.00	0.00	1.00	1.00	0.75	0.55	0.62	0.00	0.67	0.96	0.00	0.50	0.50	1.00	0.25	0.50	1.00	1.00	13.35	0.76
8	515	Aurangabad	0.40	0.60	0.71	0.61	0.32	1.00	0.50	1.00	0.38	0.00	0.65	0.30	0.00	0.45	0.17	0.91	0.50	1.00	0.75	0.50	1.00	0.00	0.25	0.75	13.20	0.75
9	528	Ratnagiri	0.40	0.69	1.00	0.72	0.20	0.50	0.25	0.75	0.13	1.00	0.57	0.45	0.10	0.23	0.03	0.88	0.00	1.00	0.75	0.50	0.50	0.00	1.00	1.00	13.06	0.73
10	508	Gadchiroli	0.47	0.70	0.88	0.93	0.00	0.83	0.17	0.00	0.44	1.00	0.18	0.82	0.66	0.00	0.00	0.66	0.50	0.25	1.00	0.50	1.00	1.00	1.00	1.00	12.88	0.71
11	523	Bid	0.25	0.67	0.71	0.64	0.61	0.80	0.20	1.00	0.07	0.75	0.94	0.78	0.00	0.00	0.00	0.60	0.50	1.00	0.75	0.75	1.00	0.50	1.00	1.00	12.80	0.71
12	530	Kolhapur	0.40	0.62	0.76	0.63	1.00	1.00	0.00	0.75	0.41	1.00	0.24	0.73	0.00	0.00	0.14	0.61	0.50	1.00	0.75	0.25	1.00	0.00	1.00	1.00	12.61	0.69
13	503	Amravati	0.45	0.68	0.82	0.63	0.13	0.29	0.07	1.00	0.39	0.75	0.33	0.34	0.00	0.00	0.00	0.67	0.50	0.75	0.00	0.25	1.00	0.50	1.00	1.00	11.80	0.61
14	527	Satara	0.33	0.67	0.71	0.66	0.58	0.75	0.25	0.75	0.37	1.00	0.85	0.73	0.00	0.00	0.03	0.50	0.00	1.00	0.75	0.50	0.00	0.75	1.00	1.00	11.56	0.59
15	517	Thane	0.14	0.80	0.80	0.60	0.09	1.00	0.67	0.00	0.94	0.50	0.11	0.11	1.00	0.28	0.17	0.64	0.50	1.00	1.00	0.50	1.00	0.75	1.00	1.00	11.34	0.57
16	511	Nanded	0.35	0.65	0.76	0.64	0.41	1.00	1.00	0.75	0.34	1.00	0.27	0.69	0.16	0.00	0.00	0.45	0.50	0.00	0.00	0.50	0.50	0.00	1.00	1.00	10.88	0.52
17	531	Sangli	0.38	0.65	0.70	0.60	0.42	1.00	0.00	1.00	0.23	0.75	0.30	1.00	0.00	0.00	0.11	0.37	0.25	0.00	0.50	0.50	0.00	0.00	1.00	1.00	10.67	0.50
18	518	Mumbai Suburban	0.65	0.44	0.76	0.59	1.00	1.00	1.00	0.00		0.25	0.60	0.70	0.30	0.00	0.61	1.00	0.25	0.00	0.00	0.50	0.75	0.50	1.00	0.00	10.36	0.47
19	526	Solapur	0.10	0.61	0.65	0.62	0.60	1.00	1.00	0.00	0.41	1.00	0.72	0.34	0.00	0.00	0.34	0.53	0.00	1.00	1.00	0.50	0.00	1.00	1.00	1.00	10.21	0.46
20	507	Gondiya	0.39	0.70	0.71	0.71	0.51	0.33	0.33	0.00	0.27	0.25	0.48	1.00	0.23	0.00	0.03	0.84	0.00	0.00	0.25	0.50	0.00	0.00	1.00	1.00	8.79	0.32
21	525	Osmanabad	0.39	0.69	0.88	0.68	0.30	1.00	0.00	0.00	0.21	0.00	0.47	0.86	0.00	0.00	0.00	0.73	0.25	0.00	0.50	0.50	0.75	0.00	1.00	1.00	8.63	0.31
22	514	Jalna	0.38	0.68	0.71	0.66	0.20	1.00	0.00	0.75	0.17	1.00	0.00	0.12	0.00	0.00	0.00	0.60	0.50	1.00	0.75	0.25	1.00	0.00	1.00	1.00	8.56	0.30
23	497	Nandurbar	0.46	0.69	0.76	0.71	0.41	0.20	0.00	0.00	0.38	0.50	0.67	0.45	0.93	0.00	0.00	0.42	0.00	0.00	0.50	0.50	0.00	0.00	1.00	1.00	8.39	0.27
24	522	Ahmadnagar	0.20	1.00	0.59	0.66	0.43	1.00	0.67	0.00	0.50	0.00	1.00	0.84	0.04	0.04	0.04	0.45	0.50	0.00	0.50	0.50	0.00	0.50	1.00	1.00	8.12	0.26
25	505	Nagpur	0.56	0.50	0.59	0.61	0.50	1.00	0.00	0.00	0.29	0.00	1.00	0.82	0.09	0.16	0.51	0.11	0.00	0.00	1.00	0.75	0.00	0.50	1.00	1.00	7.90	0.24
26	501	Akola	0.43	0.68	0.71	0.62	0.11	0.00	0.00	0.00	0.14	0.25	0.73	0.63	0.64	0.17	0.00	0.48	0.25	0.25	0.50	0.50	0.00	0.25	1.00	1.00	7.88	0.24
27	524	Latur	0.36	0.67	0.65	0.64	0.37	1.00	1.00	0.00	0.23	0.25	0.21	0.69	0.00	0.00	0.00	0.52	0.00	0.00	0.75	0.00	0.50	0.25	1.00	1.00	7.46	0.20
28	500	Buldana	0.33	0.67	0.65	0.65	0.09	1.00	1.00	0.00	0.20	0.50	0.11	1.00	0.00	0.15	0.00	0.24	0.25	0.25	1.00	0.50	0.00	0.25	1.00	1.00	7.41	0.19
29	506	Bhandara	0.54	0.69	0.88	0.77	0.37	0.67	0.33	0.00	0.27	0.50	1.00	0.84	0.00	0.00	0.00	0.09	0.25	0.25	0.25	0.50	0.50	0.50	1.00	1.00	7.27	0.19
30	504	Wardha	0.80	0.68	0.88	0.64	0.33	0.33	0.11	0.00	0.08	0.25	0.83	0.82	0.00	0.06	0.03	0.07	0.25	0.00	0.50	0.50	0.75	0.50	1.00	1.00	7.00	0.15
31	510	Yavatmal	0.17	0.67	0.65	0.62	0.10	0.67	0.67	0.00	0.34	0.50	0.36	0.00	0.72	0.17	0.00	0.28	0.25	0.25	0.75	0.00	0.00	0.25	1.00	1.00	6.97	0.15
32	520	Raigarh	1.00	0.65	0.88	0.66	0.44	1.00	1.00	0.00	0.17	0.00	0.58	0.45	0.36	0.00	0.02	0.13	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	6.49	0.10
33	499	Jalgaon	0.37	0.61	0.65	0.63	0.38	1.00	1.00	0.00	0.48	0.25	0.85	0.88	0.04	0.00	0.00	0.34	0.00	0.00	0.75	0.00	0.00	0.00	1.00	1.00	6.34	0.07
34	513	Parbhani	0.52	0.72	0.82	0.66	0.48	0.33	0.33	0.00	0.09	0.00	0.77	0.63	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.25	0.00	0.00	1.00	1.00	6.09	0.06
35	512	Hingoli	0.37	0.70	0.82	0.67	0.25	1.00	0.00	0.00	0.04	0.00	1.00	0.65	0.00	0.00	0.00	0.36	0.00	0.00	0.50	0.50	0.00	0.50	1.00	1.00	5.97	0.05
36	502	Washim	0.39	0.69	0.82	0.69	0.12	1.00	0.00	0.00	0.00	0.25	0.00	0.56	0.00	0.00	0.00	0.18	0.25	0.25	1.00	0.50	0.00	0.25	1.00	1.00	5.91	0.05
37	498	Dhule	0.36	0.70	0.76	0.64	0.29	1.00	0.50	0.00	0.12	0.00	0.72	0.45	0.07	0.09	0.00	0.30	0.00	0.00	0.50	0.50	0.00	0.50	1.00	1.00	5.87	0.04
38	509	Chandrapur	0.48	0.66	0.76	0.65	0.23	1.00	1.00	0.00	0.22	0.00	0.24	0.14	0.12	0.00	0.03	0.27	0.00	0.00	0.00	0.50	0.00	0.00	1.00	1.00	5.43	0.00

Source: Authors' analysis

Thus, the weighted score for each adaptive capacity indicator was calculated. Next, min–max normalisation was used to arrive at a value between 0 and 1. The weighted sum of the 24 adaptive capacity indicators thus obtained provides the adaptive capacity score for each district (Figure 11). A spatial index was created using districts' adaptive capacity scores, which were mapped in an ArcGIS desktop environment to produce the adaptive capacity map at the district scale.

Each indicator of adaptive capacity provides insights into the risk drivers that can be addressed to build resilience. They also offer deeper insights by highlighting patterns across districts, which can then be used to frame relevant, context-specific recommendations.

Estimating the vulnerability score

The sensitivity and adaptive capacity scores of each district were mapped by creating a spatial model using a raster calculator with the following formula:

Vulnerability = Sensitivity/Adaptive Capacity

This maps the vulnerability level on a graduated scale from very low to very high (0–1).

2.5 Mapping the risk to healthcare facilities in Maharashtra

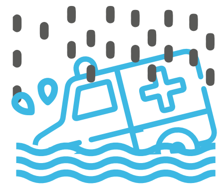
To estimate the risk posed by extreme floods and cyclones for healthcare facilities in each district, the individual scores obtained from the respective indicators are multiplied as per the formula below:

Risk = Hazard x Exposure x Vulnerability

Each of the three components – hazard, exposure, and vulnerability – was assigned equal weightage since they contribute equally to risk. To arrive at the final risk score, the individual scores for the indicators of each component were compiled using the composite indexing method, as detailed in the respective sections. The weighted sum of the normalised indicator scores determined the score of each component.

The final component scores were then normalised on a scale of 0 to 1. To determine the risk value for healthcare facilities in each district, the normalised component scores were compiled as per the aforementioned equation. The values obtained were then normalised again to fit on a scale of 0 to 1, which denotes the district's final risk score.

Lastly, based on the drivers and contributors to risk, the districts were further categorised using a risk prioritisation exercise based on the type of action strategy required to build long-term resilience.



Floods can make it difficult to access healthcare due to: lack of transportation, non-functional sub-centers, and amplifying financial constraints (Public Health Journal 2023)

Three major hospitals in Srinagar were impacted by severe flash flooding in 2014, leaving more than 300 people stranded within the hospital premises.

Image: Alamy

3. Results and discussion: Applying the framework to Maharashtra's healthcare sector

This chapter explains the application of the devised framework in a pilot study conducted in the state of Maharashtra, which has over 17,000 healthcare facilities spread across 35 districts[10]. Maharashtra allocated as much as INR 2184 billion in its 2023 budget to improve healthcare infrastructure in the state (Maharashtra Budget Analysis 2023–24). Additionally, according to a CEEW study, Maharashtra ranks third in terms of vulnerability to hydro-meteorological disasters such as droughts, floods, and cyclones (Mohanty and Wadhawan 2021; Box 3).

Therefore, these investments might be at risk given the increasing frequency and intensity of extreme climate events. Using the framework, the varying degrees of risk to healthcare facilities in Maharashtra have been calculated, and the key drivers of risk have been identified.

This risk assessment can serve as a guiding tool when formulating policies or investing in the development of healthcare facilities. It provides scientific evidence, which, when followed, can reduce redundant investments, channelise funds to the infrastructure at immediate risk, and indicate the best-fit adaptation strategies.

Maharashtra ranks 3rd on CEEW's Climate Vulnerability Index with high exposure to both floods and cyclones (CEEW 2021)

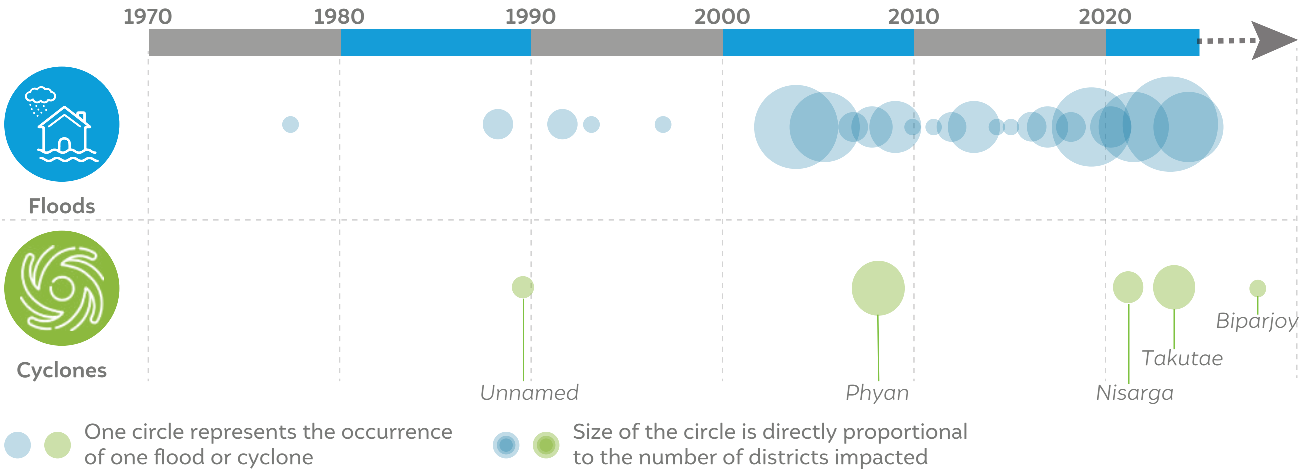
3.1 The state of hazards in Maharashtra (1970–2022)

In Maharashtra, both floods and cyclones are on the rise. Between 1990 and 2020, the state witnessed a **60 per cent increase** in the occurrence of floods and an **80 per cent increase** in the occurrence of cyclones, as recorded by the respective DDMPs (Figure 12).

Further, out of the six administrative divisions in the state, the Konkan division experienced the highest number of extreme **floods and cyclones** between 1970 and 2023, with floods occurring in the region **four times** more frequently than in the rest of the state. Within the Konkan division, the districts of **Raigad and Ratnagiri** have recorded the highest occurrences of floods and cyclones, followed by **Mumbai and Mumbai Suburban**. While the Konkan division has historically been hazard-prone, changing patterns are now observed, as districts in the **Amravati, Aurangabad, and Nashik** divisions have recorded flood occurrences for the first time since 2020 (Figure 13).

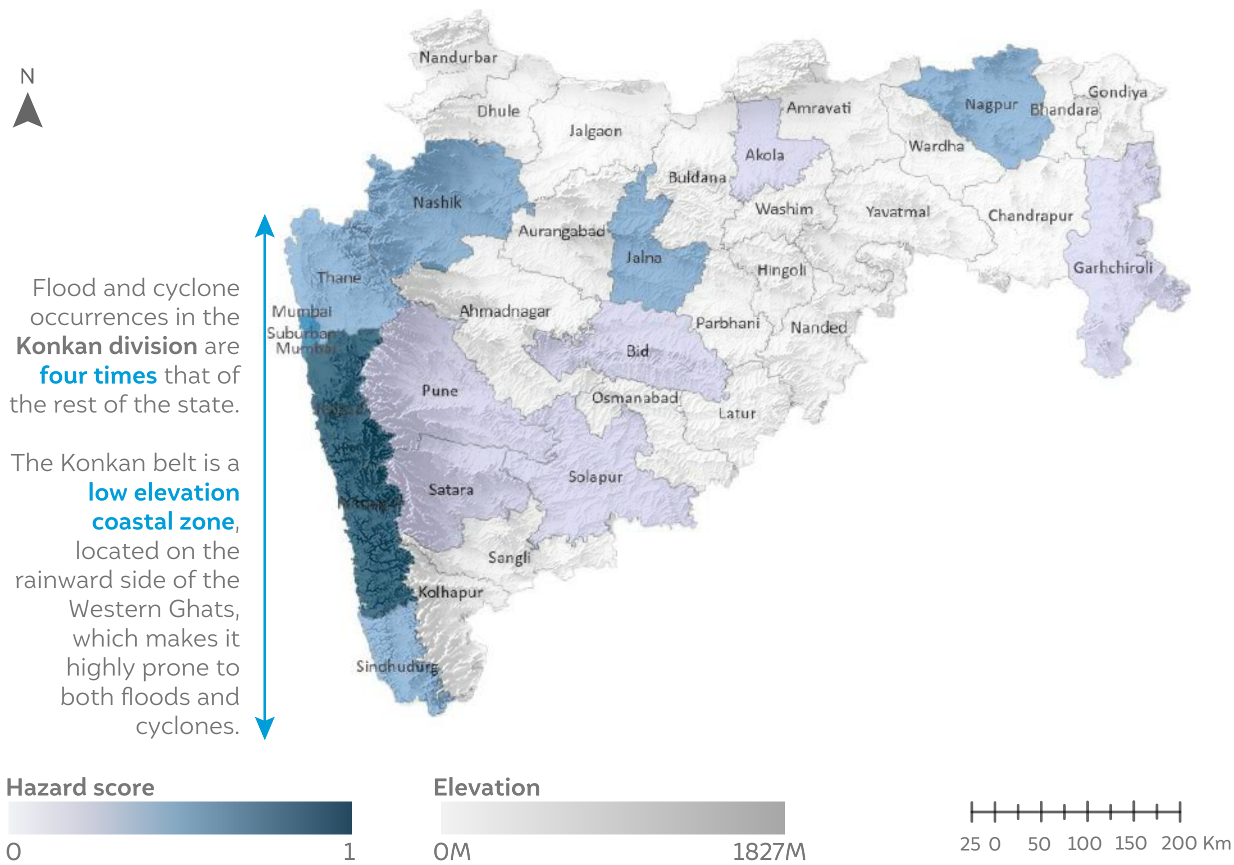
10 As per Census 2011.

Figure 12 Maharashtra observes more frequent disasters with a broader geographical impact, affecting more districts



Source: Authors' compilation based on Maharashtra's DDMPs

Figure 13 The Konkan division is most prone to floods and cyclones



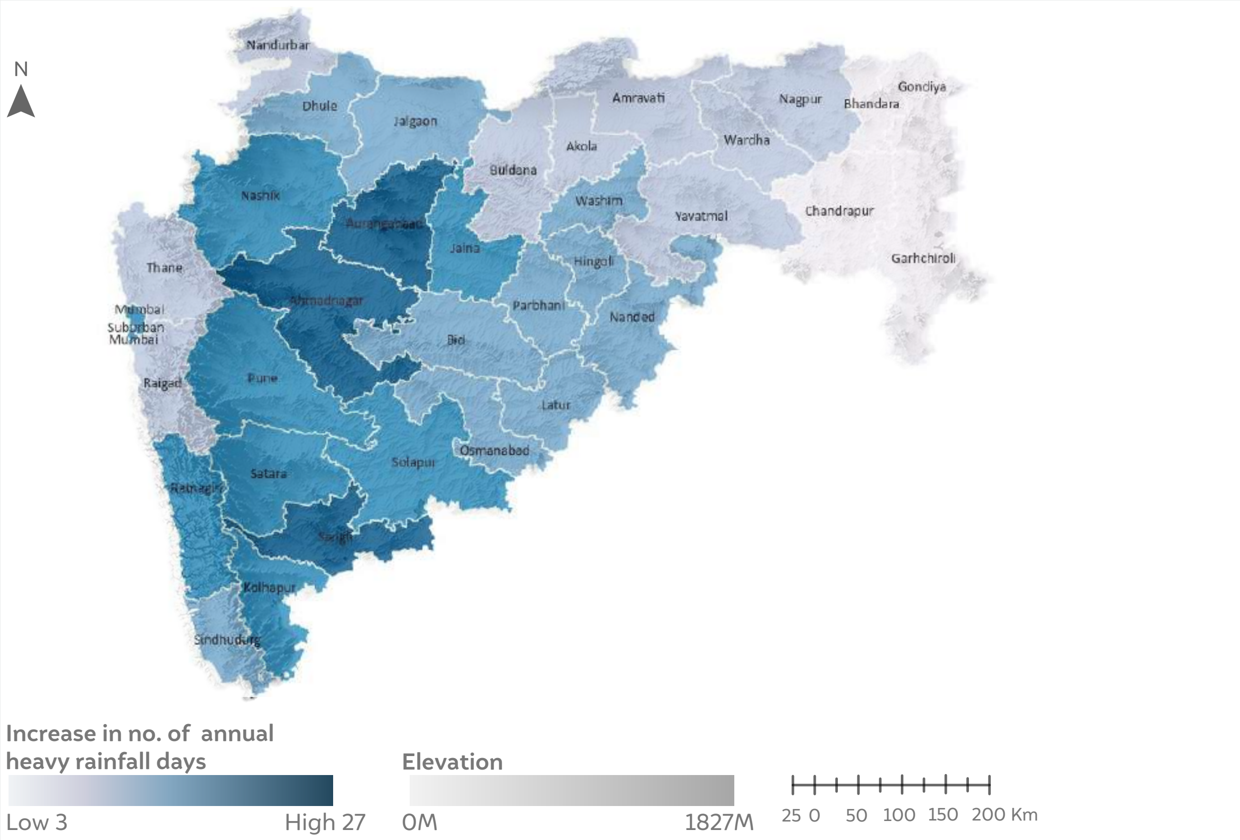
Source: Authors' analysis

Box 3 **Maharashtra's changing monsoon patterns (projections for 2020–2050)**

The increased frequency of floods and cyclones, and the emergence of new flood hotspots, highlight that the hazard component is relative to the time of observation; that is, it is expected to change as more occurrences are recorded over time. Being able to predict such hazards accurately would help administrators prioritise precautionary measures.

To explore how the hazard score may vary over the next 30 years, the evolving precipitation trend in Maharashtra has been examined by projecting the change in the number of heavy rainfall days per year. This was conducted using the Indian Institute of Tropical Meteorology (IITM)'s Regional Climate Modelling (RCM)[11] projections. These projections are based on CORDEX SA[12] for Representative Concentration Pathway[13] (RCP) 4.5 and RCP 8.5 scenarios up to 2050. This presents the likelihood of each district experiencing extreme precipitation in the future.

Figure 14 Eleven out of thirty-six districts observe an increase in the number of annual heavy rainfall days by more than 18%



Source: Authors' analysis

The analysis shows that historically drier regions such as Desh, Khandesh, Marathwada, and Vidarbha would receive higher precipitation as they are projected to witness a drastic increase in the number of annual heavy rainfall days (Figure 14). Therefore, the healthcare facilities in these districts must increase their resilience so that they can cope during such an extreme event and prevent it from turning into a disaster.

Source: Authors' analysis

11 Regional climate modelling (RCM) simulates local climate by using output from a global climate model as input to a high-resolution climate model.

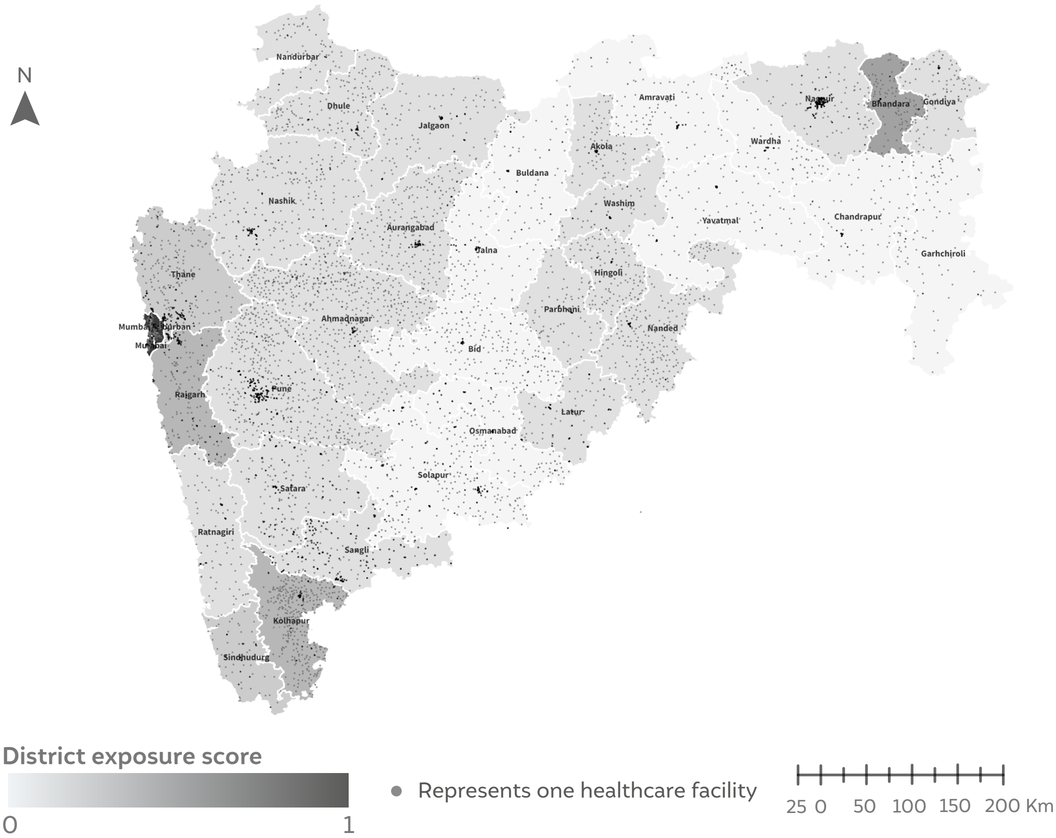
12 Coordinated Regional Climate Downscaling Experiment (CORDEX) is a World Climate Research Programme (WCRP) framework designed to evaluate regional climate model performance through a set of experiments aimed at producing regional climate projections. The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships (CORDEX n.d.).

13 The Intergovernmental Panel on Climate Change (IPCC) describes RCP 4.5 as a moderate scenario in which emissions peak around 2040 and then decline. RCP 8.5 is the highest baseline emissions scenario where emissions continue to rise throughout the twenty-first century.

3.2 The state of exposure of Maharashtra's healthcare facilities

In our study, each district's exposure is determined by the density of healthcare facilities. The number of healthcare facilities required in an area is determined by the population density, as each type of healthcare facility is meant to serve a specific population size (according to IPHS 2022). Therefore, **districts** with **higher population densities** have more healthcare facilities, resulting in higher exposure levels.

Figure 15 **Five out of thirty-six districts in Maharashtra fall in the high to very high exposure category**



Source: Authors' analysis

The Konkan division has the highest exposure, as it houses the state's largest cities. The Mumbai and Mumbai Suburban districts, being highly urbanised areas, have the highest density of healthcare facilities and, therefore, exhibit the highest exposure levels.

They are followed by Bhandara, Kolhapur, Raigad, Sindhudurg, and Thane, respectively (Figure 15). Although Pune and Nagpur house a higher number of healthcare facilities, they are scattered across the districts, which are also larger in terms of total land area, thereby reducing the density. This results in a lower exposure score, a trend widely observed across most districts in Maharashtra (see Table 3), as they currently exhibit a low to moderate exposure score. However, it must be noted that exposure will not remain constant as the state's population grows[14] and is redistributed into dense urban clusters. Moreover, to meet the observed 25 per cent shortfall in PHCs and a 56 per cent shortfall in community healthcare centres across the state,[15] a higher number of healthcare facilities or significant upgrades will be required, resulting in higher exposure scores in the near future.

14 It is estimated to grow by 15.7 per cent by 2031 as per Population Projections for India and States (2011–36).
15 As per *Rural Healthcare Statistics* (2021–22) by MoHFW.

Table 3 Mumbai and Mumbai Suburban have the highest exposure scores

S. No.	District	Total no. of HI	District area (sq. km)	HI density	Exposure score
1	Mumbai	359	157	2.29	1.00
2	Mumbai Suburban	116	446	0.26	0.93
3	Bhandara	516	4,087	0.13	0.45
4	Kolhapur	830	7,685	0.11	0.39
5	Raigad	730	7,152	0.10	0.36
6	Sindhudurg	467	5,207	0.09	0.32
7	Thane	736	9,558	0.08	0.28
8	Sangli	612	8,572	0.07	0.25
9	Ahmadnagar	1194	17,048	0.07	0.25
10	Gondia	364	5,234	0.07	0.25
11	Nagpur	659	9,892	0.07	0.24
12	Parbhani	404	6,214	0.07	0.23
13	Nandurbar	380	5,955	0.06	0.23
14	Nanded	667	10,528	0.06	0.23
15	Dhule	430	7,195	0.06	0.21
16	Pune	898	15,643	0.06	0.21
17	Nashik	890	15,530	0.06	0.20
18	Hingoli	273	4,827	0.06	0.20
19	Aurangabad	569	10,131	0.06	0.20
20	Satara	557	10,480	0.05	0.19
21	Washim	251	4,901	0.05	0.18
22	Latur	362	7,157	0.05	0.18
23	Jalgaon	594	11,765	0.05	0.18
24	Akola	278	5,673	0.05	0.18
25	Ratnagiri	387	8,208	0.05	0.17
26	Osmanabad	340	7,569	0.04	0.16
27	Jalna	321	7,694	0.04	0.15
28	Wardha	258	6,309	0.04	0.15
29	Solapur	597	14,895	0.04	0.14
30	Amravati	466	12,210	0.04	0.14
31	Chandrapur	430	11,443	0.04	0.13
32	Buldhana	363	9,661	0.04	0.13
33	Gadchiroli	484	14,412	0.03	0.12
34	Bid	316	10,693	0.03	0.11
35	Yavatmal	257	13,582	0.02	0.07

Source: Authors' analysis

3.3 The state of vulnerability of Maharashtra's healthcare facilities

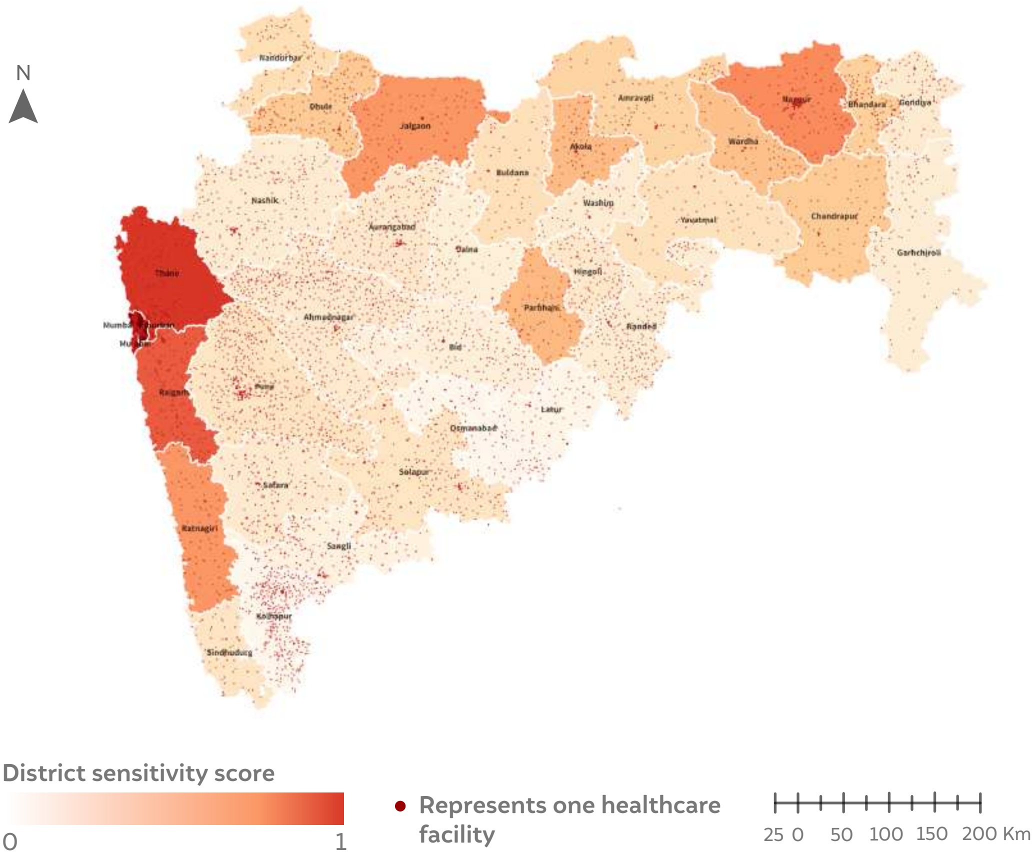
The **vulnerability** of a district's healthcare facilities is a function of two variables: their **sensitivity** to floods and cyclones and their **capacity to adapt to or cope** with a disaster. The findings from the analyses of each of these components, elucidated in the following sections, have been compiled to estimate the vulnerability score.

Sensitivity of healthcare facilities in Maharashtra

The **sensitivity** of healthcare facilities in a district refers to the degree to which they might be impacted by a flood or cyclone. In our study, sensitivity is determined using indicator categories that assess the following: whether the healthcare facility is geographically located in a susceptible area, whether it is situated in a zone of non-compliance, and/or whether it is heavily dependent on other susceptible critical infrastructures, as detailed in Table A3 in Annexure I.

The analysis revealed that healthcare facilities in **4 out of 36 districts** in Maharashtra are highly sensitive to floods and cyclones, while those in **22 districts** show low to moderate sensitivity. The **Konkan division** is most sensitive to extreme floods and cyclones. **Mumbai Suburban** is the most sensitive, as **88 per cent** of the district's healthcare facilities are located in areas highly susceptible to both floods and cyclones. It is closely followed by **Mumbai** and **Thane**. The healthcare facilities in these districts also exhibit a high dependency on other susceptible critical infrastructure assets such as roads and power stations, which magnify their sensitivity. Figure 16 provides an overview of the district-wise sensitivity of healthcare facilities in Maharashtra.

Figure 16 Healthcare facilities in Mumbai Suburban and Mumbai are highly sensitive to floods and cyclones



Source: Authors' analysis

Adaptive capacity of healthcare facilities in Maharashtra

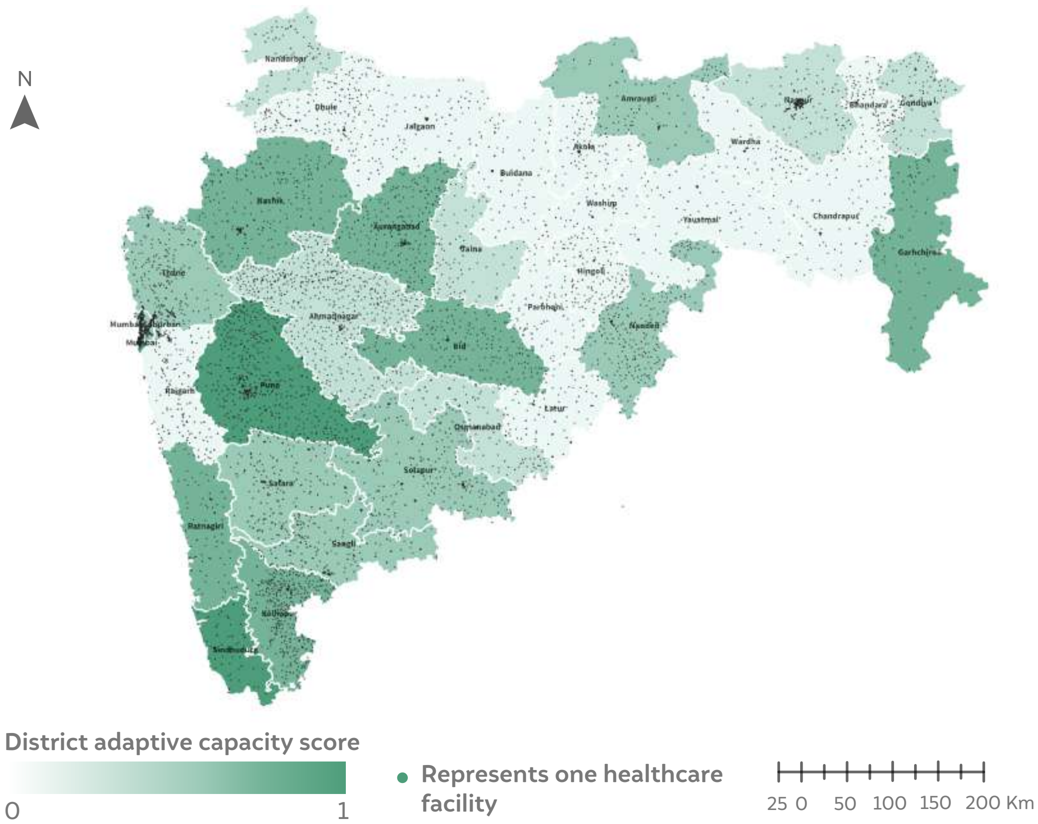
The **adaptive capacity** of a healthcare facility refers to its ability to respond to or cope with an extreme event. The analysis revealed that healthcare facilities in **8 out of 35** districts have high adaptive capacity, while those in **8 districts** possess moderate adaptive capacity. However, alarmingly, healthcare facilities in **19 districts** have low adaptive capacity.

Mumbai, Sindhudurg, and Ratnagiri, located in the coastal Konkan division, are prone to frequent floods and cyclones. These districts recorded the highest administrative capacity scores (see Figure 17), indicating that healthcare facilities in these districts are better prepared and trained for anticipatory action. This results in their high adaptive capacity.

On the other hand, the districts of Nashik, Aurangabad, Gadchiroli, and Pune have robust DDMPs that contain relevant structural and non-structural strategies for improving healthcare resilience against extreme climate events. These districts also recorded higher annual expenditures on healthcare systemic strengthening, as documented in the district's budget sheet under the NHM (NHM PIP Budget 2023).

Additionally, Pune has the largest number of NQA- and NABH-accredited hospitals, which are more operationally efficient. Therefore, Pune's healthcare system is more likely to remain functional during a disaster, contributing to its high adaptive capacity.

Figure 17 Healthcare facilities in Mumbai, Pune, and Sindhudurg have the highest adaptive capacity to floods and cyclones



Source: Authors' analysis

However, **8,404 healthcare facilities**, making up 48 per cent of the total healthcare facilities across 19 districts in the state, have low adaptive capacity. These 19 districts especially lack structural and functional capacities and recorded low expenditures on healthcare system strengthening.

Through our analysis, we found that the DDMPs of these districts have not listed norms for structural compliance of their healthcare facilities. Having failed to prioritise structural capacity, these districts have also recorded low expenditures on structurally upgrading their healthcare facilities. Additionally, healthcare facilities in these districts have lower functional capacity, with only eight accredited hospitals present across 19 districts.

In addition to these factors, healthcare facilities in Chandrapur, Dhule, Jalgaon, and Parbhani showcase very low administrative capacity or facility preparedness. Being historically less prone to floods and cyclones, the DDMPs of these districts do not yet address healthcare resilience – they neither mention the need for hospital disaster management plans nor stress the need for continuity of essential services during a disaster, as recommended by NDMA guidelines. This results in a very low adaptive capacity score, rendering these healthcare facilities highly vulnerable to extreme events. Figure 18 captures how the adaptive capacity of healthcare facilities varies among districts.

Based on these findings, Maharashtra must invest in strategic planning to improve the adaptive capacity and, thereby, the resilience of its healthcare facilities. It is interesting to note that the DDMP of most districts in Maharashtra is revised annually or biannually. This presents an opportunity to incorporate these granular findings and devise context-specific solutions.

Estimating vulnerability

The vulnerability score provides insight into whether the risk to healthcare facilities in a district might increase in the future and what the leading causes might be. The study finds that **7 out of 35 districts** in Maharashtra are highly vulnerable to extreme floods and cyclones, while **8 districts** are moderately vulnerable, and the remaining 20 districts depict low vulnerability. The vulnerability arises from either high sensitivity, low adaptive capacity, or a combination of both factors. Drawing from the analyses of the sensitivity and adaptive capacity of healthcare facilities in each district, Table 4 lists the vulnerability levels of healthcare facilities in each district.

Currently, districts in Maharashtra are vulnerable due to the very low adaptive capacity of healthcare facilities in these districts, coupled with moderate sensitivity. Therefore, it is imperative to improve their adaptive capacity. Healthcare facilities located in highly sensitive districts must especially invest in improving their adaptive capacities to reduce overall vulnerability.

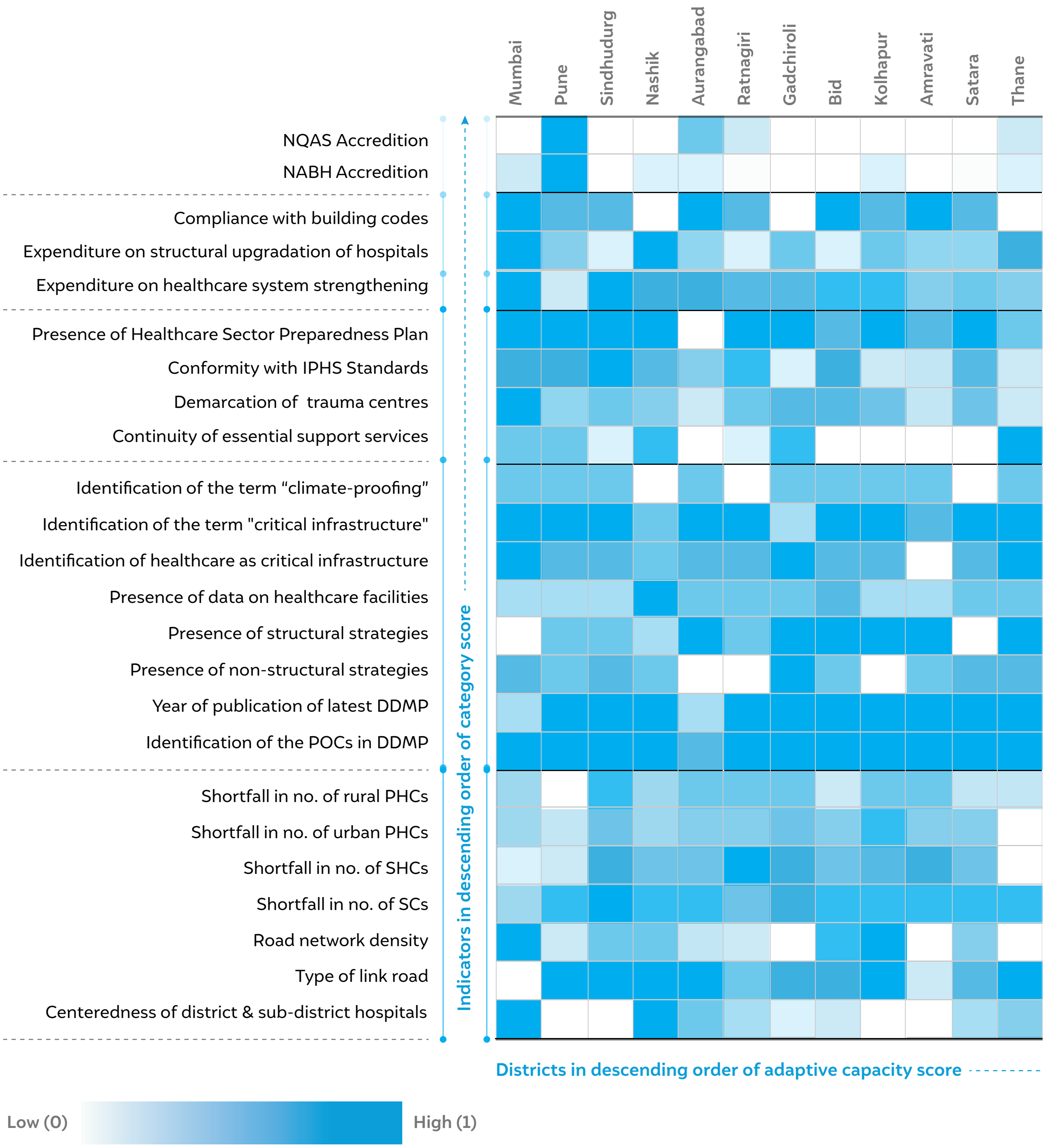
Furthermore, it is important to note that both hazard and exposure levels are expected to rise due to the combined i mpacts of climate change and rapid urbanisation. Therefore, it is imperative to reduce the vulnerability of healthcare facilities in such districts and build their capacity to withstand the impacts of extreme climate events.

Table 4 Healthcare facilities in Chandrapur, Dhule, Jalgaon, Parbhani, and Raigad are highly vulnerable due to their very low adaptive capacity scores

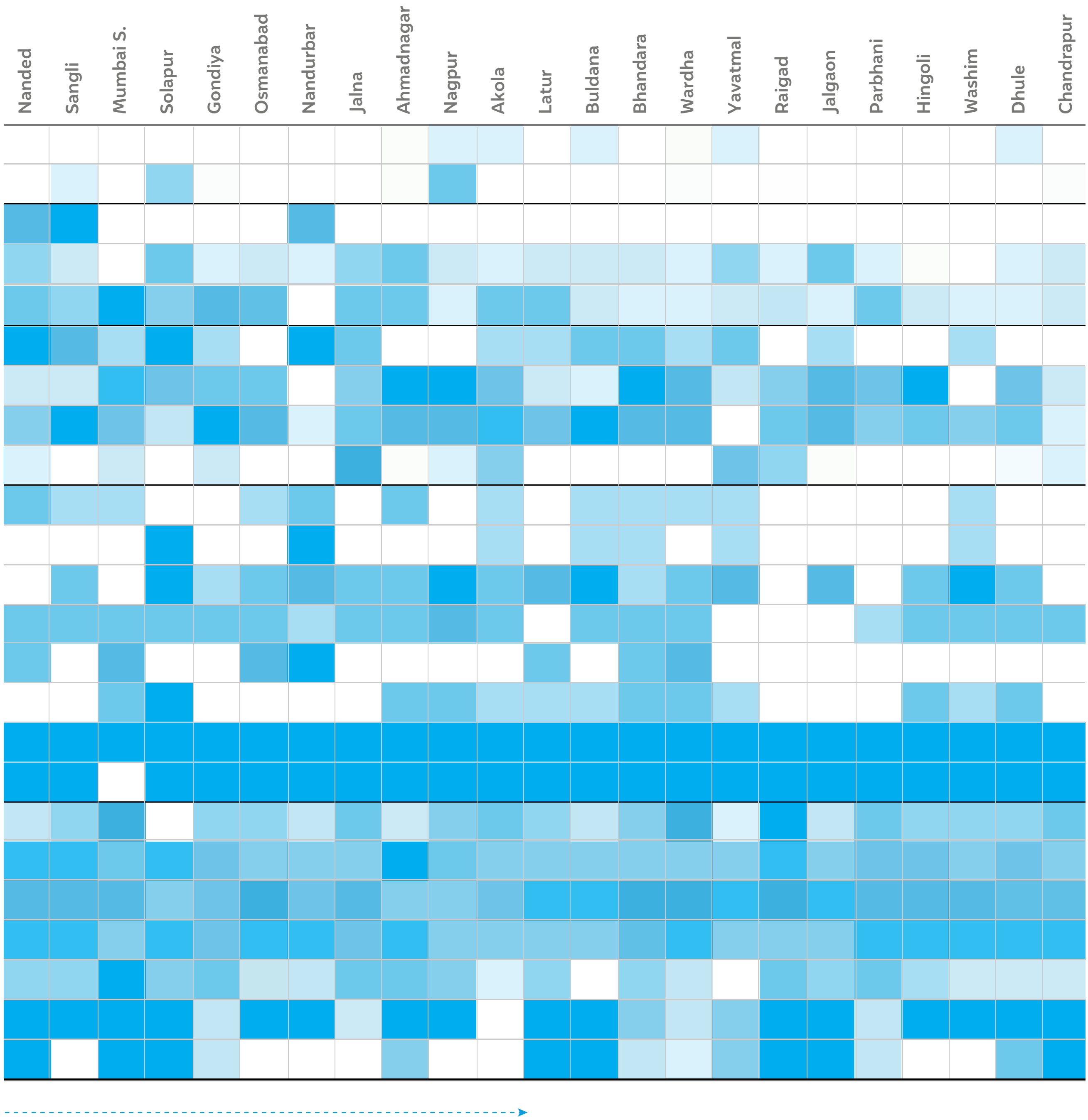
Rank	District	Sensitivity	Adaptive capacity	Vulnerability
1	Chandrapur	0.38	0.01	1.00
2	Dhule	0.37	0.04	0.94
3	Jalgaon	0.54	0.07	0.83
4	Parbhani	0.45	0.06	0.74
5	Raigad	0.69	0.10	0.71
6	Washim	0.20	0.05	0.46
7	Hingoli	0.22	0.05	0.44
8	Wardha	0.42	0.15	0.29
9	Nagpur	0.57	0.24	0.25
10	Mumbai Suburban	1.00	0.47	0.22
11	Bhandara	0.36	0.18	0.21
12	Akola	0.44	0.24	0.20
13	Yavatmal	0.26	0.15	0.19
14	Buldhana	0.27	0.19	0.15
15	Thane	0.77	0.57	0.14
16	Nandurbar	0.28	0.27	0.11
17	Mumbai	0.85	1.00	0.09
18	Ahmadnagar	0.21	0.26	0.09
19	Ratnagiri	0.54	0.73	0.08
20	Gondia	0.21	0.32	0.07
21	Latur	0.13	0.20	0.07
22	Jalna	0.18	0.30	0.06
23	Amravati	0.33	0.61	0.06
24	Solapur	0.24	0.46	0.05
25	Osmanabad	0.12	0.31	0.04
26	Nanded	0.19	0.52	0.04
27	Satara	0.21	0.59	0.04
28	Sangli	0.16	0.50	0.03
29	Aurangabad	0.22	0.75	0.03
30	Sindhudurg	0.24	0.82	0.03
31	Pune	0.24	0.85	0.03
32	Gadchiroli	0.19	0.71	0.03
33	Nashik	0.20	0.76	0.03
34	Bid	0.17	0.71	0.03
35	Kolhapur	0.00	0.69	0.00

Source: Authors' analysis

Figure 18 **Healthcare facilities in 19 districts in Maharashtra lack the functional, structural, and/or administrative capacity to tackle the impacts of extreme climate events**



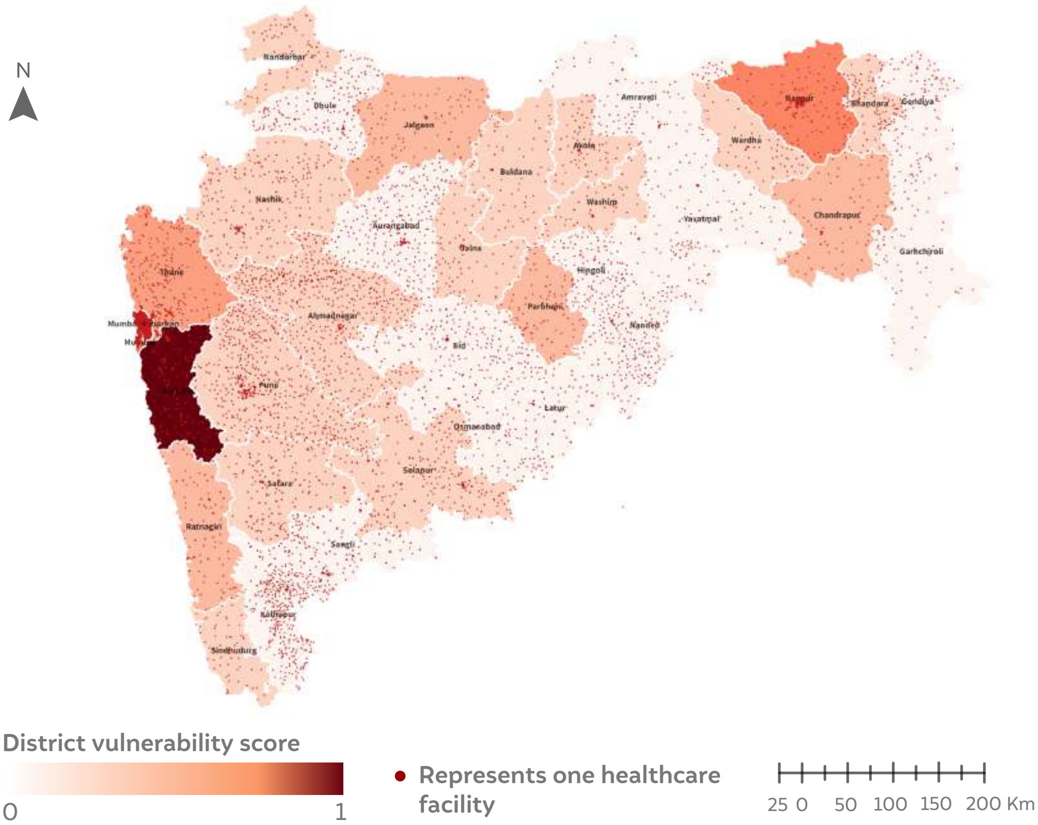
Source: Authors' analysis


Nanded
Sangli
Mumbai S.
Solapur
Gondiya
Osmanabad
Nandurbar
Jalna
Ahmadnagar
Nagpur
Akola
Latur
Buldana
Bhandara
Wardha
Yavatmal
Raigad
Jalgaon
Parbhani
Hingoli
Washim
Dhule
Chandrapur

3.4 The state of risk to Maharashtra's healthcare facilities

The combination of the hazard, exposure, and vulnerability components provides the cumulative risk score. The study finds that approximately **11 per cent of Maharashtra's healthcare facilities** are at **moderate to very high risk** from floods and cyclones, and they are concentrated in four **densely populated districts**: **Raigad, Mumbai Suburban, Mumbai, and Nagpur**. Three out of four of these districts are situated in the coastal Konkan division, which is most prone to both floods and cyclones (hazard) and also observes the highest density of healthcare facilities (exposure). The existing vulnerabilities of the healthcare facilities in these districts further amplify risk. Figure 19 shows the risk map of healthcare facilities across districts in Maharashtra.

Figure 19 **Healthcare facilities in Raigad are at very high risk, followed by those in Mumbai Suburban and Mumbai**



Source: Authors' analysis

Healthcare facilities in other administrative divisions face much lower risk levels due to significantly lower hazard and exposure scores, as highlighted in Table 5 However, healthcare facilities in districts such as Chandrapur, Dhule, and Parbhani will likely be at risk in the future as they have underlying vulnerabilities due to very low adaptive capacities.

Table 5 Healthcare facilities in Raigad and Mumbai Suburban are at high risk from floods and cyclones

District	Hazard score	Exposure score	Vulnerability	Risk score	Risk level
Raigad	1.00	0.36	0.71	1.00	Very high
Mumbai Suburban	0.73	0.93	0.22	0.59	High
Mumbai	0.73	1.00	0.09	0.25	Moderate
Nagpur	0.55	0.24	0.25	0.13	Moderate
Thane	0.45	0.28	0.14	0.07	Low
Parbhani	0.09	0.23	0.74	0.06	Low
Jalgaon	0.09	0.18	0.83	0.05	Low
Ratnagiri	1.00	0.17	0.08	0.05	Low
Chandrapur	0.09	0.13	1.00	0.05	Low
Akola	0.27	0.18	0.20	0.04	Low
Bhandara	0.09	0.45	0.21	0.03	Low
Washim	0.09	0.18	0.46	0.03	Low
Sindhudurg	0.55	0.32	0.03	0.02	Low
Jalna	0.45	0.15	0.06	0.02	Low
Ahmadnagar	0.18	0.25	0.09	0.01	Low
Wardha	0.09	0.15	0.29	0.01	Low
Nashik	0.45	0.20	0.03	0.01	Low
Nandurbar	0.09	0.23	0.11	0.01	Low
Solapur	0.27	0.14	0.05	0.01	Low
Satara	0.27	0.19	0.04	0.01	Low
Buldhana	0.09	0.13	0.15	0.01	Low
Pune	0.27	0.21	0.03	0.01	Low
Yavatmal	0.09	0.07	0.19	0.00	Very low
Latur	0.09	0.18	0.07	0.00	Very low
Gadchiroli	0.27	0.12	0.03	0.00	Very low
Nanded	0.09	0.23	0.04	0.00	Very low
Sangli	0.09	0.25	0.03	0.00	Very low
Bid	0.27	0.11	0.03	0.00	Very low
Osmanabad	0.09	0.16	0.04	0.00	Very low
Aurangabad	0.09	0.20	0.03	0.00	Very low
Dhule	0.00	0.21	0.94	0.00	Very low
Kolhapur	0.09	0.39	0.00	0.00	Very low
Amravati	0.00	0.14	0.06	0.00	Very low
Gondia	0.00	0.25	0.07	0.00	Very low
Hingoli	0.00	0.20	0.44	0.00	Very low

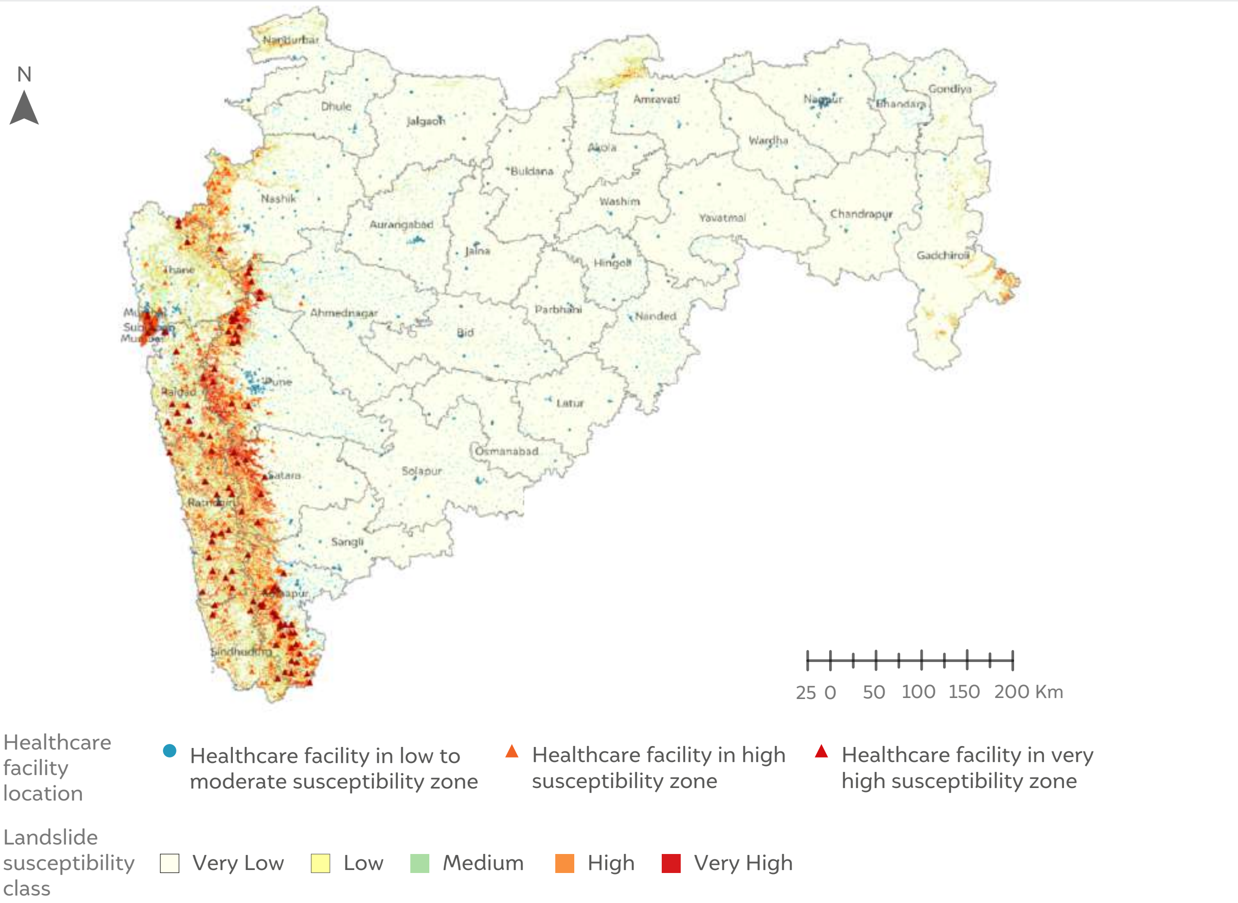
Source: Authors' analysis

Furthermore, our analysis of projected rainfall trends predicts an average increase of 15 per cent in annual heavy rainfall days, with traditionally drier regions such as Desh and Vidarbha receiving more precipitation. Urbanisation and population growth in these areas would also require the establishment of larger healthcare facilities, which would increase exposure levels. Ultimately, this would render currently vulnerable healthcare facilities at risk unless necessary measures are undertaken. Therefore, there is a need to consider both current and future risk scenarios, interpret the risk drivers, and plan for long-term resilience.

Box 4 **Assessing the risk from associated events such as rainfall-induced landslides**

Indian coastal regions are frequently affected by floods and cyclones, which often trigger secondary disasters such as rainfall-induced landslides (Amarasinghe et. al. 2024). These cascading events amplify disaster risks, leading to greater damage and losses (Rao and Singh 2020). Given the unpredictability of point-based events like landslides, it thus becomes crucial to assess their risk using geospatial technology. Landslide susceptibility maps, which analyse topographic and hydrological factors, can identify areas at high risk of floods and potential landslides (Kumar et al. 2022). These maps serve as valuable tools in hazard management, allowing for targeted resource allocation to the most vulnerable areas. A recent study by Sharma et al. (2024) developed a high-resolution (approximately 100 meters) landslide susceptibility map for India. Such maps can serve as a critical base layer for disaster preparedness, by identifying healthcare facilities situated in at-risk zones (see Figure 20).

Figure 20 **9 per cent of healthcare facilities in coastal districts of Maharashtra are situated in high landslide-risk zones**



Source: Authors' analysis

Our analysis reveals that while most facilities in the state are not susceptible to landslides, over 600 healthcare facilities in 16 districts of Maharashtra are situated in moderate to high landslide susceptibility zones. Additionally, more than 110 facilities, located in the Western ghats, are situated in zones of very high susceptibility (see Table 6).

Table 6 More than 750 healthcare facilities across 16 districts of Maharashtra are located in landslide-susceptible areas

District	No. of healthcare facilities in moderate landslide susceptibility zones	No. of healthcare facilities in high landslide susceptibility zones	No. of healthcare facilities in very high landslide susceptibility zones	Total no. of healthcare facilities in landslide susceptible zones
Mumbai Suburban	86	84	12	182
Kolhapur	38	46	32	116
Mumbai	44	50	2	96
Pune	25	30	16	71
Raigad	29	32	9	70
Ratnagiri	16	20	18	54
Thane	25	15	7	47
Nashik	15	20	1	36
Ahmednagar	12	10	4	26
Sindhudurg	14	10	2	26
Satara	9	6	8	23
Nandurbar	5	0	0	5
Sangli	2	1	0	3
Amravati	2	0	0	2
Beed	2	0	0	2
Total	**324**	**324**	**111**	**759**

Source: Authors' analysis

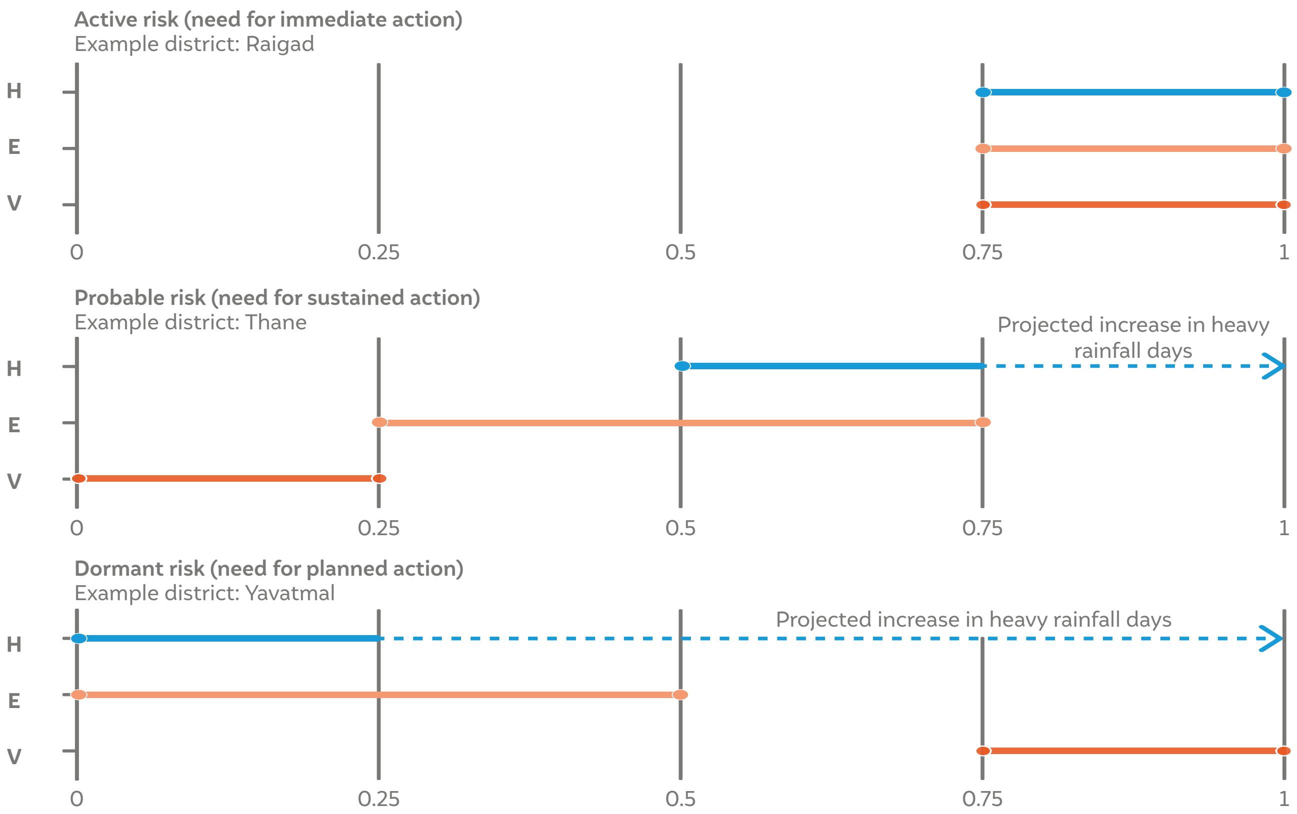
The finding deepens the concern that healthcare facilities are not adequately equipped to withstand landslides (Sharma et al. 2024). In the long term, relocation or capacity enhancement of these facilities is therefore necessary to adapt to potential risks. Healthcare facilities should build resilience against landslides, which requires a combination of structural and non-structural adaptation measures, such as improving drainage systems, reinforcing slopes, and enhancing early warning mechanisms (Kumar et al. 2023). Additionally, it must be noted that unregulated urbanisation exacerbates the issue by destabilising slopes, turning them prone to collapse during heavy rainfall (Patil and Joshi 2021). Thus, implementing stringent regulations on land use and development of critical infrastructure such as healthcare facilities is essential to prevent further degradation of slope stability, as well as ensure minimal disruption of essential services during a disaster.

Source: Authors' analysis

Prioritisation of districts based on risk drivers

A prioritisation exercise based on an analysis of current and future risk drivers can help increase efficiency and facilitate long-term planning. Based on various combinations of hazard, exposure, and vulnerability, three emerging risk categories were identified, as depicted in Figure 21.

Figure 21 **The risk to healthcare facilities can be categorised into three categories based on the risk drivers**



Source: Authors' analysis

Active risk

(Hazard score (H): 0.75 to 1, exposure score (E): 0.75 to 1, vulnerability score (V): 0.75 to 1)

The first category, 'active risk', is characterised by moderate to very high (0.4 to 1.00) scores for all three components, resulting in a moderate to high-risk score. The districts in this category already face high risk and will continue to experience increasing risk as the number of annual heavy rainfall days rises. For example, the coastal districts of Mumbai Suburban, Mumbai, and Raigad fall under this category. Immediate action is therefore necessary to improve the adaptive capacity – especially structural, functional, and administrative capacity – of healthcare facilities in these districts to protect against future loss and damage.

Dormant risk

(Hazard score (H): 0 to 0.25, exposure score (E): 0 to 0.25, vulnerability score (V): 0.75 to 1)

The second risk category comprises districts that are currently at low risk due to low hazard and exposure scores but have underlying vulnerabilities. Examples include Dhule, Chandrapur, and Parbhani, among others, which have very low adaptive capacity. The healthcare facilities in these districts require coordinated and well-planned action strategies, guided by the findings of a thorough risk assessment. These districts should plan for long-term resilience, investing in consistent efforts to improve the adaptive capacity of existing facilities, as well as strategically planning new infrastructure in less sensitive locations.

Probable risk

(Hazard score (H): 0.5 to 0.75, exposure score (E): 0.25 to 0.75, vulnerability score (V): 0 to 0.25)

The third category of 'probable risk' comprises districts with moderate scores for each risk component. These districts are currently at low risk despite experiencing moderate hazard and exposure. This is because they also have low sensitivity and a moderate adaptive capacity score. For example, Ratnagiri district, located in the Konkan division, is highly hazard-prone and sensitive. However, healthcare facilities in the district have a moderate adaptive capacity, thereby reducing the overall risk.

However, as these districts are also expected to witness increasing precipitation trends, healthcare facilities here must continue to "sustain" efforts to keep the vulnerability level low. Most districts in Maharashtra fall under the third category, as detailed in Table 7.

Table 7 Healthcare facilities in 19 out of 35 districts in Maharashtra need sustained action to build resilience against floods and cyclones

Category	Action type	Districts	Total no. of assets	Percentage of healthcare facilities in the state
Active risk: Currently at moderate to high risk	**Immediate action**	Raigad, Mumbai Suburban, Mumbai, Nagpur	1,521	10.7
Dormant risk: Likely to observe future risk in BAU due to low adaptive capacity	**Planned action**	Akola, Bhandara, Buldhana, Chandrapur, Dhule, Hingoli, Jalgaon, Parbhani, Sangli, Thane, Wardha, Washim, Yavatmal	5,402	31.1
Probable Risk: Likely to observe future risk unless adaptive capacity steadily increases	**Sustained action**	Ahmadnagar, Amravati, Aurangabad, Bid, Gadchiroli, Gondia, Jalna, Kolhapur, Latur, Nanded, Nandurbar, Ratnagiri, Sindhudurg, Nashik, Osmanabad, Pune, Satara, Solapur	10,432	58.2

Source: Authors' analysis

These insights thus provide Maharashtra with the opportunity to strategise resource allocation, develop a suitable roadmap for implementation, and prioritise districts that need immediate intervention.

Scaling the framework in other states

The Maharashtra case study showcases how the framework can be applied to assess the risk to healthcare facilities in the state. Similarly, it can be applied to districts across any other state as it is designed to be scalable.

Indicators in the framework have been selected to rely on publicly available datasets. Indicators for the hazard, exposure, and sensitivity components (detailed in Annexure II) remain uniform across states as they are either quantitative (e.g., data on disaster occurrence, the number of healthcare facilities) or geospatial in nature (e.g., the percentage of healthcare facilities in flood-susceptible areas).

Data for 12 out of 24 indicators for adaptive capacity can be retrieved from readily available national sources such as the NHM website, the *Annual Rural Healthcare Statistics Report* by MoHFW, or the NABH website. Another 10 indicators can be assessed by evaluating the respective DDMPs, available on the websites of the respective state disaster management authorities (SDMAs), while the remaining indicators can be assessed geospatially.

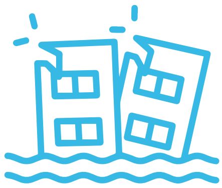
Therefore, the easy-to-implement framework can mainstream risk assessment of healthcare facilities, encouraging state health departments to make risk-informed decisions towards climate-proofing their current and future infrastructure.

The All India Institute of Medical Sciences (AIIMS) in Delhi has installed a 9-kilowatt rooftop solar plant to reduce carbon emissions.

Image: Alamy

4. Recommendations for building the resilience of healthcare facilities in India

To ensure that current and future healthcare facilities are resilient against the impacts of extreme climate events, they must be supported by policy and action at scale. The following interconnected recommendations can enhance the resilience of healthcare infrastructure by highlighting prioritised actions and the respective roles and responsibilities of each governing authority.



The National Centre for Disease Control (NCDC) issues regular advisories to prevent health damage due to floods

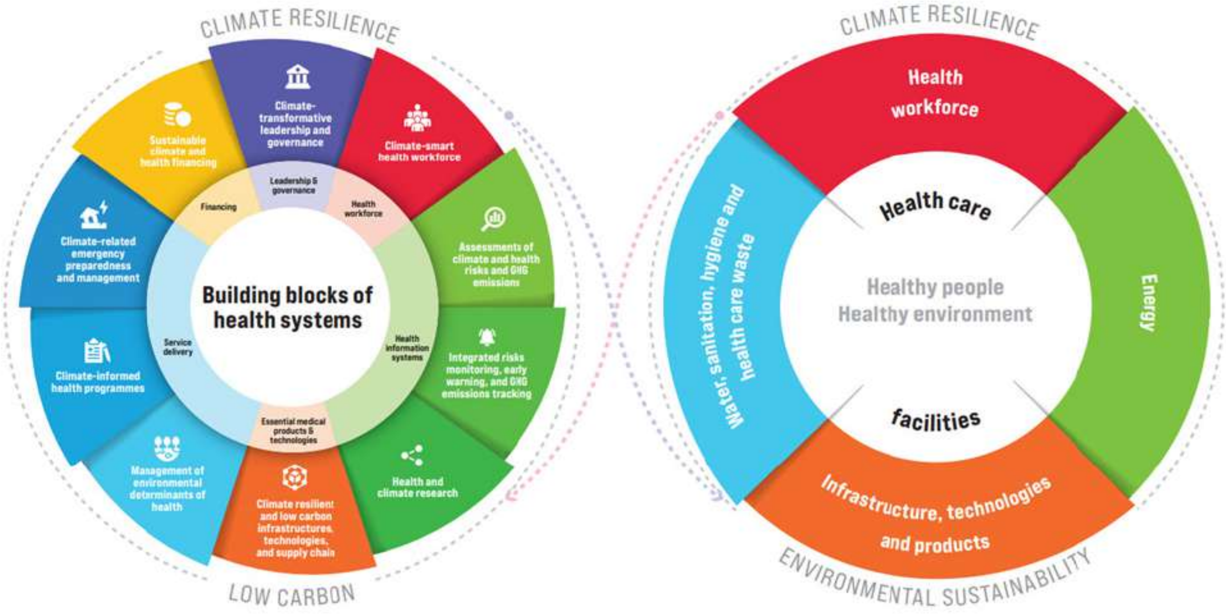
4.1 The *National Programme on Climate Change and Human Health* should identify the characteristics of healthcare infrastructure resilience

The *National Health Policy 2017*, emphasises the importance of resilient healthcare infrastructure, especially during extreme climate events such as floods and cyclones. However, it emphasises emergency response and mass casualty management, which are equally important in healthcare service delivery but incomplete without resilient infrastructure. The *National Programme on Climate Change and Human Health* (NPCCHH), launched in 2019, provides comprehensive guidelines on *Green and Climate Resilient Healthcare Facilities*. Still, the guidelines mainly address mitigation strategies such as the solarisation of facilities, efficient waste management, and water use, but they fail to address the resilience of healthcare infrastructure against disasters.

Therefore, these guidelines must be updated and revised with **clearly defined actions** for climate change adaptation. However, effective adaptation of healthcare infrastructure requires on-the-ground assessment and real-time monitoring. Simple tools, such as checklists, can ensure that the national guidelines are implemented locally.

As part of our study, a **Healthcare Facility Resilience Checklist** has been prepared, inspired by and meant to complement the checklist by NPCCHH for green healthcare facilities (Annexure III). Built on the recommendations of the World Health Organization (WHO) for building climate-resilient healthcare, this checklist, when co-developed with the implementing authority, can serve as a self-assessment tool for healthcare facilities to evaluate their vulnerabilities (Figure 22). This can further provide scientific evidence for healthcare administrators to prioritise adaptation actions and invest in pinpointed solutions, guided by the requirements of their specific facility. Integrating the checklist into NPCCHH would ensure implementation across states by mainstreaming risk assessments and building holistic resilience of healthcare infrastructure as standard practice.

Figure 22 **Healthcare systems in India can draw inspiration from WHO's Operational framework for building climate-resilient and low-carbon health systems**



Source: WHO 2020. Operational Framework for Building Climate-resilient and Low-carbon Health Systems. Geneva: World Health Organization.

4.2 District health departments must assess on-ground risk and build the resilience of healthcare facilities

A quantitative risk assessment can help identify inherent vulnerabilities in healthcare facilities, enabling the selection of risk-informed solutions. Such an assessment will yield granular results when conducted at the district level, allowing the district health administrator to adopt context-specific solutions. By following resources such as the Healthcare Facility Resilience Checklist, district health departments can regularly collect data from each healthcare facility. Leveraging expert knowledge of hazard occurrence and underlying geographical vulnerabilities, the district disaster management authority can coordinate with the health department to conduct a district-level risk assessment of existing healthcare facilities. The state can then utilise this data to develop action plans suited to the state's priorities.

However, since no solution is one-size-fits-all, the strategies outlined by a state-level plan may not always be feasible or impactful in a particular district, as they are subject to time, cost, and resource constraints (see Box 5). Knowledge of local prevailing factors lies with the local administrators. Therefore, an asset-level risk assessment must be followed by an analysis of these factors to help shortlist and tailor those strategies that would produce the most desirable outcome in terms of resilience building.

Box 5 **Feasibility versus impact: Deciding the suitability of adaptation strategies based on local constraint factors**

Factors such as the duration of a project, cost, and available resources often pose constraints, preventing an adaptation strategy from being successfully implemented. To understand the importance of such factors in building healthcare infrastructure resilience, we synthesised the recommendations of the WHO Guidance on Climate Resilient and Environmentally Sustainable Healthcare Facilities, 2020, designed to achieve infrastructure resilience. The following six key strategies were identified:

- Hazard and vulnerability mapping at the local scale
- Structural reinforcement through retrofitting
- Adoption of technologies such as early warning systems for effective disaster communication
- Improved sustainability of healthcare facility operations through facility preparedness and capacity building
- Development of health information systems with Climate Information for mapping target groups and catchment areas for emergency preparedness
- Development of an emergency preparedness plan for main and subsequent disasters such as epidemics

An expert opinion survey was conducted with 15 experts from the cross-sectoral fields of climate change and human health to rank these strategies based on feasibility and impact, considering their suitability to the Indian context. The survey revealed that emergency preparedness plans are the most feasible and impactful, while structural reinforcement is often not viable due to a lack of resources and technical expertise. Table 8 provides the ranks assigned to each strategy, where "rank 1" represents the most feasible or impactful.

Table 8 A feasibility versus impact assessment of strategies for improving healthcare infrastructure resilience can ease implementation on-ground

Theme	Strategy	Feasibility ranking	Impact ranking	Rationale
Risk mapping	Hazard and vulnerability mapping of healthcare facilities to assess risk and exposure	2	2	Awareness of risk levels in the facility enables risk-informed decision-making and action toward climate-proofing.
Structural reinforcement	Retrofitting of existing buildings by incorporating building regulations and expert advice on incorporating topography, flood history, and local climate	6	4	While retrofitting is important and impactful, its feasibility is limited, as most facilities lack the resources and capacity required to retrofit structures.
Innovation and technology	Use of technology for hospital early warning systems and effective communication during disasters	4	3	Dependency on weather data and limited network coverage in remote areas, such as hilly regions, reduces the feasibility of hospital early warning systems. Furthermore, most facilities are unable to interpret the data directly.
Facility preparedness	Sustainability of healthcare facility operations (facility preparedness and capacity-building)	5	5	Health facilities in India face challenges in terms of funding, manpower, and resources, which reduces their feasibility.
	Health information systems and climate information: mapping target groups and catchment areas for emergency preparedness	3	6	As patient registers are available with their respective healthcare facilities, PHCs can be trained to map areas as part of micro-plans for vulnerable populations.
Policy and planning	Emergency preparedness plan for main and subsequent disasters such as epidemics	1	1	Contingency plans at the local and subnational scales, such as hospital disaster management plans and district action plans for climate change and human health (DAPCCHH), are under development and can easily be replicated. Therefore, they represent the most feasible and impactful strategy at present.

Source: Authors' compilation from discussions during the multi-stakeholder consultation

Source: Authors' compilation based on expert opinion survey

Since these factors vary based on the case study area, the knowledge of the administrators, and other local factors, district administrators must invest in resilience-building activities after assessing local constraints. This approach would successfully translate state-level strategies into district-level outcomes, thus building resilience in the most resource-efficient way.

Knowledge of such factors resides with district-level health departments or lower, who are experienced and aware of on-ground realities. Their tacit knowledge should therefore be leveraged in the process of building resilience. An additional risk prioritisation exercise, as outlined in Section 3.4, is required to improve the context specificity of solutions and achieve maximum results through optimal resource utilisation.

Checklists are vital for building resilient healthcare facilities, facilitating self-assessment and ensuring adherence to climate resilience standards

4.3 State health departments should mandate all the districts to assess risks at the asset level

In India, the development of healthcare infrastructure falls under state jurisdiction, whereas climate action and disaster management are governed centrally. SAPCCs focus on climate change mitigation and adaptation, and SDMPs address preparedness, response, and recovery. State healthcare policies, in contrast, govern overall infrastructure development. Therefore, the sector's cross-cutting nature poses significant challenges in governance, hindering progress toward building systemic resilience.

To ease implementation, state health departments should lead the coordination of action between agencies by delineating specific roles and responsibilities, setting yearly targets, and monitoring progress against KPIs. By collecting data from district authorities, state health departments can accelerate resilience building by developing an inventory of data on the status of climate-proofing healthcare infrastructure across districts in the state. The SDMA can then help identify priority areas based on the varying levels of risk across the state. Accordingly, the state health department can track current and upcoming infrastructure projects – objectives can be realigned, investments can be streamlined to priority areas, and funds can be directed in accordance with the state healthcare budget.

The data inventory can be developed by synthesising district-level risk assessments of healthcare facilities, followed by periodic surveys to track progress. Tools like the **Healthcare Facility Resilience Checklist** can further aid in standardising data collection. Furthermore, an analysis of risk factors and resilience characteristics across districts would provide the state with a compendium of best practices, which can be used by state authorities to develop a healthcare sector preparedness plan.

The state health department, as the leading agency, can be instrumental in monitoring progress towards state health targets, tailoring solutions suited to local contexts, and thus uniformly reducing risks to healthcare infrastructure across the region.

4.4 The *Indian Public Health Standards* should monitor the resilience of healthcare facilities

The IPHS are a set of standards designed to improve the quality of healthcare delivery in the country under the NHM. These standards currently define the target population size for each type of healthcare facility; however, there is scope to standardise various other aspects of healthcare facility resilience, which, as of now, remain scattered across multiple non-statutory guidelines and codes.

For example, several national authorities have developed relevant codes and standards that oversee the structural resilience of buildings. IS Codes, created by the Bureau of Indian Standards (BIS), address building design and construction in flood- and cyclone-prone areas (BIS 2005). Furthermore, building on these standards, the NIDM released a *Guideline for Hospital Safety* in 2016, which outlines essential IS Codes for healthcare facility resilience.

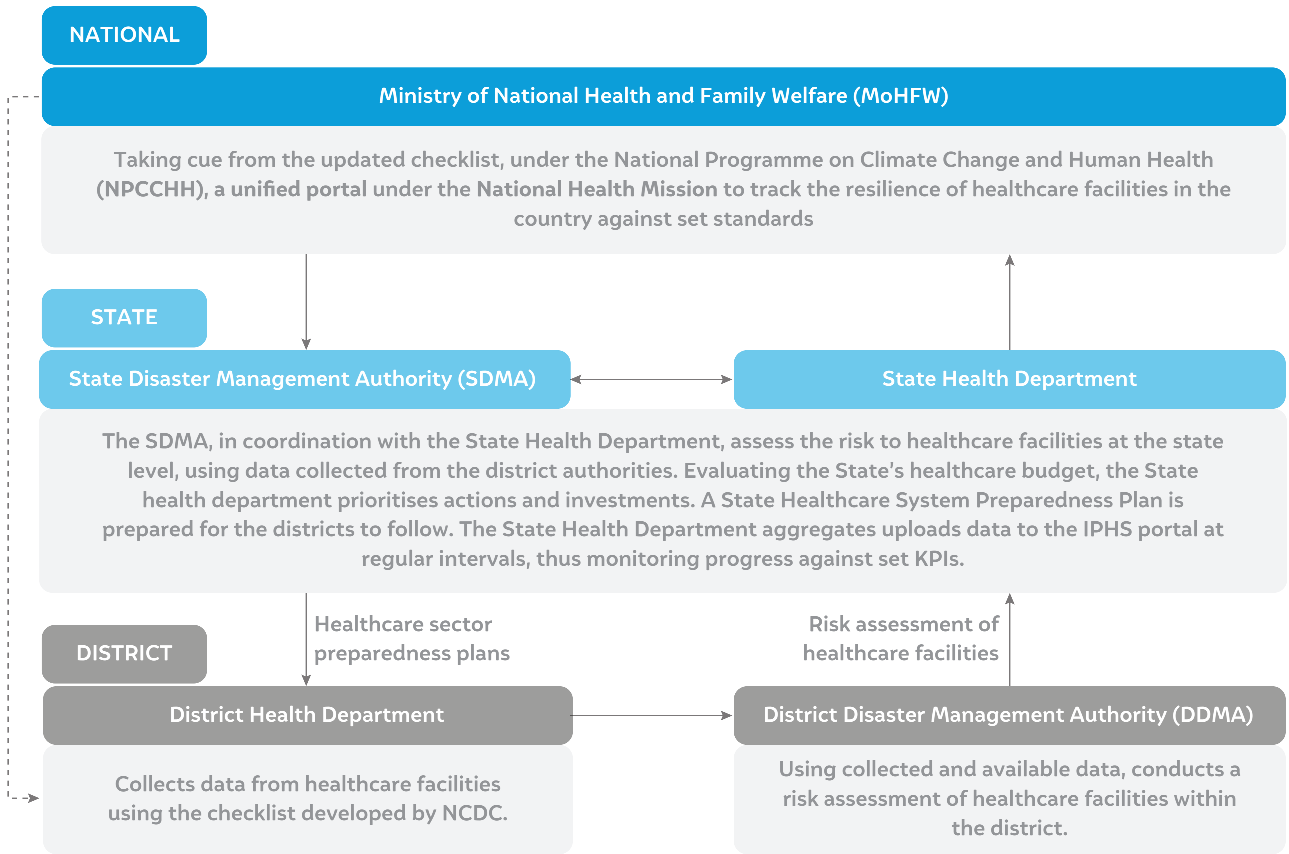
However, whether these standards are followed on the ground is unclear, as there is limited scope to monitor hospital construction methods. By incorporating the prepared geospatial layer of healthcare facility locations (exposure layer), the IPHS can build a comprehensive database of hospital buildings. The database, which already contains important information such as facility category, can further facilitate the collection of data related to building height, number of storeys, building area, building age, and so on through an open-access portal that can be accessed by nodal authorities in the state. This dataset can complement the hospital infrastructure layouts developed by IPHS in 2022 and strengthen healthcare infrastructure management through data-driven decision-making.

Therefore, the IPHS should invest in developing an open online portal so that state and district health administrators assessing the asset-level risk of healthcare facilities can upload the real-time status of various parameters. Backed by enforced standards, this will facilitate real-time monitoring of healthcare facility resilience through a unified national platform.

Thus, beyond their mandate, the IPHS can track the resilience of healthcare facilities across India against set national standards, thereby strengthening and widening the scope of the NHM.

The aforementioned recommendations, therefore, propose an interconnected system of solutions, which, when executed simultaneously, will simplify the exercise of building resilience in healthcare facilities at every scale. Figure 23 outlines the suggested institutional process.

Figure 23 A double-loop interdepartmental institutional process can accelerate the resilience building of healthcare facilities



Source: Authors' compilation

4.5 The National Health Mission should catalyse climate finance for healthcare infrastructure resilience

Lastly, the financial sector must be incentivised to invest in climate-resilient infrastructure. The NHM provides financial assistance to states for the structural upgradation of healthcare infrastructure. However, increased investments are required to accelerate risk-informed decision-making and improve the resilience of healthcare systems. Since healthcare facilities across the country draw funding from varied sources based on their respective administrative authorities, there is no one-size-fits-all approach that can address all existing financial requirements.

Under the NPCCHH, states are now in the process of preparing state action plans on climate change and human health (SAPCCHH), which contain health adaptation plans for climate-resilient healthcare facilities as one of their components. Such plans should align with the state healthcare budget to delineate funds for related activities. Similarly, for healthcare facilities within urban areas, that is, municipalities, municipal corporations, and nagar panchayats, central schemes such as the *Smart City Mission* under the Ministry of Housing and Urban Affairs should allocate separate funds for their upgradation in line with the objectives of national programmes such as the NHM and the NPCCHH. At the decentralised level, urban local bodies can further utilise innovative finance mechanisms to boost the volume of funds available. For example, issuing green bonds to develop energy-efficient healthcare infrastructure can fund hospital retrofitting. Public–private partnerships (PPPs) can attract private investment in climate-resilient healthcare by supporting government programmes such as NPCCHH and incentives for building and operating green hospitals. Finally, microfinance can support small and rural healthcare providers in adopting eco-friendly technologies, while community-based financing mechanisms enable local health centres to implement sustainable practices.

Although the *National Health Policy* aims for 2.5% of GDP in health spending, actual expenditure was only 1.6% in 2020-21 (Economic Survey of India 2022)

5. Conclusions and way forward

Image: Alamy

While India has initiated efforts to build the resilience of its healthcare facilities through interventions such as the NPCCHH, these endeavours exhibit dispersion, lack an umbrella definition, and overlook critical aspects of infrastructure resilience. Interdisciplinary research and collaboration through workshops and roundtables, such as those conducted by the NIDM, can foster a shared understanding of risks and resilience, shaping future policies and plans in this cross-cutting sector. Global health entities, such as WHO, have already developed comprehensive guidelines and manuals delineating strategies for climate-resilient healthcare systems such as the *WHO Framework for Climate Resilient and Low Carbon Health Systems* (WHO 2023). These initiatives serve as noteworthy models from which India can draw inspiration, tailoring its approach to suit its specific contexts and requirements, and mainstreaming risk assessment at the central level.

At the state level, the widespread adoption and operationalisation of contingency plans prepared in line with national guidelines are indispensable for augmenting capacities and averting redundant investments in healthcare infrastructure. States like Kerala and Assam, with existing emergency preparedness plans for hospitals, can widen their scope to include risk assessments to further streamline their actions and define priorities.

India's healthcare sector expenditure rose 14% last year, highlighting the government's focus on public healthcare and social security (PIB 2024)

Furthermore, initiatives such as the district action plans for climate change and human health (DAPCCHH) under the NPCCHH can bring about transformations in the management of healthcare infrastructure at the district level. As these plans remain in the formulation stage for most districts to date, they must include quantitative and geospatial analyses of influencing factors such as heat, floods, cyclones, and air pollution on disease growth. This would help healthcare administrators identify and map target populations vulnerable to climate change-induced diseases.

In further alignment with the objectives of the NPCCHH, developing disaster management plans and standard operating procedures emerges as a key priority for building resilience at the grassroots level. A thorough understanding of risk drivers is, therefore, essential at the facility level so that each facility can self-assess its weaknesses, build its own capacities, and be sufficiently equipped to cope when a disaster strikes. The study, therefore, addresses the lack of a unified framework through which such an assessment must be carried out. Through a scalable set of indicators available from publicly accessible datasets, the study paves the way for policymakers, administrators, and investors to conduct scientific risk assessments that inform their policy decisions. Additionally, the institutional process suggested can ensure decentralised risk assessments, considering local constraint factors, while ensuring that the process is standardised and monitored at the national level.

However, risk assessment is not the last step in achieving resilience; it is only the first step. Ancillary measures, such as improving access to early warning systems in hospitals and building robust information systems, necessitate substantial financial backing and research efforts. Therefore, funds allocated for healthcare system upgrades, such as those under the NHM, should be further earmarked for targeted actions to formalise a need-based approach, ensuring the holistic strengthening of the healthcare resource system.

Lastly, recognising that infrastructure operates within an interconnected system, it is imperative to build the resilience of complementary infrastructure such as transportation, power, water supply, and telecommunication. These networks endure considerable damage from natural disasters like floods and cyclones, which, in turn, magnifies the risk to healthcare facilities. Therefore, despite significant advances, there is still a long way to go to achieve a radical paradigm shift that can mainstream risk-informed decision-making, integrating it into critical infrastructure life cycles.

Acronyms

ALL	annual average losses
ADB	Asian Development Bank
AHP	analytical hierarchy process
CDRI	Coalition for Disaster Resilient Infrastructure
CEA	Central Electricity Authority
CGHS	Central Government Health Scheme
CORDEX	Coordinated Regional Climate Downscaling Experiment
CRMM	common risk mitigation mechanism
DAPCCHH	district action plans for climate change and human health
DDMP	district disaster management plan
DRRWG	Disaster Risk Reduction Working Group
EM - DAT	emergency events database
GIS	geographic information system
IPCC	Intergovernmental Panel on Climate Change
IPHS	Indian Public Health Standards
JHPIEGO	Johns Hopkins Program for International Education in Gynecology and Obstetrics
KPI	key performance indicator
LMIC	low- and middle-income countries
MoHFW	Ministry of Health and Family Welfare
NABH	National Accreditation Board for Hospitals
NCDC	National Centre for Disease Control
NDMA	National Disaster Management Authority
NHM	National Health Mission
NIDM	National Institute of Disaster Management
NIP	National Infrastructure Pipeline
NPCCHH	National Programme on Climate Change and Human Health
PMGSY	*Pradhan Mantri Gram Sadak Yojana*
PMJAY	*Pradhan Mantri Jan Arogya Yojana*
SBI	State Bank of India
SDMP	state disaster management plan
SFDRR	Sendai Framework for Disaster Risk Reduction
UNDRR	United Nations Office for Disaster Risk Reduction
WGDRR	Working Group on Disaster Risk Reduction
WMO	World Meteorological Organisation

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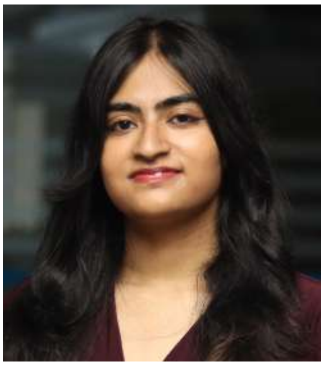

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