

# Dealing with extreme weather events in India—A vulnerability assessment study, current status and way forward

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## ARTICLE INFO

Received: 15 October 2023

Accepted: 22 November 2023

Available online: 16 December 2023

doi: 10.59400/ephr.v1i1.1280

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**ABSTRACT: Introduction:** Climate change has increased the frequency and intensity of daily weather extremes. Extreme weather events (EWE) can result in damage to health. As climate-related events become more frequent and intense, the implications for healthcare systems and access to medical services become even more pronounced. The study aims to estimate the vulnerability of India and its states towards the EWE by calculating a vulnerability index by identifying the specific extreme weather conditions in India. It also explores ways to make the healthcare system resilient to climate change. **Methodology:** The study combines quantitative data analysis and qualitative content analysis to assess vulnerability, analyze the current healthcare system, and propose recommendations for managing the impact of EWE on healthcare. Secondary data on historical climate and weather from IMD was collected to identify patterns and trends in EWE in India. Healthcare data on healthcare infrastructure, admissions rates related to EWE, and disease outbreaks was collected from reports. Policy documents, reports, and research articles related to healthcare system preparedness for EWE were analyzed quantitatively to identify vulnerability indicators and previous disaster experiences. The vulnerability index was calculated by combining selected indicators using appropriate weighting and normalization techniques to quantify the vulnerability of the healthcare system to EWE. After the calculation of sensitivity, exposure, and adaptive capacity separately, the vulnerability index was calculated using the following formula: Vulnerability is equal to exposure plus sensitivity minus adaptive capacity. **Results:** The association between daily variation in meteorological conditions and mortality has been found to be significant, as reported from previous studies on a wide range of populations in India. The ten most vulnerable states to EWE due to climate change, according to the estimations on the vulnerability index, are Meghalaya at the topmost followed by Madhya Pradesh, Rajasthan, Gujarat, West Bengal, Assam, Karnataka, Odisha, Tripura, and Uttar Pradesh. **Conclusion:** The study shows that linkages between climate change and human health are complex and multi-layered, and predictions of future health impacts of climate change are still uncertain.

**KEYWORDS:** extreme weather events; vulnerability index; India; health; climate change

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## 1. Introduction

Climate change indeed has far-reaching consequences across multiple domains<sup>[1,2]</sup>. Its effects on food security<sup>[3,4]</sup>, agriculture<sup>[5-7]</sup>, forestry<sup>[8]</sup>, economics<sup>[9,10]</sup> hydrology<sup>[11,12]</sup>, land cover<sup>[13]</sup>, renewable energy<sup>[14]</sup>, and biodiversity<sup>[15]</sup> are profound and interconnected. Managing these impacts becomes especially challenging in low- and middle-income countries, where resources and infrastructure may be limited<sup>[16]</sup>. The regional, sectoral, and structural variations further complicate the task of mitigating and adapting to these changes effectively.

The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) end of the range of observed values of the variable is called an extreme weather event (EWE). Extreme weather conditions, such as hurricanes, heatwaves, and severely cold temperatures, have become increasingly frequent and intense in recent decades due to climate change. These EWEs have devastating impacts on various aspects of human life, including public health. Consequently, understanding the consequences of EWE on health and assessing the effectiveness of healthcare systems in dealing with them is of utmost importance for policymakers and healthcare professionals.

Extreme weather events (EWE) can have severe implications for human health, both directly and indirectly. On one hand, they can directly cause injuries or fatalities. On the other hand, they can indirectly contribute to physical illnesses, mental health disorders, property damage, water contamination, and the resurgence of infectious diseases<sup>[17,18]</sup>. With the projected increase in EWE due to climate change, the number of people affected by cardiovascular diseases, respiratory ailments, and mental health issues could also rise<sup>[19]</sup>.

These impacts are particularly concerning for vulnerable populations such as the elderly, young children, individuals with pre-existing health conditions, and those who are socially isolated [20–22]. As climate change continues to unfold, addressing these health challenges and ensuring the resilience of communities will become increasingly critical.

The impacts resulting from sudden shocks of extreme climate and weather events and climate-sensitive disasters (CSDs) on human well-being and health are an area that is getting increased attention because the slow-onset changing patterns of climate will bring more frequent and severe EWEs, leading to a greater burden of disease<sup>[23-27]</sup>. The increasing evidence of the links between extreme El Niño events and global warming suggests that the occurrence of such uneven EWEs and their associated climate hazards could increase in the future due to climate change<sup>[6]</sup>, which, in turn, is likely to trigger disasters and health vulnerability to climate<sup>[7-9]</sup>. EWEs can be harmful to humans and their life-supporting systems and even cause loss of life. Therefore, managing their risks and disasters is crucial when considering their inter-linkages with human well-being and health<sup>[1-3,7,9-11]</sup>.

The magnitude and pattern of impacts from extreme weather and climate events are due to the characteristics of the extreme event, the extent of exposure of human and natural systems to the event, the susceptibility of those systems to harm, and their ability to cope with and recover from the event<sup>†</sup>.

There is abundant literature on factors that increase vulnerability to extreme weather and climate events<sup>[28]</sup>, with less emphasis on how extreme events themselves alter the sensitivity and coping capacity of human systems to future events. Vulnerability mapping was the method most previous research used to study EWE, which focused on present conditions and integrated it with future visioning exercises. All values lend themselves to spatial representation, emphasizing the need to integrate mapping with

storytelling and alternative methods to articulate values comprehensively. Vulnerability and adaptation assessments provide information on the nature and scale of potential health risks attributed to climate change and identify both vulnerable populations and health system weaknesses<sup>[29]</sup>. The health system's vulnerability and adaptation were assessed in Vietnam from 2013 to 2017, and “the level of exposure to climate change”, “health sensitivity,” and “adaptive capacity” were reported as high, high, and very low, respectively<sup>[30]</sup>.

The wide range of factors that describe vulnerability can be divided into environmental, social, and economic dimensions. Environmental dimensions include physical variables (e.g., location-specific context for human-environment interactions); geography, location, and place; and settlement patterns and development trajectories. Social dimensions include demographic variables (education, human health, and well-being); cultural variables; and institutions and governance. Cross-cutting factors include relevant and accessible science and technology. In the health sector, important factors include the health of the population and the status of health systems (e.g., the ability of healthcare facilitates, laboratories, and other parts of the health system to manage an extreme event).

The reason for conducting a study on the impact of EWE on public health is the potential increase in the prevalence of various health issues during and after these events. Secondly, understanding the relationship between EWE and healthcare systems is crucial in order to enhance disaster preparedness and response strategies. Adequate and efficient healthcare systems play a pivotal role in minimizing the impact of extreme weather conditions on public health. By identifying the strengths and weaknesses of healthcare systems in dealing with these events, policymakers and healthcare professionals can implement appropriate measures to prevent or mitigate potential health risks and ensure better health outcomes for affected individuals.

Furthermore, studying the response of healthcare systems during EWE can provide insights into the allocation of healthcare resources in emergency situations. Assessing the capacity of hospitals, clinics, and other healthcare facilities to handle sudden surges in patient demand resulting from EWE can facilitate better resource management. It will enable policymakers and healthcare institutions to develop appropriate contingency plans, allocate sufficient medical personnel and supplies, and ensure the overall resilience of healthcare systems in extreme weather conditions. In conclusion, conducting a study on the impact of extreme weather conditions on public health and the importance of healthcare systems is crucial in today's changing climate.

## **2. Methodology**

**Research design:** This research employs a mixed-methods approach to comprehensively address the research topic. It combines quantitative data analysis and qualitative content analysis to assess vulnerability, analyze the current healthcare system, and propose recommendations for managing extreme weather conditions' impact on healthcare. The primary objective is to assess the vulnerability of India to extreme weather conditions and to propose strategies for enhancing the resilience of its healthcare system.

**Data collection:** Secondary data of historical climate and weather data from sources like the National Family Health Survey (NFHS), the Indian Meteorological Department (IMD), NITI Aayog, etc. was collected to identify patterns and trends in extreme weather events in India. Healthcare data on hospital admissions, EWE, disease outbreaks, and healthcare infrastructure was taken from reports of Indian

government health agencies. Policy documents, reports, and research articles related to healthcare system preparedness for extreme weather conditions from Google Scholar and the library were analyzed.

Information on EWE in the past 24 h and forecasts and warnings are published in IMD's All India Weather Summary and Forecast bulletins and daily press releases. Each day's report was downloaded from the IMD website and mapped out the events by state, Union Territory (UT), and event type. On loss and damage due to EWE, IMD uses media reports and publishes the number of human deaths and livestock losses in its "Climate Summary for the Month". Till March 2023, the loss and damage data were provided state-wise. Starting in April, the IMD changed its reporting method to provide only the national loss and damage numbers. In June 2023, IMD did not provide the loss and damage numbers for the month. Another source of data was the Home Ministry's Disaster Management Division. The department under the Union Ministry of Home Affairs issues a "situation report regarding flood/heavy rainfall in the country" as and when the event happens. It includes the forecast from IMD and the Central Water Commission (on floods). It also has a section on damages reported by the states/Union Territories in the past 24-hour period. Since 23 June 2023, the situation reports have provided "cumulative loss and damage data for the monsoon season". The cumulative datasheet provides information on human deaths during this period because of drowning, lightning, landslides, and other reasons. It also provides information about the damage to houses, crops, and livestock during this period in the affected states. The situation reports are primarily for floods, heavy rainfall, and cyclones; India needs a similar daily assessment for all weather-related disasters and the loss and damage they cause. One of the key indicators to establish the extent of damage is "people affected". It is also a target under the Sendai Framework for Disaster Risk Reduction (target B-1) by the UN Office for Disaster Risk Reduction. While DMD's daily situation report provides information on this globally accepted parameter of population affected, it is not included in the cumulative loss and damage data sheet. DMD needs states to provide this data at the end of each weather disaster so that it can be included in the cumulative data that is issued for the monsoon period. In addition, each state has its own disaster management authority (SDMA), which reports on the events on its websites. However, the data is sketchy and not released regularly. In the case of any discrepancy in the three sources—IMD, DMD, and media reports—the source with the highest reported number has been considered.

**Vulnerability index:** developed a vulnerability index by combining selected indicators using appropriate weighting and normalization techniques to quantify the vulnerability of the healthcare system to extreme weather events. Identified vulnerability indicators such as healthcare infrastructure, resource availability, adaptive capacity, population density, and previous disaster experiences. The vulnerability of a region was calculated with the help of three indicators: i) sensitivity index, ii) exposure index, and adaptive capacity. The variables used to determine each index and the source of data are given in **Tables 1–3**. For example, critical infrastructure (accessibility and availability), shelters (access), and population density—these indicators are directly correlated with adaptive capacity, except for population density. Higher literacy translates to greater awareness and, hence, better preparedness. A total of 17 variables were finalized as per the Sendai Framework for Disaster Risk Reduction (SFDRR) and National Disaster Management Authority (NDMA) guidelines for evaluating the vulnerability index of a region.

**Healthcare infrastructure analysis:** evaluated the adequacy of healthcare facilities, equipment, and services to manage the health impacts of extreme weather conditions.

**Healthcare response assessment:** Analyzed the effectiveness of the healthcare system in responding to and managing health issues arising from extreme weather events, including disaster preparedness and response plans.

**Table 1.** Variables used to determine sensitivity index.

S. No	Socio-economic	Description	Sources
1	Scheduled tribe or caste households	Calculated as proportion of households belonging to scheduled caste or tribe	National Family Health Survey-5 (Household file), India (2019–2021)
2	Poor households	An asset deprivation indicator was computed as the proportion of households that did not have any of the following: a motorized vehicle (a two-wheeler, car or truck, or tractor), television, computer, bicycle, refrigerator, thresher, or air-conditioner or cooler	National Family Health Survey-5 (Household file), India (2019–2021)
3	Elderly population	Calculated as proportion of individuals in the population aged 60 years or older	National Family Health Survey-5 (Household file), India (2019–2021)
4	Population density	Calculated as a ratio of population of a unit (district or state) and its area in km <sup>2</sup>	Area data: 2011 census; 19 population data: linearly projected population for 2019 using growth rate calculated for each district based on 2001 and 2011 census
5	Urbanization	Calculated as proportion of urban households among all households	National Family Health Survey-5 (Household file), India (2019–2021)
6	Men with any chronic morbidity	Calculated as proportion of men aged 40–54 years with chronic health conditions, such as cardiovascular disease, diabetes, asthma, or cancer	National Family Health Survey-5 (Household file), India (2019–2021)
7	Women with any chronic morbidity	Calculated as proportion of women aged 40–49 years with chronic health conditions, such as cardiovascular disease, diabetes, asthma, or cancer	National Family Health Survey-5 (Household file), India (2019–2021)

**Table 2.** Variables used to determine exposure index.

S. No.	Exposure	Description	Sources
1	National multidimensional poverty index	India's MPI has three equally weighted dimensions health, education, and standard of living which are represented by twelve indicators	National Multidimensional Poverty Index Baseline Report Based on NFHS-5 (2019–2021) By Niti Aayog
2	Extreme weather conditions	Days with EWC	Statement on Climate of India during 2022-IMD Report
3	Human lives lost	The number of people who died in 2022 due to the EWEs	Down to earth Report
4	Damaged houses	The number of houses that got destroyed in 2022 due to the EWEs	Down to earth Report
5	Animals died	The number of animals that died in 2022 due to the EWEs	Down to earth Report

**Table 3.** Variables used to determine adaptive capacity.

S. No.	Adaptive capacity	Description	Sources
1	Literacy	Calculated as proportion of population who completed secondary or higher level of education	National Family Health Survey-5 (Person file), India (2019–2021)
2	Households with health insurance	Calculated as proportion of households with at least one member covered under any health insurance scheme	National Family Health Survey-5 (Person file), India (2019–2021)
3	District hospitals	The number of district hospitals in each state	Rural Health Statistics 2020–2021
4	Number of doctors	The number of doctors registered by the medical council of India till 2020	PIB, Medical Council of India
5	Households with health insurance	Calculated as proportion of households with at least one member covered under any health insurance scheme	National Family Health Survey-5 (Person file), India (2019–2021)

### 3. Data analysis

Both quantitative and qualitative analyses were used to identify trends in EWE and their correlation to health outcomes. Content and thematic analysis of interview transcripts, policy documents, and reports was done to understand vulnerability and the coping mechanisms of existing strategies and policies for healthcare system resilience.

- Thematic analysis: extracted themes and patterns from interview transcripts related to vulnerability, coping mechanisms, and suggestions for improvement.
- Content analysis: analyze policy documents and reports to understand existing strategies and policies for healthcare system resilience.

Research validity and reliability: Employed appropriate techniques to ensure the validity and reliability of the research findings, such as triangulation of data sources and repeated reviews from supervisors and other faculties.

Procedure for the calculation of the vulnerability index:

The meteorological data was collected from various government and other reliable sources. The method used for computing the vulnerability index is:

The detailed procedure:

- 1) Indicators were employed to determine vulnerability in different areas at the state level.
- 2) The indicators were organized in ascending or descending order of prevalence within the state data file, with a higher indicator value signifying higher vulnerability.
- 3) State ranks were then assigned, with the lowest rank value given to tied cases. The percentile rank was subsequently computed, indicating the percentage of districts or states with rankings at or below a certain score.
- 4) The percentile rank for each indicator in each district or state was calculated using the formula  $P = (\text{rank} - 1) / (N - 1)$ , where  $P$  represents the percentile rank and  $N$  is the total number of districts or states.
- 5) A higher percentile rank indicated greater relative vulnerability, with a score of 1.0 denoting the highest vulnerability and 0.0 representing the lowest vulnerability.
- 6) No specific weighting scheme was utilized, so each indicator was given equal weight when calculating domain vulnerability.
- 7) Similarly, equal weights were assigned to each domain when calculating the overall vulnerability index.
- 8) After the calculation of sensitivity, exposure, and adaptive capacity separately, the vulnerability index was calculated using the following formula:

$$\text{Vulnerability} = ((\text{Exposure} + \text{Sensitivity}) - \text{Adaptive capacity})$$

### 4. Results

As per the analysis, 27 of 35 states and UTs are highly vulnerable to extreme hydro-met disasters and their compounded impacts. The 35 states were divided into three zones on the scale of vulnerability index: high, moderate, and low (**Figure 1**). Analysis suggests that India's western and central zones are more vulnerable to drought-like conditions and their compounding impacts (**Table 4**). The northern and north-eastern zones are more vulnerable to extreme flood events and their compounding impacts. Meanwhile, India's eastern and southern zones are highly vulnerable to extreme cyclonic events and their

impacts. The eastern and southern zones are also becoming extremely prone to cyclones, floods, and droughts combined.

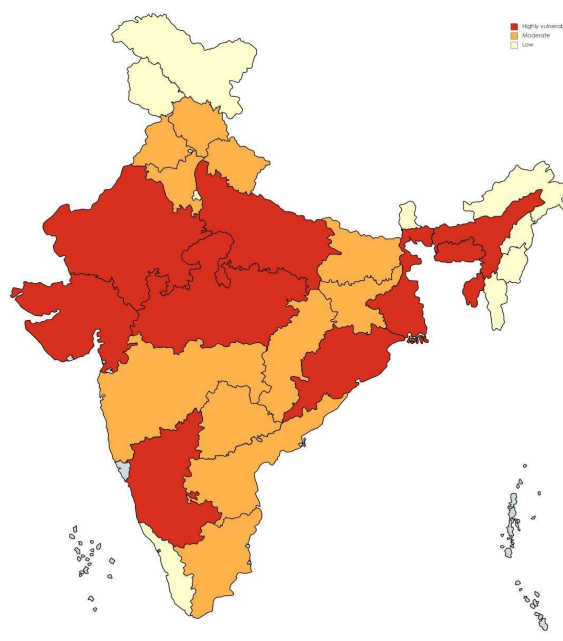


Figure 1. Map showing the distribution of vulnerability index among states.

Table 4. Region-wise vulnerability of Indian states.

Zones	Components of vulnerability		
	Exposure	Sensitivity	Adaptive capacity
Northern	Medium	High	Low
Southern	Medium	High	Low
Eastern	High	High	Medium
Western	High	Medium	Low
North -Eastern	Low	Medium	Low
Central	Medium	Low	Low

The southern and western regions are the most vulnerable to extreme droughts and are affected every year. These regions are predominantly affected by agricultural droughts. Since the 2000s, the northern, eastern, and central zones have been moderately vulnerable and are predominantly affected by meteorological and agricultural droughts. The north-eastern region is least vulnerable to extreme drought events.

A surge in extreme events has been observed across India after 2005. Sensitivity analysis shows that this is primarily triggered by landscape disruptions. Various studies have confirmed the impact of landscape changes on the incidence of EWE. Other factors, such as the urban heat island effect, land subsidence, and microclimate changes, are also triggering the intensification of EWE in India. Table 4 shows how individual regions are affected by each component of vulnerability. The north-eastern and eastern zones of India are highly exposed to extreme flood events.

The ten most vulnerable states to EWE due to climate change, according to the estimations on the vulnerability index, are Meghalaya at the topmost, followed by Madhya Pradesh, Rajasthan, Gujarat, West Bengal, Assam, Karnataka, Odisha, Tripura, and Uttar Pradesh. These states are prone to multiple

EWEs, e.g., Odisha is vulnerable to cyclones and floods and Maharashtra to cyclones, floods, and droughts. The compounding impacts of extreme events make it a daunting task for decision-makers to plan mitigation strategies. There are gaps in healthcare delivery like inadequate infrastructure, limited resources, and fragmented coordination between different levels of healthcare services.

The reason for Meghalaya being the most vulnerable state is that it has very low coverage of crop insurance, a low number of health care workers, and a high incidence of both water and vector-borne diseases, making it the most vulnerable state in India.

## **5. Discussion**

The paper deals with a critical and multifaceted issue at the intersection of climate change, public health, and infrastructure preparedness. As climate-related events become more frequent and intense, the implications for healthcare systems and access to medical services become even more pronounced. The current state of the Indian healthcare system reveals several gaps that must be addressed to effectively tackle the challenges posed by EWE. These gaps include inadequate infrastructure, limited resources, and fragmented coordination between different levels of healthcare services. Furthermore, marginalized communities are disproportionately affected, emphasizing the importance of an equitable approach to disaster preparedness and response.

In charting a way forward, it is imperative that policymakers, healthcare practitioners, and community leaders collaborate to strengthen the healthcare system's adaptive capacity. Investments should be directed towards upgrading infrastructure to withstand climate-related disruptions, enhancing healthcare workforce training in disaster response, and establishing robust communication and coordination mechanisms. Additionally, integrating climate resilience considerations into health policies and strategies will ensure a proactive and sustainable response to future challenges.

Public awareness campaigns and education initiatives should be undertaken to empower communities to be more resilient in the face of EWE. This involves disseminating information about risk reduction, emergency protocols, and the importance of early medical intervention during disasters<sup>[31]</sup>.

Incorporating technological advancements, such as telemedicine and data-driven predictive modeling, can play a pivotal role in bridging the gaps in healthcare accessibility during EWE<sup>[32]</sup>. These innovations can facilitate remote medical consultations, real-time tracking of healthcare resources, and the timely deployment of medical teams to affected areas.

In essence, addressing the vulnerabilities exposed by EWE within the Indian healthcare system demands a comprehensive, holistic, and collaborative approach. Studies suggest that investing in disaster-/climate-resilient infrastructure can help realize benefits worth USD 4.2 trillion in vulnerable countries; moreover, each dollar invested can fetch benefits worth USD 4<sup>[33]</sup>.

By recognizing the interconnections between climate change, healthcare infrastructure, and community well-being, India can navigate the challenges posed by EWE while simultaneously building a more resilient and adaptive healthcare system. The time to act is now, as the health and prosperity of the nation depend on our ability to forge a path towards a safer and more secure future.

## **6. Conclusion**

The study shows that linkages between climate change and human health are complex and multi-layered, and predictions of the future health impacts of climate change are still uncertain. The current state of the Indian healthcare system reveals several gaps that must be addressed to effectively tackle the



challenges posed by EWE. Precisely, at a time when India is confronted with development imperatives, we will also be severely impacted by climate change. With close economic ties to natural resources and climate-sensitive sectors, India may face a major threat and require serious adaptive capacity to combat EWE due to climate change.

## Author contributions

Conceptualization, VJ and D; methodology, VJ; software, D; validation, VJ, D and VKT; formal analysis, D; investigation, D; data curation, D; writing—original draft preparation, VJ; writing—review and editing, VJ; visualization, D; supervision, VKT. All authors have read and agreed to the published version of the manuscript.

## Conflict of interest

The authors declare no conflict of interest.

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