Climate Change Vulnerability in India: An Integrated Assessment

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Climate Change Vulnerability in India: An Integrated Assessment

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Abstract

India is one of the world's most disaster-prone countries, highly exposed to recurrent natural hazards of earthquakes, cyclones, floods, landslides, and droughts. The problem gets further compounded by climate change and environmental degradation, increasing the frequency and intensity of disasters. However, these extreme events as such do not necessarily cause extreme disaster risk; the risk on the other hand occurs only when potentially vulnerable populations and assets remain exposed to the impacts of such extreme events. This paradigm thus recognises the spectrum of man-environment relations as an integral part of disaster risk along with the 'naturalness'. The present paper seeks to synthesise the major assessment exercises of climate change vulnerability of India within the conceptual framework of an integrated social vulnerability paradigm. The contribution of this paper is in terms of its attempt to (i) develop an integrated conceptual framework of climate change vulnerability, within which a review of the important climate change vulnerability indices is presented and the position of India therein is assessed and (ii) build up a modified disaster outcome indicator-based vulnerability index and a comprehensive vulnerability input indicator-based index in a comparative actual-potential vulnerability structure in line with our integrated conceptual framework for analysing India's vulnerability condition . Two broad types of vulnerability indices are considered here: India-specific and global indices, including WorldRiskIndex, the Global Climate Risk Index, the UN Multidimensional Vulnerability Index, and the Notre Dame-Global Adaptation Index.

Key Words: Climate change, Mitigation, Hazard, Disaster, Vulnerability, Exposure, Sensitivity, Adaptive capacity, Coping Capacity, India.

Acknowledgement

1 Introduction

Climate science is now categorically clear that human activities – especially since the Industrial Revolution – have consistently and in a very short span of time considerably increased the concentration of heat-trapping greenhouse gases (GHGs),[1] such as carbon dioxide (via fossil- fuel combustion and deforestation), methane (from rice cultivation, livestock, landfills, and other sources) and chlorofluorocarbons (from industrial sources). The consensus among scientists is that the emissions of anthropogenic greenhouse gases are the main cause of rising temperatures in our planet's atmosphere and oceans (Allen et al., 2018; U.S. Global Change Research Program 2017; Intergovernmental Panel on Climate Change (IPCC) 2013). Compared to the 1880-1900 average, the global temperature has already (by 2015) increased by more than 1o C.[2]

It is feared that additional warming (above the current 1.2 °C or 2.2 °F) will risk further sea level rise, extreme weather, biodiversity loss and species extinction (Arias et al. 2021). According to the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC 2021), the current trends indicate that the world is set to exceed the 2015 Paris Agreement's target of global average maximum temperature increase of 1.5 degree C by the early 2030s that would further accelerate the pace and severity of extreme weather events. The Global Disaster Assessment Report on Disaster Risk Reduction (2022) of the UN Office for Disaster Risk

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[1] An understanding of the greenhouse effect dates from the nineteenth century itself: the French mathematician and physicist Joseph Fourier in 1827 recognized that the atmosphere was trapping heat; three decades later, the Irish physicist John Tyndall in 1861 identified the types of gases responsible for such trapping; and at the end of the century, the Swedish scientist Svante Arrhenius in 1896 gave calculations of the possible effects of doubling GHGs.

[2] https://www.munichre.com/en/risks/climate-change.html. Accessed 09.11.2022.

Reduction (UNDRR)[3] shows that the last two decades saw a significant increase in the number of disaster events reported per year. "While there were relatively more disaster peak years in the decade 2000-2009 compared with 2010-2019, overall frequency remains at an all-time high. Between 1970 and 2000, reports of medium- and large-scale disasters averaged around 90-100 per year, but between 2001 and 2020, the reported number of such events increased to 350-500 per year. These included geophysical disasters such as earthquakes, tsunamis and volcanoes, climate- and weather-related disasters, and outbreaks of biological hazards including pests and epidemics." (UNDRR 2022: 17). In particular, the UNDRR reported in 2018 that climate related and geographical disasters had killed 1.3 million people worldwide and injured 4.4 billion between 1998 and 2017, and the disaster-hit countries experienced direct economic losses valued at US$ 2,908 billion, of which climate-related disasters caused US$ 2,245 billion or 77% of the total. This is up from 68% (US$ 895 billion) of losses (US$ 1,313 billion) reported between 1978 and 1997. Overall, the reported losses from extreme weather events rose by 151% between these two 20-year periods. (UNDRR, 2018).[4]

Given such burning facts of climate change risks, one of the significant contributions of climate change economics is the range of policy options opened up to ameliorate the impacts of climate risks; in general, three strategies have been identified: (1) mitigation, (2) climate engineering, and (3) adaptation (Tietenberg and Lewis 2018: 402; IPCC 2001).

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3 Formerly, UN International Strategy for Disaster Reduction (UNISDR)
4 Attribution science, a recent, rapidly growing field of climate science, aims to investigate the links between climate change and extreme weather events. Note that even though attribution science cannot determine any causal link between climate change and an extreme weather event, it can determine how, and also estimate by how much, anthropogenic climate change affects the magnitude and probability of an event. (https://www.preventionweb.net/understanding-disaster-risk/)

While mitigation takes up the GHG emissions at the very sources, geoengineering is proposed to reduce the concentration of GHGs in the atmosphere, and adaptation addresses the effects of the climate change risks.

Mitigation strategies are designed to curtail the sources of anthropogenic emissions of GHGs, as well as to enhance the capacity of carbon sinks, for example, through reforestation. Considering the GHG sources, for example in the energy supply sector, the policies reducing fossil fuel subsidies and imposing taxes or carbon charges on fossil fuels can encourage mitigation technologies of fuel switching from coal to gas or alternative green energy sources, such as wind, photovoltaics or hydro that generate less or no carbon dioxide. Similarly, in the waste management sector, for example, policies such as financial incentives for improved waste management, renewable energy incentives/obligations, waste management regulations, etc. can lead to mitigation technologies like waste incineration with energy recovery, composting of organic waste, controlled wastewater treatment and recycling and waste minimization. In the buildings sector, policies prescribing appliance standards and labelling, as well as building codes and certification can ensure mitigation technologies in terms of efficient lighting and daylighting and more efficient electrical appliances and heating and cooling devices.

Climate engineering or, alternatively, geoengineering, efforts that seek "to stabilize the climate system by directly managing the energy balance of the Earth, thereby overcoming the enhanced greenhouse effect" (IPCC 2001: 374) are of recent origin in science discourse. Even though a number of technically feasible options are known, their costs, effectiveness, and side effects are less understood (Denton, et al., 2014: Chapter 20). Such intentional large-scale interventions in the energy balance of the

Earth system include efforts to reduce the amount of absorbed solar energy in the climate system or to increase the uptake of CO2 from the atmosphere. The former, for example, works by means of injecting sulphates into the stratosphere, and the latter by means of scrubbing CO2 from the air and of chemical interventions to increase uptakes by oceans, soil, or biomass (ibid). Research on this strategy is yet to fructify, and the current efforts are hence focussed on mitigation and adaptation.[5] At the same time, Denton, et al. (2014: 1114) caution about the possibility "that optimism about geoengineering options might invite complacency regarding mitigation efforts."

It must be noted that even in a scenario of relatively stabilised emissions that guarantee to maintain temperature increase at 1.5 or 2 degrees above the pre-industrial levels, climate change risks and its effects would still last for many years. This necessitates adaptation measures to cope with climate change risks, that is, "adjustment in natural or human systems to a new or changing environment in response to actual or expected climatic stimuli or their effects" (IPCC 2001: 365). At the community level, adaptation measures can be early warning systems, disaster preparedness, awareness-raising of citizens, and specific legislative changes for buildings and constructions to regulate heat in the internal environment. At the household level, the measures are using fan, air conditioning, open roof top, wearing sun-protective clothing, house design, change in outdoor/ indoor time allocation, etc.

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5 Accordingly, the IPCC is currently organized into three Working Groups: (i) Working Group I (WGI) addresses observed and projected changes in climate; (ii) Working Group II (WGII) addresses vulnerability, impacts, and adaptation related to climate change; and (iii) Working Group III (WGIII) addresses options for mitigation of climate change (IPCC 2001:237)

In short, mitigation aims to reduce GHG emissions so as to slow down or to prevent climate change, while adaptation aims to reduce vulnerability to the effects of climate change. That is, mitigation reduces the causes of climate change, whereas adaptation reduces its effects.

The present paper seeks to synthesise the available assessment attempts of climate change vulnerability of India within the conceptual framework of an integrated social vulnerability paradigm. The paper contributes to the existing literature in terms of developing an integrated conceptual framework of climate change vulnerability by explicitly including the source of the anthropogenic greenhouse gas emissions and describing climate change vulnerability as the net result of exposure and sensitivity to climate change impacts in a possibly amended context of adaptive and coping capacity/resilience in the social-economic-institutional-political space. The paper then presents a review of the important climate change vulnerability indices within this conceptual framework and assesses the position of India therein, and builds up a modified disaster outcome indicator-based vulnerability index and a comprehensive vulnerability input indicator-based index in a comparative actual-potential vulnerability outline in line with our integrated conceptual framework for analysing India's vulnerability condition. An attempt also is made to synthesise and document the relevant concepts and schools of thoughts.

What follows is divided into four sections, beginning with a discussion on climate change vulnerability assessment by introducing first the relevant concepts within the conceptual framework of a traditional climate change impact assessment and then the three major schools of thought that stand out in the long history of vulnerability assessment. This serves as the background for presenting our integrated conceptual framework of climate

change vulnerability. Section 3 of the paper gives a brief discussion on disasters in India, one of the world's most disaster-prone country, highly exposed to recurrent natural hazards of earthquakes, cyclones, floods, landslides, and droughts. The next section presents the review of the major climate change vulnerability indices, both global and India-specific, and the penultimate part attempts to constrict a modified disaster outcome indicator-based vulnerability index and a comprehensive vulnerability input indicator-based index in a comparative actual-potential vulnerability framework within the conceptual paradigm that we have developed. The final section concludes the study.

2. Climate Change Vulnerability Assessment

There is a vast scientific literature on the relationship between climate change and extreme weather/climate events ("climate extremes", IPCC 2012: 4) as well as on their implications for society and sustainable development. We are already experiencing these impacts, as the climate extremes disrupt the eco-system, damage the economic sectors and adversely affect human health and productivity.[6] These risks are feared to continue to increase in the future, becoming more systematic and complex (IPCC 2014; World Economic Forum 2022).

2.1 Climate Change Impact Assessment

Impact assessments are used to evaluate the potential effects of a climate change scenario and compare them to a hypothetical constant climate scenario (Füssel and Klein, 2006: 312). Figure 1 presents the conceptual framework of a climate impact

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[6] "In 2020, multiple cities around the world experienced extreme temperatures not seen for years—such as a record high of 42.7°C in Madrid and a 72-year low of -19°C in Dallas, and regions like the Arctic Circle have averaged summer temperatures 10°C higher than in prior years" (World Economic Forum 2022: 8-9).

assessment (main concepts along with their relationships), starting from anthropogenic emissions to atmospheric concentrations of greenhouse gases and to climate change. Mitigation seeks to reduce both the level of emissions and concentrations. Other two concepts in the Figure are exposure and sensitivity that we explain below.

1. Exposure to climate risks

The term exposure (to climate variations, extreme events, or diseases) refers to the external contact between a system and the climate. The external climate events impact the system producing an effect. For example, a coastal community remains exposed to cyclones, rising sea levels and saltwater intrusion into aquifers. The characteristics of exposure are in terms of the frequency, magnitude and duration. In reference to Fig. 3, the exposure of a system depends on the level of global climate change and concentrations (as there is a direct effect from

Fig. 1: Conceptual Framework of a Traditional Climate Change Impact Assessment
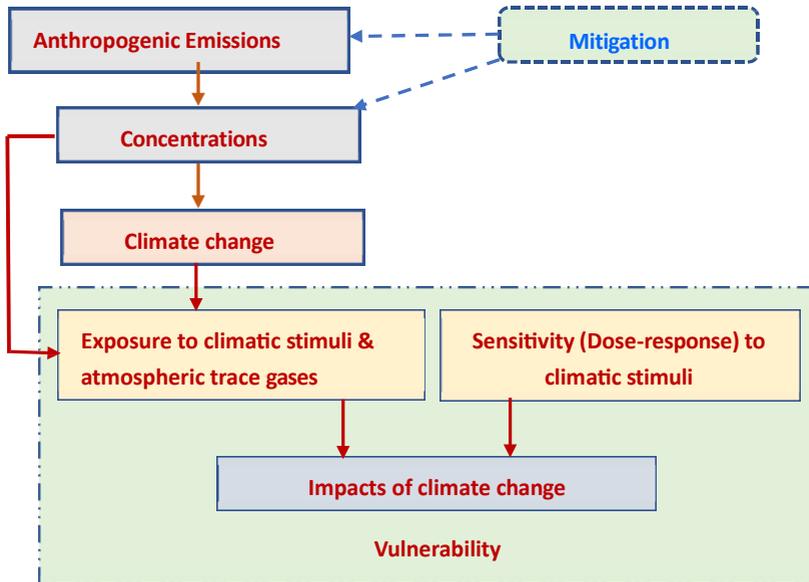
atmospheric composition of trace gases)[7] and also on the system's location thanks to the spatial differentials of anthropogenic climate change.

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[7] "Well-known examples include the direct effect of carbon dioxide on plant physiology and the combination of local air pollution and high temperatures in causing respiratory diseases in humans" (Füssel and Klein, 2006: 314).

2. Sensitivity to climate change

Sensitivity (dose-response) is an internal characteristic of the system and refers to the degree to which the system is affected by the exposure; the "effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)" (IPCC 2001: 993). Sensitivity is similar to immunity in the sense that a person is considered more sensitive (less immune) to variations in weather condition if that person gets afflicted by seasonal illness whenever the weather condition changes (exposure). Continuing with the earlier example, the coastal community remains more sensitive to cyclones if they have only sea-based livelihoods, or if their area is devoid of wind-resistant trees, or it is below the sea level. Sensitivity is conditioned by both human and environmental endowments; the former include population, entitlements, institutions and economic structures, and the latter include natural/biophysical endowments such as soils, water, climate, minerals and ecosystem structure and function.

Exposure and sensitivity together result in climate impact on the system.

Note that the concepts of emissions, concentrations and climate change are applicable at the global level, and hence their boxes (in Fig. 2.3) are represented with bold borders, whereas the concepts of exposure, sensitivity and impacts are relevant only at the level of the systems, and hence their boxes are shown with thin borders. Also note that there is no explicit reference to vulnerability in the traditional impact assessments; hence it is represented here in a box with dashed line border.

Three more concepts are in order for definition: resilience, adaptive capacity and vulnerability.

1. Resilience (coping capacity)

Vulnerability and resilience[8] have emerged as central concepts in the climate and wider global environmental change literature (Janssen and Ostrom 2006). Resilience refers to the ability of a system to withstand (cope with) climate change hazards and to return to pre-disaster normal condition (Kohlitz et al. 2017); it also implies the ability to improve disaster preparedness of community, and to speed up the restoration process (Marzi et al., 2019). According to the Hyogo Framework for Action (UNDRR 2005: 4), disaster resilience is "determined by the degree to which the social system is capable of organising itself to increase the capacity for learning from past disasters for better future protection and to improve risk reduction measures." Note that the Sustainable Development Goal (SDG)-13 aims to assess disaster risk reduction (DRR) strategies and strengthen resilience to mitigate disaster-related losses. Particularly, SDG-13.1 requires strengthening resilience and adaptive capacity to climate- related hazards and natural disasters in all countries.

2. Adaptive Capacity

Adaptive capacity is the capability of an individual or household or community to develop resilience and thus adjust to the climate risks. It is a function of availability of and access to financial, technical, educational, and community resources. Thus, the coastal community in our earlier example is considered to have high

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[8] The IPCC defines resilience as "the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation" (IPCC, 2014b: 1772)

adaptive capacity if they have access to a system of early warnings of cyclones and also the ability to move and access to a shelter. Higher the adaptive capacity, greater the resilience. In this sense, the two are often considered synonymous, despite the subtle difference that resilience is an outcome process. Note that adaptive capacity also reduces sensitivity that in turn also contributes to resilience.

Note that the four concepts (exposure, sensitivity, adaptive capacity and coping capacity/resilience) are interrelated; thus, increasing adaptive capacity and thus resilience would reduce the sensitivity of the system to climate change. For example, the coastal community can reduce their sensitivity to climate change risks by investing in a tree plantation program, by setting up an early warning system and/or building resilient infrastructure (the ability to invest represents adaptive capacity that enhances resilience).

These concepts combine to define vulnerability of the system to climate change. High vulnerability results from high exposure to climate risks and high sensitivity along with low adaptive and coping capacities of the system.

3. Vulnerability

The climate extremes hit the poorest countries the hardest as they remain the most vulnerable to such hazards, with a lower coping capacity. The study of climate change vulnerability in relation to adaptive capacity is of recent origin that has brought together experts from diverse fields such as climate science, disaster management, medical science, social science, economics, political science and so on along with their own terminologies and approaches (IPCC, 2001; Adger et al., 2002; Burton et al., 2002). The concept of 'vulnerability' is an elusive one, and hence an

evolving one also. "The current literature encompasses more than 30 different definitions, concepts and methods to systematize vulnerability", and "the different definitions and approaches show that we are still dealing with a paradox: we aim to measure vulnerability yet we cannot define or assess it precisely" (Birkmann 2013: 20).

The term 'vulnerable' comes from the Latin noun *vulnus* (meaning 'wound') that led to the Latin verb *vulnerare* (meaning 'to wound'), and then to the Late Latin adjective *vulnerabilis,* which became 'vulnerable' in English in the early 1600s.[9] Thus, its commonplace meaning is being prone to or susceptible to injury or damage. Vulnerability is officially defined as the "characteristics and circumstances" of people "that make [them] susceptible to the damaging effects of a hazard" for example, "poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management" (UNDRR 2009:12-13). Other three related terms are natural hazards, disasters and risk, with the first two often used interchangeably, despite a clear difference: while a natural hazard represents the potential or likelihood of an extreme natural event in interaction with humans, a disaster is the actual event with real damages and losses (Tobin and Montz, 1997). A hazard potentially "exists because humans or their activities are constantly exposed to natural forces", [for example], "by locating property on floodplains, undertaking agriculture on the slopes of active volcanoes, or developing homes and resorts in hurricane-prone coastal zones" (Tobin and Montz, 1997:9). That is, "hazard, strictly speaking, refers to the *potential* for damage that exists only in the presence of a *vulnerable* human community"

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[9] https://www.govinfo.gov/content/pkg/USCOURTS-ca4-19-02203/. Accessed 11.04.2023.

(Hewitt 1983:5). The risk is the potential (probability) for loss and damage when the threat does occur from interactions between natural or human induced hazards and vulnerable/capable conditions (UNISIDR 2004). Arguing that the risk of disaster is a function of the natural hazard and the number of people, exposed in different degrees of vulnerability to that hazard, Blaikie et al. (1994) schematised a pseudo-equation: Risk = (Probability of Hazard) x (Degree of Vulnerability).

2.2 Schools of Thought on Vulnerability Assessment

Three major schools of thought stand out in the long history of vulnerability assessment: (i) geographic development and poverty (food security, livelihood) research; (ii) hazard and disaster risk reduction research; and (iii) climate change science and, in particular, the research on adaptation (Birkmann 2013:12).

(a) The geographic development and poverty research

The first school arose in the 1970s from the discussions about the root causes of famine and hunger in terms of the food availability decline thesis of basic needs approach of the International Labour Organization versus the food entitlement decline thesis, based on Amartya Sen (1981) in the context of the famines in different parts of the world: the Great Bengal Famine of 1943 (Chapter 6), the Ethiopian famines of 1973-75 (Chapter 7), famines in the Sahel region of Africa during the early 1970s (Chapter 8), and the Bangladesh famine of 1974 (Chapter 9). Robert Chambers (1989) appears to have been the first to conceptualise vulnerability in this context: "Vulnerability here refers to exposure to contingencies and stress, and difficulty in coping with them. Vulnerability has thus two sides: an external side of risks, shocks, and stress to which an individual or household is subject; and an internal side which is

defencelessness, meaning a lack of means to cope without damaging loss." (Chambers, 1989:1). Following this, the literature on 'coping strategies' in the 1980s and 1990s highlighted the importance of social and psychological vulnerabilities and losses (Corbett, 1988; Davies, 1996). Similarly, studies by Watts and Bohle (1993, p. 46) and Bohle (2001, 2002a and b) argued that local and historical dispositions of poverty, hunger and famine make up the space of vulnerability, seen as a multi-level and multidimensional social space defined by political, economic and institutional factors.

(b) The hazard and disaster risk reduction research

The second school of hazard and disaster risk reduction research came up in the 1980s, particularly following the report of the United Nations Disaster Relief Co-ordinator (UNDRO) Commission (1980) and the research works of Burton et al. (1978), Hewitt (1983), Susman et al. (1983), among others. In this research, vulnerability is seen as describing (i) endowed vulnerabilities, reflecting natural conditions and (ii) amended vulnerabilities, reflecting the effect of human behavior, the built environment, and policy decisions. The first one, the traditional, or the first generation, view ('the risk-hazard paradigm'), takes a physical science perspective and attributes the responsibility for disasters to the geophysical processes; that is, large-scale disasters are taken as consequences of extreme geophysical events (with attention largely focussed on technocratic solutions). Vulnerability here is conceptualised as a dose- response relationship between an exogenous hazard to a system and its adverse effects (UNDHA, 1993; Dilley and Boudreau, 2001; Downing and Patwardhan, 2003), "rather than encompassing facets of the human world" (Montz et al. 2017: 13). During the 1970s, questions were raised against the technocratic hazard paradigm of the 'naturalness' that was dominant

within the United Nations (UN)[10] and international funding agencies such as the World Bank. The new movement ushered in the second generation view of amended vulnerability, 'the social vulnerability (social constructivist) paradigm' that regards (social) vulnerability as an a priori condition of a household or a community determined by socio-economic and political factors (Dow, 1992; Wisner et al., 1994; Adger and Kelly, 1999).

The first impetus to *socializing the disasters* seems to have come from the paper on "Taking the Naturalness out of Natural Disasters" by O'Keefe, Westgate, and Wisner (1976: 566), who argued "the case that disasters are more a consequence of socio-economic than natural factors". They empirically illustrated the "most important tendency [in terms of] an increase in the occurrence of [largescale] disasters over the last 50 years [1947-70]", "where damage exceeds $1 million", "paralleled by an increasing loss of life per disaster." They observed the "greatest loss of life per disaster" "in underdeveloped countries" along with "general indications that the vulnerability of these countries in particular is increasing" (ibid).

Subsequently, Ian Burton *et al.* (1978 [1993:222]) criticised the "natural science" and technological preoccupations of the United Nations' studies: "This natural-science view of disaster not only puts the emphasis in scientific research on natural phenomena qua "cause" of disaster, but also introduces a bias into the choice of mitigating measures and of ways to reduce impact". Similarly,

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[10] "The UN General Assembly's declaration of the 1990s as the International Decade for Natural Disaster Reduction (IDNDR) was, without doubt, directly influenced by the natural sciences. In fact, the need for this initiative was first promoted by Frank Press, a well-known specialist on Earth sciences, in the US to specifically foster the study of natural hazards." (Cardona 2004: 41)

Kenneth Hewitt followed arguing that the technocratic approach had not viewed hazards "as integral parts of the spectrum of man-environment relations or as directly dependent upon those" (Hewitt 1983: 10), rather it had treated hazard as a specialized problem for advanced research by scientists, engineers and bureaucrats. He asserted that the "narrow focus upon 'the hazard' as an occasion of natural extremes, and upon the loss, crisis, relief and rehabilitation in disasters, can mislead us as to the decisive human ingredients of natural hazards. We easily come to ignore a range of other highly pertinent but ongoing relations to habitat. A t most they are seen as conditions it is hoped to have restored, but not as important sources of vulnerability. Also, we tend to disregard important constraints upon effective social response to risks from nature that depend upon the 'normal' socioeconomic order" (Hewitt 1983: viii). Asserting that it is "always important to consider both the extreme physical event and the vulnerability of the population in any definition of disaster", Paul Susman *et al.* (1983: 264), defined vulnerability as "the degree to which different classes in society are differentially at risk, both in terms of the probability of occurrence of an extreme physical event and the degree to which the community absorbs the effects of extreme physical events and helps different classes to recover." Vulnerability thus is seen as socioeconomic causes of differential sensitivity and exposure; according to them, *"without people, there can be no disaster.* And poor people are generally more vulnerable than rich ones. Disaster is therefore defined as *the interface between an extreme physical event and a vulnerable human population."* (ibid. Italics as in the original).

These contributions were instrumental in triggering "a stronger political ecology perspective compared to a rather hazard-oriented human-environmental perspective in risk and disaster research" (Birkmann 2013: 14). Notably, for example, the research network 'La Red' *(Red de Estudios Sociales en Prevención de Desastres en América*

Latina: the Latin American Network for the Social Study of Disaster Prevention in Latin America) argued that vulnerability is socially constructed and sought to examine different dimensions of vulnerability, such as physical, economic, social, political and cultural aspects. According to them, therefore, "it is necessary to model vulnerability taking into account – as well as the physical aspects – social factors, such as the fragility of the family and the collective economy; the absence of basic social utilities; lack of access to property and credit; the presence of ethnic and political discrimination; polluted air and water resources; high rates of illiteracy; and the absence of educational opportunities" (Cardona 2004:43).

The vulnerability paradigm has spawned a number of disaster models, such as the Foundational Risk-Hazard models that seeks to assess the impact of a hazard as a function of exposure to the hazard event and the sensitivity (dose–response) of the exposed entity (Burton et al. 1978; Kates 1985). However, the model fails to consider the differential exposures of different entities and the corresponding consequences, as well as the role of political economy, particularly social structures and institutions, in determining these differential exposures and consequences (Wisner et al., 1994, Hewitt, 1997). This recognition resulted in the famous Pressure and Release (PAR) model (of Wisner et al., 1994) that defines disaster as a damaging event owing to the complex interaction between hazard and vulnerability. "The basis for the PAR idea is that a disaster is the intersection of two opposing forces: those processes generating vulnerability on one side, and the natural hazard event (or sometimes a slowly unfolding natural process) on the other. The image resembles a nutcracker, with increasing pressure on people arising from either side—from their vulnerability and from the impact (and severity) of the hazard for those people. The 'release' idea is incorporated to conceptualise the reduction of disaster: to relieve the pressure,

vulnerability has to be reduced." (Wisner et al. 1994: 46). The model in effect seeks to explain the causal structure of social vulnerability by describing a pathway, "progression of vulnerability or chain of causation" (op cit.: 79). The 'Release' part of the model represents "the realisation that to release the pressure that causes disasters, the entire chain of causation needs to be addressed right back to the root causes, and not just the proximate causes or triggers of the hazard itself or the unsafe conditions of vulnerability" (ibid.).

Even though the original PAR model considers aspects of exposure, it fails to "directly associate these with susceptibility as a part of vulnerability" (Hammer et al. 2019: 3). Moreover, it also suffers from a lack of environmental focus, with an insufficient canvas for the broader concerns of sustainability (Turner et al. 2003) as well as the human–environment interactions and the vulnerability of the biophysical world (Kasperson et al. 2003). Recognising that the PAR model is "static" and "does not provide a detailed and theoretically informed analysis of the precise interactions of environment and society", Wisner et al. (1994: 79-80) also presents "the Access [to resources] model, which deals with the amount of 'access' that people have to the capabilities, assets and livelihood opportunities that will enable them (or not) to reduce their vulnerability and avoid disaster". Thus, vulnerability is characterised as including both an external dimension in terms of the 'exposure' of a system to the stressors and an internal dimension in terms of its 'sensitivity' and its 'adaptive capacity' to the stressors.

Susan Cutter (1996) developed an integrative (synthetic) hazards-of-place model that integrates biophysical and social determinants of vulnerability. The model conceptualizes risk (as "an objective measure of the likelihood of a hazard event") as interacting with mitigation (as "measures to lessen risks or reduce their impact")

to produce the hazard potential. "The hazard potential is either moderated or enhanced by a geographic filter (site and situation of the place, proximity) as well as the social fabric of the place. The social fabric includes community experience with hazards, and community ability to respond to, cope with, recover from, and adapt to hazards, which in turn are influenced by economic, demographic, and housing characteristics. The social and biophysical vulnerabilities interact to produce the overall place vulnerability" (Cutter et al. 2003: 243). The Social Vulnerability Index, "the most widely referenced index for social vulnerability assessments" (Dunning and Durden 2013: 4), is based on this model.

(c) The climate change science (and climate change adaptation research)

The third school of thought on vulnerability arose with the climate change science, especially in the framework of the IPCC Working Group II that dealt with impacts, adaptation and vulnerability to climatic change (IPCC 2012). It must be noted that the initial reports of the IPCC had a primary focus only on mitigation (that is, reducing greenhouse gas emissions and enhancing their sinks), leaving the question of adaptation (that is, moderating the adverse effects of unmitigated climate change) as a minor one (IPCC, 1990). However, the primary focus has shifted to adaptation and vulnerability reduction since the fourth IPCC assessment report (AR4). For example, the fifth Assessment Report (AR5) contains four chapters dealing with different aspects of adaptation (Chapter 14: Adaptation Needs and Options; 15: Adaptation Planning and Implementation; 16: Adaptation Opportunities, Constraints, and Limits; and 17: Economics of Adaptation) (IPCC, 2012).

It must be noted that vulnerability concepts in climate change science is differentiated from disaster risk research in terms of the question of whether (biophysical) vulnerability also includes physical characteristics of climate change. However, the understanding of vulnerability in the fourth IPCC assessment report (AR4) that defined vulnerability as "the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including the character, magnitude and rate of climate change" (IPCC 2007: 883) was strongly determined from an impact-oriented or risk assessment perspective of vulnerability (Füssel and Klein 2006: 322), that is, the first generation 'risk-hazard paradigm', focusing on the direct consequences of climate change on global social systems, regional systems, global biological systems and geophysical systems due to the variations in "mean temperature increases above 1990-2000 levels" (IPCC 2007: 787–789), which is questionable (Birkmann 2013: 60).

A self-critique on this concept of vulnerability came out in 2012 in the IPCC special report that finally recognised the social vulnerability paradigm, stating that the earlier "definition makes physical causes and their effects an explicit aspect of vulnerability while the social context is encompassed by the notions of sensitivity and adaptive capacity….. In the definition used in this report, the social context is emphasized explicitly, and vulnerability is considered independent of physical events" (IPCC, 2012a, p. 33). That is, the new approach recognises that weather and climate events (extreme events) as such do not necessarily result in extreme disasters; rather, disaster risk occurs only when extreme events can affect exposed populations and assets that remain potentially vulnerable to such impacts.

The IPCC 2012 Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change

Adaptation (SREX) "was the first IPCC report to systematically bring together researchers and perspectives from disaster risk research and climate change science" (Birkmann 2013: 60). The SREX approach recognized that the "character and severity of impacts from climate extremes depend not only on the extremes themselves but also on exposure and vulnerability" (IPCC 2012: 4). Exposure is defined as a 'spatial concept', representing presence of a vulnerable system at a location of hazard occurrence; that is, it represents the "presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC, 2014: 1765). Vulnerability is defined as the "propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014: 1775). Sensitivity is the "degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC, 2014: 1772-73). Adaptive capacity is "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014: 1758). For example, if a comprehensive crop insurance system is available to the farmers, they will be able to cope with the crops damages caused by hazards such as floods or drought.

The disaster risk arises from the interaction of weather and climate hazard, exposure and vulnerability. According to the SREX approach, both natural climate variability and anthropogenic climate change influence and drive the damaging

disasters of weather and climate extremes; on the other hand, the socio-economic development has a significant role in reducing exposure and thus vulnerability of human society and natural ecosystems to weather and climate events by means of disaster risk management and adaptation to climate change, thus reducing disaster risk as well as increasing resilience to the risks that cannot be eliminated. Thus, the SREX framework highlights "the necessity to focus on changes in the climate system, as well as to assess development processes and their implications for vulnerability and exposure in order to understand disaster risk" (Birkmann 2013: 61; also see IPCC (2012: Chapter 2) for the different factors and dimensions of vulnerability and exposure that the current assessments consider).

2.3 Climate Change Vulnerability Assessment: An Integrated Conceptual Framework

Combining our adapted conceptual framework of the traditional climate impact assessment (Fig. 1) and the IPCC SREX framework, we develop an integrated conceptual framework of

Fig. 2: An Integrated Conceptual Framework of Climate Change Vulnerability
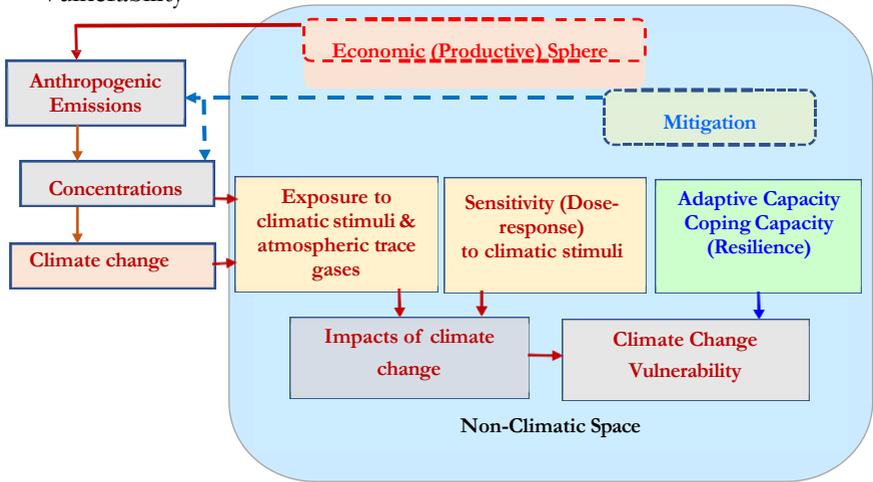
climate change vulnerability (Fig. 2). We explicitly show the productive part of the economic sphere of the non-climatic space as the source of the anthropogenic greenhouse gas emissions to atmospheric concentrations (of greenhouse gases) and to climate change. Mitigation efforts in the non-climatic space seeks to reduce both the level of emissions and concentrations. Climate change vulnerability is the net result of exposure and sensitivity through climate change impacts vis-à-vis adaptive and coping capacities/resilience in the social-economic- institutional-political space.

Based on this framework, below we present a review of the important vulnerability indices and discuss the position of India therein, starting with a brief discussion on disasters in India.

3 Disasters in India

India is one of the world's most disaster-prone countries, highly exposed to recurrent natural hazards of earthquakes, cyclones, floods, landslides, and droughts (Table 1). According to the National Disaster Management Authority (NDMA), the apex body for Disaster Management in India, more than 12% of the total geographical area (of 329 million hectares) of India is flood prone; and the average annual flood damage during the ten-year period of 1996 to 2005 was Rs. 4745 crores as compared with the corresponding average of Rs. 1805 crores for the previous 53 years.[11] It is also estimated that on an average, every year floods affect 75 lakh hectares of land, causing 1600 deaths and damages to crops, houses and public utilities to the tone of Rs.1805 crores. Moreover, the Indian subcontinent, with a long coastline of 8041 kilometres, also lies exposed to nearly 10 per cent of the world's tropical cyclones, with five to six tropical cyclones every year on an average. According to the NDMA, during the period from 1891 to 1990, there were 295 cyclones on the East (262) and West (33) coasts of India, out of which 111 were very severe.

India is also vulnerable to earthquakes, given her increasing population and unscientific and extensive urbanisation. Based on the current seismic zone map of the country, the NDMA points out that over 59 per cent of India's land area is under threat of moderate to severe seismic hazard, with the entire Himalayan belt lying prone to great earthquakes of high magnitude (exceeding 8.0). This region in fact experienced four such high magnitude earthquakes in a relatively short span of about 50 years from 1897 to 1950.

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[11] https://ndma.gov.in/. Accessed on 10.08.2023.

Tornadoes are 'extreme weather events', with infrequent occurrence but high damage potential. In India, the Eastern parts, particularly West Bengal and Orissa, are vulnerable to tornadoes during the late afternoon of the pre-monsoon months (March-May). According to Peterson and Mehta (1981), 51 tornadic events had been reported across the Indian Subcontinent since 1835.

The problem gets further compounded by climate change and environmental degradation, increasing the frequency and intensity of disasters as well as vulnerability. It is pointed out that there was a three-fold rise in widespread extreme rainfall events during 1901–2015 across central and northern India and parts of Western Ghats (Roxy et al., 2017). Such extreme rain events are attributed to the increase in the fluctuations of the monsoon westerly winds, due to increased warming in the Arabian Sea (Roxy et al., 2017; Simpkins, 2017). The increasing trend of urban flood disasters in India over the past several years also is an instance of such cloud bursts. The most notable amongst them were in Hyderabad (2000), Ahmedabad (2001), Delhi (2002; 2003; 2009; 2010), Chennai (2004), Mumbai (2005), Surat (2006), Kolkata (2007), Jamshedpur (2008), and Guwahati (2010).

Table 1: Major Disasters in India

Disasters	Region	Year	Deaths
Famine	Northeast India	1770	Many millions
	East coast of Bengal	Oct-42	Four million
	Bombay	26 May 1618	2,000
	Gujarat	16 June 1819	Over 1,500
	Kashmir	6 June 1828	1,00
	Northern India	26 August 1833	About 500

Earthquakes	Bengal and Assam	12 June 1897	6,000
	Himachal Pradesh	04-Apr-05	Over 20,000
	Bihar	15-Jan-34	Over 11,000
	Quetta (now in Pakistan)	31-May-35	Over 30,000
	Assam	15-Aug-50	Over 1,500
	Maharashtra	30-Sep-93	9748
	Bhuj, Gujarat	26-Jan-01	About 20,000
	Kashmir	08-Oct-05	Over 86,000
	North India-Nepal	25-Apr-15	8964
Tsunami	South-Eastern shores of India	26-Dec-04	Over 10,000
Tornadoes	Calcutta	8 April 1838	215
	Assam	19-Apr-63	140
	Odisha	10-Apr-78	150
	West Bengal-Odisha	24-Mar-98	160
	Calcutta	1737	3,000

Source: Compiled from different sources, including Gunn (2008)

4 Climate Change Vulnerability Indices

As we have already seen, climate change vulnerability assessment belongs to the third school of vulnerability (the climate change science and climate change adaptation research), having the possible coverage of both the first and second generation paradigms. We consider here four global disaster vulnerability indices (Global Climate Risk Index CRI), WorldRiskIndex (WRI), Notre Dame-Global Adaptation Index-related vulnerability index (ND-GAINVI)) and the UN Multidimensional Vulnerability Index (UNMVI), and two India-specific vulnerability indices. Except the WRI, all the others are climate-specific and belong to

the third school of vulnerability; the WRI may be included in the second generation of the second school of thought, i.e., in the school of hazard and disaster risk reduction research with social vulnerability paradigm. The Global CRI, as the name suggests, belongs to the third school of climate change science and climate change adaptation research but with the first generation, risk-hazard, paradigm. All the other indices belong to the third school with the second generation paradigm (Table 2).

Table 2: Climate Change Vulnerability Indices: Schools of Though and Paradigms

Indices	Agency	Period/Year	School of Thought	Paradigm
Global Climate Risk Index	German thinktank, Germanwatch, based on the data from the Munich Re NatCat SERVICE11, reported in	Annual since 2006	Climate change science and climate change adaptation research	Risk-hazard (First generation)
WorldRiskIndex- related Vulnerability Index	WorldRiskReports of *Bündnis Entwicklung Hilft* (Alliance Development Works), initially with the United Nations University in Bonn since 2011 and now with the Institute for International Law of Peace and Armed Conflict of the Ruhr University Bochum since 2018.	Annual since 2011	Hazard and disaster risk reduction research	Social vulnerability (Second generation)
Notre Dame-Global Adaptation Index-related Vulnerability Index	Climate Change Adaptation Program of the University of Notre Dame's Environmental Change Initiative	Annual since 1995	Climate change science and climate change adaptation research	Social vulnerability (Second generation)

UN Multi-dimensional Vulnerability Index	Office of the High Representative for the Least Developed Countries, Landlocke d Developing Countries and Small Island Developing States)	2022 (Preliminary)	Climate change science and climate change adaptation research	Social vulnerability (Second generation)
Climate vulnerability index for the Indian Himalayan Region	Department of Science and Technology, Govt of India (Climate Vulnerability Assessment for Adaptation Planning in India Using a Common Framework, covering all the states and districts in India).	2020	Climate change science and climate change adaptation research	Social vulnerability (Second generation)
Micro level vulnerabil ity index for India	Council on Energy, Environment and Water (CEEW, South Asia's top thinktank, New Delhi)	2021	Climate change science and climate change adaptation research	Social vulnerability (Second generation)

Evidently, the indices are not readily comparable; the methods followed in constructing the indices differ, except for the normalisation (Table 3). Normalisation is generally carried out based on the functional relationship of vulnerability with indicators. Where indicators positively influence vulnerability, normalisation is done using (actual value – minimum value) divided by range, that is, (maximum value – minimum value), and for negatively related indicators, we have (maximum value – actual value) divided by range. However, methods differ, especially since the (latent) dimensions and (observable) indicators used are mostly different. Also note that the CRI and the WRI are reported as risk indices, while the ND-GAIN represents an adaptation gap index. Evidently, the risk indices do not follow the usual definition of risk as the product of probability of hazard and degree of vulnerability, schematised in the pseudo-equation

of Blaikie et al. (1994). The CRI considers only the climate change disaster risk outcome indicators (fatalities and economic losses, both absolute and relative values), while the other indices are in terms of input dimensions (Table 3); thus, the CRI is the weighted

Table 3: Climate Change Vulnerability Indices: Dimensions/ Indicators and Aggregation Method

Indices	Major Indicators/Dimensions	Index Aggregation
Global Climate Risk Index	Death toll; Deaths per 100 000 inhabitants; Absolute losses in PPP; and Losses per GDP unit3	Weighted average of ranks in the four indicators, with weights: absolute values, 1/6; and relative values, 1/3.
WorldRiskIndex-related Vulnerability Index	Exposure (42), Susceptibility (31), Lack of coping capacities (12) and Lack of adaptive capacities (12)	WRI = Square root of (Exposure) x (Vulnerability). (Vulnerability = Unweighted GM of Normalised scores of Susceptibility, Lack of coping capacities and Lack of adaptive capacities)
Notre Dame-Global Adaptation Index-related Vulnerability Index	Exposure (12), Sensitivity (12), Adaptive capacity (12) of different sectors and Readiness/ Coping capacity (9)	AM of the 6 sector scores, obtained as the AM of each sector's constituent indicators. (Vulnerability = Unweighted AM of Normalised scores of Exposure, Sensitivity and Lack of adaptive capacities)
UN Multi-dimensional Vulnerability Index	Vulnerability (14) and Lack of resilience (13) in Economic (8), Environmental (9) and Social (10) domains	NA
Climate vulnerability index for the Indian Himalayan Region	Socio-economic features and livelihood (5); Biophysical aspects (5); Institution and infrastructure (4)	Arithmetic mean of all the normalised scores of indicators of dimensions

Micro level vulnerability index for India	Exposure (2), Sensitivity (5), and Adaptive capacity (7)	Vulnerability = (Exposure x Sensitivity) / (Adaptive Capacity). (Using normalised scores)

Note: Figure in brackets in the second column gives number of (sub-) indicators

AM of the actual disaster outcome measures, while the WRI is obtained by the GM of exposure and vulnerability, and the ND-GAIN gives a measure of gap between readiness (coping capacities) and vulnerability. Also, the WRI-related Vulnerability Index (WRI-VI) and the ND-GAIN-related Vulnerability Index ND-GAIN-VI) represent different dimensions of vulnerability (WRI-VI in terms of unweighted GM of normalised scores of susceptibility, lack of coping capacities and lack of adaptive capacities, and ND-GAIN-IV in terms of unweighted AM of normalised scores of exposure, sensitivity and lack of adaptive capacities), and, again, the indicators (and sub-indicators) used are mostly different.

All these three indices are annual, while the remaining three are available only for a latest year. The UNMVI uses 27 vulnerability and resilience indicators in economic, environmental and social domains (for the preliminary results of 2022). In the case of the India-specific indices, the Department of Science and Technology (DST, 2020) of the Government of India considers sensitivity and adaptive capacity indicators, while the Council on Energy, Environment and Water (CEEW, 2021) uses exposure, sensitivity and adaptive capacity indicators.
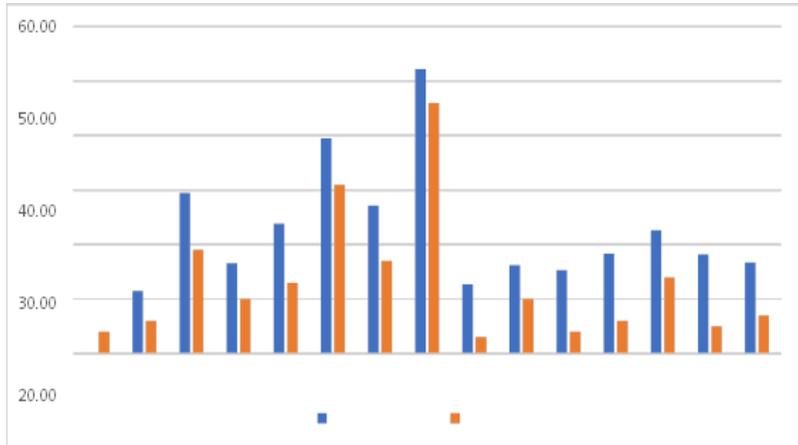
Global Climate Risk Index

The Global Climate Risk Index (CRI), from the German thinktank, Germanwatch, analyses and ranks countries and regions on the basis of the extent to which the impacts of climate

related extreme weather events (storms, floods, heatwaves etc.) have affected them. The CRI uses the normalized indicators to rank the affected countries and estimates the score of each country as a weighted average of its ranks in the four indicators, using the weights: (i) death toll, 1/6; (ii) deaths per 100 000 inhabitants, 1/3; (iii) absolute losses in PPP, 1/6; and (iv) losses per GDP unit, 1/3. "While absolute numbers tend to overestimate populous or economically capable countries, relative values give more prominence to smaller and poorer countries. In order to consider both effects, the analysis of the CRI is based on absolute (indicators 1 and 3) as well as on relative (indicators 2 and 4) scores. Being double weighted in the average ranking of all indicators generating the CRI Score, more emphasis and therefore higher importance is given to the relative losses." (Eckstein et al., 2021: 30). For example, in the Climate Risk Index for 2019, India ranks 1st in annual fatalities among all countries considered, 36th in fatalities per 100,000 inhabitants, 1st in losses and 13th in losses per unit GDP. Hence,

CRI Score of India = 1 x 1/6 + 36 x 1/3 + 1 x 1/6 + 13 x 1/3 = 16.67, with a rank of 7.

Note that lower index scores indicate higher risk, as the score is a weighted average of ranks in the respective indicators; rank 1 indicates the most vulnerable case. India has been one of the worst-hit countries in the world, with a climate risk index less than 20 in many of the recent years (Fig. 4). During the period from 2006 (reported in 2008) to 2019 (reported in 2021), the climate risk related average death toll in India was 36043 per year and the average absolute losses (in US$ PPP) was almost 20000 per year. The death toll varied in the range of 1168 in 2012 and 7437 in 2013 and the absolute losses (in US$ PPP) in the range of 591.28 in 2012 and 68812.35 in 2019.

Fig 4: Climate Risk Index and Rank for India: 2005 – 2019

Source: Compiled from Germanwatch Global Climate Risk Index (various years).

World Risk Index-related Vulnerability Index

The World Risk Index (given as WorldRiskIndex), indicating the probability that a country is affected by a disaster, comes from the WorldRiskReports of Bündnis Entwicklung Hilft (Alliance Development Works), developed in cooperation initially with the United Nations University in Bonn since 2011 and now with the Institute for International Law of Peace and Armed Conflict (IFHV) of the Ruhr University Bochum since 2018. The 2022 World Risk Index is a fundamentally revised one, covering all the UN-recognized (193) countries and over 99 percent of the world's population. With the new conceptual and methodological adjustments, the 2022 index remains incomparable with the earlier ones, as risk scores of some countries have changed very substantially as compared with the previous scores; the WorldRiskIndex now comprises 100 indicators instead of the previously used 27 indicators (*Bündnis Entwicklung Hilft* (2022:9).

For example, the new indices of India and the United States of America show much higher risk for these countries than the earlier low risk scores.

"The risk assessment in the WorldRiskReport is based on the general notion that the emergence of a disaster not only depends on how severely natural hazards hit a society, but also on how vulnerable society is to their effects." (*Bündnis Entwicklung Hilft* (2022:13). The index is assumed to be "based on the interaction between the spheres of exposure and vulnerability" (ibid.): WorldRiskIndex = Square root of [(exposure) x (vulnerability)]. Exposure is given in terms of the number and share of the population regarding the intensity levels (strong, severe, extreme) of earthquakes, tsunamis, cyclones, coastal floodings, riverine floodings, droughts and sea level rise. Vulnerability is composed of three indicators: (i) susceptibility, as a function of public infrastructure, housing conditions, nutrition and the general economic framework; (ii) coping capacities, as a function of governance, disaster preparedness and early warning, medical services, social and economic security; and (iii) adaptive capacities to future natural events and climate change. The indicators used for these three dimensions are:

1. Susceptibility: (i) Socio-Economic Development (ii) Socio-Economic Deprivation (iii) Societal Disparities (iv) Vulnerable Populations Due to Violence, Conflicts and Disasters (v) Vulnerable Populations Due to Diseases and Epidemics;

2. Lack of Coping Capacities: (i) Recent Societal Shocks (ii) State and Government (iii) Health Care Capacities; and

3. Lack of Adaptive Capacities: (i) Education (ii) Research (iii) Long-Term Health and Deprivation Effects (iv) Investment Capacities.

The sub-indicators of these indicators are given in Appendix Tables 1(a), 1(b) and 1(c). The different dimensions and the final index are computed using unweighted GM of the normalised values. Figure 5 reports the WorldRiskIndex (WRI) for India from 2011 to 2022. It should be noted that the latest 2022 scores are not comparable with the earlier ones, as already explained. It is significant to note that vulnerability decreased over these years, and exposure remained almost constant, resulting in risk reduction. This vulnerability decrease in turn was due to the fall in the susceptibility, and to some extent in the lack of adaptive capacities, as the lack of coping capacities declined very slowly.

Fig 5: WRI-related Vulnerability Measures for India
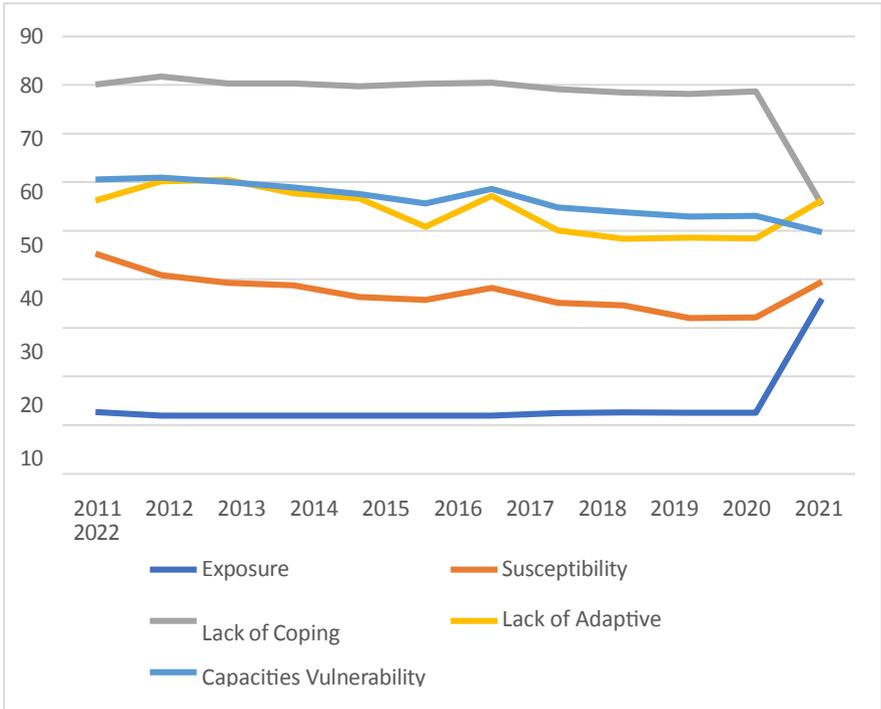
Source: WorldRiskReports of Bündnis Entwicklung Hilft (Various years)

The Notre Dame-Global Adaptation Index-related Vulnerability Index

The Notre Dame-Global Adaptation Index (ND-GAIN) is a free opensource index being released since 1995 by the Climate Change Adaptation Program of the University of Notre Dame's Environmental Change Initiative (ND-ECI), that assesses a country's current vulnerability to climate disruptions (of 182 countries) and its readiness to leverage private and public sector investment for adaptive actions (of 192 countries). We consider

these two measures together for a vulnerability index, the focus of this study.

In order to measure vulnerability and readiness, the ND-GAIN brings together over 74 variables to form 45 core indicators. In the case of vulnerability, the index considers six life- supporting sectors such as food, water, health, ecosystem services, human habitat and infrastructure. Each sector represents an indicator that in turn is represented by three sub- indicators (components): (i) the exposure of the sector to climate-related or climate-exacerbated hazards; (ii) the sensitivity of that sector to the impacts of the hazard and (iii) the (lack of) adaptive capacity of the sector to cope or adapt to these impacts (Appendix Table 2(a)). The readiness measure (representing coping capacities) is composed of three components: (i) economic readiness, (ii) governance readiness and (iii) social readiness (Appendix Table 2(b)). The first (economic readiness) component considers the investment climate that facilitates mobilization of capital from private sector, while the second (governance readiness) component measures the degree of the stability of the society and institutional arrangements that contributes to the investment risks, assuming that a stable country with high governance capacity can reassure investors of the uninterrupted growth of the invested capital; and the third (social readiness) component assesses social conditions that help society to make efficient, equitable and fruitful use of investment.

The ND-GAIN-related vulnerability measures are shown in Fig. 5. The vulnerability was gradually declining over time, from a score of 0.555 in 1995 to 0.506 in 2020; so was sensitivity from a score of 0.415 to 0.356 during the same period, whereas exposure remained at the same level of a score of 0.572 (Figure 5). The readiness appeared to have some perceptible improvement during

a few years of the middle period only to fall in 2014 and to register a slow rise thereafter.

Figure 5: ND-GAIN-related Vulnerability Measures of India
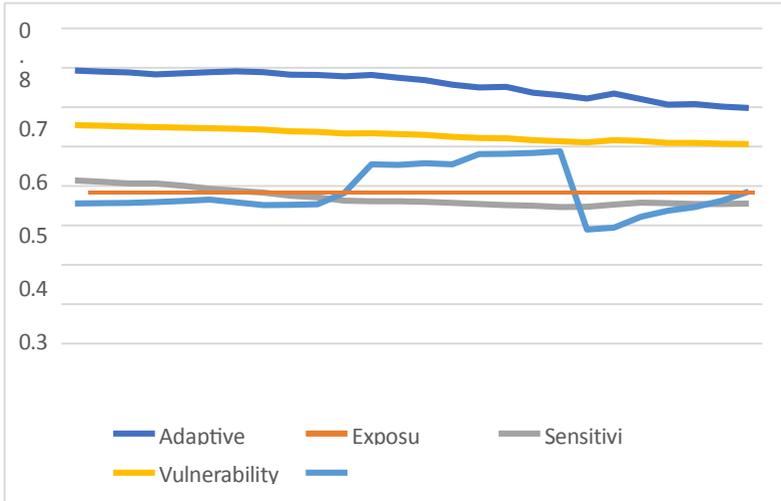
The UN Multidimensional Vulnerability Index

Following the requests from Small Island Developing States (SIDS) in 1992 at the United Nations Conference on Environment and Development for the developing a globally accepted vulnerability assessment, the UN (Office of the High Representative for the Least Developed

Countries, Landlocked Developing Countries and Small Island Developing States) has started on a multidimensional vulnerability index (MVI), based on 27 indicators of vulnerability and (lack of) resilience in economic, environmental and social domains (see

Appendix Table 3).[12] The (preliminary) MVI score for India is reported as 45.98 in a (0, 100) scale, with minimum score for Indonesia (32.11) and maximum for Yemen (72.87).[13]

India-specific Vulnerability Indices

Based on the SREX approach of IPCC, the Department of Science and Technology of Government of India, in collaboration with the 12 Himalayan States, came up with a first-of- its kind vulnerability map and report "Climate Vulnerability Assessment for the Indian Himalayan Region Using a Common Framework" in 2018-19 for the entire Himalayan region, under the National Mission for Sustaining the Himalayan Ecosystem (NMSHE) and the Indian Himalayas Climate Adaptation Programme (IHCAP), launched by the Government of India as part of National Action Plan on Climate Change (Sharma, et. al., 2018; Barua, et. al., 2019). The NMSHE was able to build capacities of all the 12 Indian Himalayan Region states for assessments of climate-related vulnerability and also for adaptation planning and execution, and resulted in the development of a state-level vulnerability map of the entire Indian Himalayan Region and also of separate district-level maps.

The success of this capacity building programme stimulated an extension of the project (Climate Vulnerability Assessment for Adaptation Planning in India Using a Common Framework) to all the 29 states and 612 districts in India, covering the same geographical area as the current 718 districts (Department of Science and Technology, 2020). A vulnerability index was derived for each state/district in India, using 14 indicators of vulnerability,

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[12] Available at https://www.un.org/ohrlls/mvi/. Accessed 12.06.2023.

[13] https://www.un.org/ohrlls/content/mvi-preliminary-country-scores. Accessed 12.06.2023.

capturing both sensitivity and adaptive capacity of states. The indicators came from three broad categories (Department of Science and Technology, 2020: 10):

1. Socio-economic features and livelihood: (i) percentage of population living below the poverty line, (ii) income share from natural resources, (iii) share of horticulture in agriculture, (iv) proportion of marginal and small landholdings, and (v) women's participation in the workforce.
2. Biophysical aspects: (i) yield variability of food grains, (ii) area under rainfed agriculture, (iii) forest area per 1000 rural population, (iv) incidence of vector-borne diseases and (v) incidence of water-borne diseases.
3. Institution and infrastructure: (i) area covered under centrally funded crop insurance schemes (such as Pradhan Mantri Fasal Bima Yojna and Revised Weather-based Crop Insurance Scheme, (ii) implementation of Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), (iii) road and rail-network, and (iv) the density of healthcare workers.

The vulnerability indices were constructed by taking a simple arithmetic mean of all the normalised scores. Using these indices, the study identified the most vulnerable states and districts in the country with respect to the current climate risk and the major drivers of vulnerability, as such identification is the first step for prioritising investment in climate adaptation. Jharkhand came out with the highest (0.67) and Maharashtra with the lowest (0.42) vulnerability index, the small range signifying that all the states need to address the vulnerability concerns (Fig. 6). The high prioritisation of adaptation interventions goes to the

Figure 6: Vulnerability indices of the Indian states
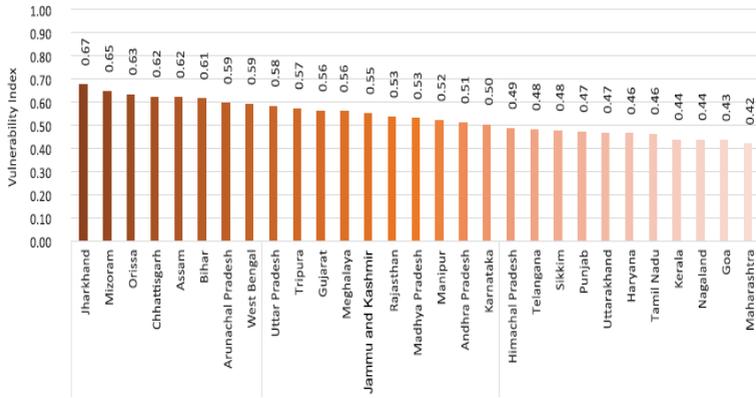
Source: Department of Science and Technology (2020: Figure 4, page 13).

high vulnerability states in the eastern part of the country such as Jharkhand, Mizoram, Orissa, Chhattisgarh, Assam, Bihar, Arunachal Pradesh, and West Bengal. The major drivers of state-level vulnerability were identified as (i) lack of forest area per 1000 population leading to a lack of alternative livelihood based on forest resources, (ii) high proportion of area under rainfed agriculture, and (iii) lack of coverage of central crop insurance schemes (Department of Science and Technology, 2020: 14).

District-level vulnerability indices also lie within a small range of 0.34 - 0.75. Over 60% districts of Assam (about 92%), Bihar (about 82%), and Jharkhand (about 63%) fall in Quartile I (top 25%) of highly vulnerable districts (Appendix Table 4), requiring high attention to adaptation planning. Major drivers of vulnerability across the districts included lack of area under horticulture (396 districts), lack of forest area per 100 of rural population indicating lack of alternative livelihoods based on forest products (336 districts), and lack of coverage of central

crop insurance schemes (306 districts) (Department of Science and Technology, 2020: 35).

Close on the heel followed a micro-level vulnerability assessment by the Council on Energy, Environment and Water (CEEW, South Asia's top think tank, New Delhi), an integrated mapping of exposure at the micro level (districts in India), assessing sensitivity through a spatial-temporal analysis, and evaluating adaptive capacity in terms of socio-economic and governance mechanisms. The study used the following component-based indicators for the vulnerability assessment (Mohanty and Wadhawan 2021: 14):

1. Exposure: frequency and intensity of extreme events (floods, droughts, cyclones, and their associated events, as well as compounding impacts, i.e., flood & drought, flood & cyclone, drought & cyclone, and flood, drought & cyclone events);

2. Sensitivity: landscape-based indicators: (i) land use and land cover, (ii) elevation, (iii) slope, (iv) ground water and (v) soil moisture; and

3. Adaptive capacity: (i) effectiveness of District disaster management plans, (ii) Gross district domestic product, (iii) literacy rate, (iv) sex ratio, (v) availability and accessibility to critical infrastructure, (vi) availability of disaster-ready shelters, and (vii) population density.

The composite vulnerability index was obtained by aggregating index values for individual components of exposure, sensitivity, and adaptive capacity. Since both exposure and sensitivity are positively and adaptive capacity is negatively related to vulnerability, the vulnerability index was estimated as Vulnerability = (Exposure x Sensitivity)/ Adaptive Capacity.

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The study found that more than 80 percent of India's population live in districts highly vulnerable to extreme hydro-met disasters (floods, cyclones, and droughts) and their compounded impacts (Mohanty and Wadhawan 2021: iv). Assam, Andhra Pradesh, Maharashtra, Karnataka, and Bihar were found to be the five most vulnerable states in India (Fig. 7). Andaman and Nicobar Islands, Daman and Diu, Dadra and Nagar Haveli, Leh Ladakh, Lakshadweep, Meghalaya, Mizoram, and Punjab appeared to have (close to) zero overall vulnerability index.

Fig. 7: Overall Vulnerability Indices of States
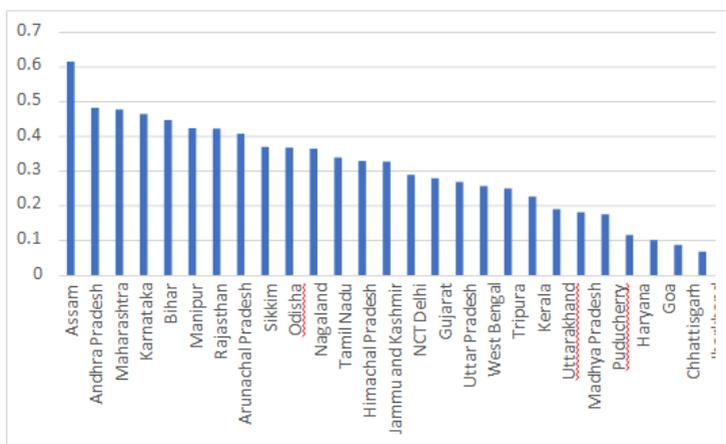
Source: Mohanty and Wadhawan (2021: Table 15, page 48).

5. An Integrated Assessment of Vulnerability in India

As already indicated, the indices are not readily comparable, as the (sub-) indicators as well as the aggregation methods used are mostly different. Thus, the CRI, based on the rank of the disaster outcome measures, with lower index scores indicating higher risk, is in no way in line with the other indices, based on vulnerability

input measures, with higher values denoting higher degrees of vulnerability.

It is in fact possible to construct such a comparable index using the normalised scores of the outcome indicators directly. The relevant data for all the countries are available for 2006-2017, and we make use of these data to construct a modified CRI for all the countries for these years. Since we are measuring the degree of vulnerability across countries, normalisation is done by dividing the vulnerability differential (actual value – minimum value) by the range; and the normalised values are aggregated using weighted geometric mean (GM), where the weights have been derived from principal components analysis (PCA). A part of the results for India and a few other countries (her neighbours and a couple of advanced countries) is given in Table 4. It is significant to note that the ranks of the countries according to the original and the modified indices do not differ much, a result that supports our exercise to obtain a vulnerability index, in line with the original WRI but comparable with the others, with higher values representing higher degrees of vulnerability.

It is important to note that India figured five times as the most vulnerable country and three times as the second most vulnerable country during these 12 years among these countries, showing India's vulnerable position in respect of climate change disasters.

Table 4: Modified CRI

	2006	2007	2008	2009	2010	2011
Afghanistan	16.76	10.40	1.19	6.79	1.71	3.89
Bangladesh	6.31	78.41	0.03	8.92	0.17	3.18
Bhutan	0.00	0.14	0.41	23.00	0.00	0.00
China	47.62	29.59	6.63	21.06	12.05	13.69

India	54.62	18.55	1.45	27.83	1.95	19.41
Indonesia	30.29	9.66	0.07	3.51	0.38	1.66
Japan	3.81	1.75	0.00	2.08	0.05	2.95
Nepal	7.81	9.69	0.37	9.71	0.53	7.26
Pakistan	11.98	15.23	0.02	1.69	12.63	15.25
Russia	5.48	0.25	0.00	0.96	80.27	0.09
Sri Lanka	4.64	2.02	0.13	0.19	0.44	6.54
United Kingdom	0.37	10.45	0.14	1.75	1.51	0.22
United States	23.43	19.50	7.90	20.67	7.08	37.51
	2012	2013	2014	2015	2016	2017
Afghanistan	22.19	2.18	1.64	1.44	4.09	3.13
Bangladesh	8.13	0.99	0.00	0.30	5.32	3.89
Bhutan	0.00	0.07	2.55	0.70	1.83	0.00
China	23.29	17.59	1.61	2.33	52.80	6.72
India	0.98	25.94	10.02	4.03	47.00	20.63
Indonesia	3.54	1.97	0.00	0.45	4.49	1.42
Japan	7.19	1.10	0.11	0.46	1.55	0.95
Nepal	13.09	2.90	0.05	0.86	5.71	2.09
Pakistan	22.82	5.51	0.00	1.76	11.65	2.34
Russia	22.35	1.04	0.00	0.22	1.37	0.33
Sri Lanka	4.46	1.40	0.33	0.08	4.35	3.00
United Kingdom	0.65	7.41	30.90	0.28	0.64	0.05
United States	31.87	8.41	0.30	1.74	25.11	18.95

On the other hand, the other two annual series of indices, WRI-VI and ND-GAIN-VI, are aggregated from vulnerability input indicators. However, the input (latent) dimensions and (observable) indicators differ here also. As already explained, the WRI-VI considers vulnerability in terms of susceptibility, lack of

adaptive capacities and lack of coping capacities, whereas, the ND-GAIN-VI combines exposure, sensitivity and lack of adaptive capacity. An integrated climate change vulnerability index should aggregate all the four dimensions of exposure, susceptibility (sensitivity), lack of adaptive capacities and lack of coping capacities (readiness), as our integrated vulnerability framework (given above) suggests. Using the data on these dimension indices, we attempt to construct a comprehensive input-based vulnerability index for India here.

Table 5: DFA-weighted Dimension Indices for India

	Exposure			Susceptibility (Sensitivity)		
Year	WRI (0.501)	ND-GAIN (0.499)	Combined (DFA-wt GM)	WRI (0.667)	ND-GAIN (0.333)	Combined (DFA-wt GM)
2011	12.68	57.15033	26.862	45.3	35.162	41.638
2012	11.94	57.15	26.065	40.88	35.022	38.830
2013	11.94	57.15	26.065	39.31	34.640	37.690
2014	11.94	57.15	26.065	38.72	34.712	37.338
2015	11.94	57.15	26.065	36.37	35.262	35.997
2016	11.94	57.15	26.065	35.79	35.772	35.784
2017	11.94	57.15	26.065	38.22	35.632	37.339
2018	12.47	57.1503	26.638	35.16	35.417	35.245
2019	12.58	57.15031	26.756	34.61	35.390	34.868
2020	12.51	57.1503	26.681	32.08	35.554	33.196
	Lack of Adaptive Capacities			Lack of Coping Capacities (Readiness)		
Year	WRI (0.406)	ND-GAIN (0.594)	Combined (DFA-wt GM)	WRI (0.239)	ND-GAIN (0.761)	Combined (DFA-wt GM)
2011	56.24	65.150	61.375	80.11	51.85	57.527
2012	60.18	63.626	62.204	81.78	51.65	57.635
2013	60.55	63.032	62.012	80.31	51.18	56.996
2014	57.71	62.210	60.343	80.31	71.06	73.163
2015	56.64	63.446	60.590	79.75	70.59	72.679
2016	50.78	62.044	57.199	80.22	67.80	70.582
2017	57.17	60.646	59.211	80.47	66.27	69.412

2018	50.08	60.802	56.198	79.11	65.36	68.407
2019	48.4	60.164	55.079	78.45	63.74	66.978
2020	48.6	59.823	54.985	78.15	61.40	65.042

The ND-GAIN measures are available for 1995-2020, while the WRI measures, for 2011-2022 only; hence our period of study is 2011-2020. Since we have a time series data set, the weights for aggregation through GM are derived from dynamic factor analysis; Table 5 reports the DFA- weighted GM indices of the four dimensions, exposure, sensitivity, and lack of adaptive and coping capacities (readiness) for India during this period. Note that the ND-GAIN readiness index is converted into lack of readiness measure in terms of its complement (1 – readiness, as percentage). These four dimensions are in turn combined into a DFA-weighted GM to obtain the integrated climate vulnerability index for India (Table 6).

Table 6: Potential and Actual Vulnerability Measures for India

Year	Exposure (0.128)	Sensitivity (0.332)	Lack of Adaptive capacities (0.347)	Lack of Coping Capacities (0.193)	(Potential: Input-based) Integrated VI	(Actual: Outcome-based) Modified CRI
2011	26.86	41.64	61.37	57.53	47.94	19.41
2012	26.06	38.83	62.2	57.64	46.9	0.98
2013	26.06	37.69	62.01	57	46.29	25.94
2014	26.06	37.34	60.34	73.16	47.97	10.02
2015	26.06	36	60.59	72.68	47.39	4.03
2016	26.06	35.78	57.2	70.58	46.1	47
2017	26.06	37.34	59.21	69.41	47.17	20.63
2018	26.64	35.25	56.2	68.41	45.44	
2019	26.76	34.87	55.08	66.98	44.81	
2020	26.68	33.2	54.99	65.04	43.79	

Note: Figures in brackets are the DFA weights.

As already indicated, the CRI is a disaster outcome indicator-based measure and the other indices, including our integrated climate change vulnerability index (ICVI), are vulnerability input indicator-based ones. That is, CRI represents actual vulnerability, while the input-based indices may be taken as potential vulnerability measures, given the degree of exposure, sensitivity, and lack of both adaptive and coping capacities. And the gap between the two (actual vs. potential) may be interpreted as representing an 'efficiency' in disaster vulnerability management. Table 6 also presents our modified PCA-weighted GM measure of CRI, which is comparable in terms of degrees of vulnerability similar to other indices. We find that only in one year the actual exceeded the potential. However, it is evident from the Table that we need to go a long way still.

It is important to note that both the actual and the potential measures of vulnerability were on an average falling gradually over time, with the actual one going through some (natural) wild swings as may be expected and the latter crawling down slowly. Given a constant degree of exposure, sensitivity was declining, as also the lack of adaptive capacities, while the lack of coping capacities increased from an initial low level, with a very slow decline thereafter. That the readiness to cope with the climate vulnerability remains weak explains the slow decline in vulnerability despite the positive contributions from the other factors.

Note that a hazard becomes disaster only in the presence of vulnerable people exposed to it ("without people, there is no disaster"), and the degree of disaster can be minimised by enhancing adaptive and coping capacities of people exposed, and this control can also minimise the erratic nature of disaster that otherwise mimics the erratic nature of hazards. Thus, the erratic nature of the actual vulnerability index of India over the period as

a reflection of that of disasters in turn implies an ineffective control over them, given the higher levels of the lack of both adaptive and coping capacities (Table 6). That is, what stands out in this exercise is that India still remains highly vulnerable to climate change extreme events, despite the low levels of exposure and sensitivity, owing to the high levels of lack of adaptive and coping capacities. This in turn signifies the need to mobilise resources for enhancing these capacities; and it is here the significance of climate finance mobilisation becomes all the more imperative and inevitable.

6 Conclusion

The world has now recognised the scientific consensus that the emissions of anthropogenic greenhouse gases since the industrialisation period are the main cause of rising temperatures in our planet's atmosphere and oceans, accelerating the pace and severity of extreme weather events. The Global Disaster Assessment Report on Disaster Risk Reduction (2022) of the UN Office for Disaster Risk Reduction (UNDRR) shows that the last two decades saw a significant increase in the number of disaster events reported per year. India is one of the world's most disaster-prone country, highly exposed to recurrent natural hazards of earthquakes, cyclones, floods, landslides, and droughts. However, these extreme events as such do not necessarily cause extreme disaster risk; rather, the risk occurs only when potentially vulnerable populations and assets remain exposed to the impacts of such extreme events. This paradigm thus recognises the spectrum of man-environment relations as an integral part of disaster risk along with the 'naturalness'.

The contribution of the present paper lies in its attempt to (i) develop an integrated conceptual framework of climate change vulnerability, within which a review of the important climate

change vulnerability indices is presented and the position of India therein is assessed. and also (ii) build up a modified disaster outcome indicator-based vulnerability index and a comprehensive vulnerability input indicator-based index in a comparative actual-potential vulnerability framework.

The paper has considered four global vulnerability indices and two India-specific (state-wise) indices. While the Global Climate Risk Index, the WorldRiskIndex, and the Notre Dame- Global Adaptation Index are available for a number of years, others are the results of one-time exercise only. Except the Climate Risk Index, all others are offshoots of social vulnerability paradigm. The annual CRI considers the indicators of (i) number of deaths, (ii) number of deaths per 100,000 inhabitants, (iii) sum of losses in US$ in purchasing power parity (PPP) and (iv) losses per unit of gross domestic product (GDP). The annual WorldRiskIndex is based on the interaction between exposure and vulnerability, where the latter is composed of susceptibility, coping capacities and adaptive capacities. The preliminary (2022) UN multidimensional vulnerability index is based on 27 indicators of vulnerability and resilience in economic, environmental and social domains. The annual ND-GAIN measures of vulnerability and readiness combine over 74 variables to form 45 core indicators. In the case of vulnerability, the index considers six life-supporting sectors such as food, water, health, ecosystem services, human habitat and infrastructure, with each sector being represented in terms of exposure, sensitivity and adaptive capacity. The 2018-19 vulnerability index of the Department of Science and Technology of Government of India, in collaboration with the 12 Himalayan States, used 14 indicators of vulnerability, capturing both sensitivity and adaptive capacity of the Indian states, while the 2021 micro-level (districts in India) vulnerability assessment by the Council on Energy, Environment and Water used the indicators of exposure, sensitivity, and adaptive capacity.

However, most of these indices remain incomparable, as the number and nature of the sub- indicators used are different. While the CRI shows India as one of the worst-hit countries in the world with higher risk in many of the recent years, the WRI shows a gradual improvement in the rank of India with declining scores of vulnerability (due to the fall in susceptibility) and thus risk, exposure remaining almost constant. The same trend in general is available with the ND-GAIN results with a gradually declining vulnerability and sensitivity along with an almost constant exposure.

The vulnerability assessment by the Department of Science and Technology of Government of India shows Jharkhand with the highest (0.67) and Maharashtra with the lowest (0.42) vulnerability index, the small range signifying that all the states need to address the vulnerability concerns. The study by the Council on Energy, Environment and Water also finds that more than 80 percent of India's population live in districts highly vulnerable to extreme hydro-met disasters (floods, cyclones, and droughts) and their compounded impacts, with Assam, Andhra Pradesh, Maharashtra, Karnataka, and Bihar being the five most vulnerable states in India.

A clear indication of the assessment exercise of this paper is towards the absence of a comprehensive, integrated, social vulnerability index. Though the UN multidimensional vulnerability index is conceived as a comprehensive one, it is stated to be still in a preliminary stage, with a number of climate-environment-related indicators remaining absent in it. A major problem with such an exercise would be the availability of reliable data on all the relevant indicators. However, we have made an attempt in this paper towards this direction, on the premise that a comprehensive climate change vulnerability index should aggregate all the four dimensions of exposure, susceptibility

(sensitivity), lack of adaptive capacities and lack of coping capacities (readiness), as our integrated vulnerability framework (that we have developed above) suggests. Using the data on these dimension indices from the WRI and ND-GAIN reports, we have constructed a comprehensive input-based vulnerability index for India here, representing potential vulnerability. Since the CRI represents a rank-based index, with lower values showing higher levels of vulnerability, it is not at all comparable with the other indices. Therefore, using the CRI data we have also built up an actual vulnerability index, significantly loyal to the original CRI in terms of ranks, but comparable with other indices and also with our potential vulnerability index with higher values representing higher degrees of vulnerability.

The actual vs. potential vulnerability framework helps us analyse India's high vulnerability condition: we find that India still remains highly vulnerable to climate change disasters, despite the low levels of exposure and sensitivity, primarily because of the high levels of lack of adaptive and coping capacities. This in turn is a significant pointer to the essential exercise of mobilising resources for enhancing these capacities; and it is here the significance of climate finance mobilisation becomes all the more imperative and inevitable.

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Appendix Table 1(a): WRI Indicators and Sub-indicators of Susceptibility

1. Socio-Economic Development	2. Socio-Economic Deprivation	3. Societal Disparities
Life Expectancy at Birth	Lack of Access to At Least Basic Drinking Water Services (Percent)	Income Gini Coefficient
Life Expectancy at Age 70	Lack of Access to at Least Basic Sanitation Services (Percent)	Income Top-Bottom Decentile Ratio
Gross National Income Per Capita (USD PPP)	Lack of Access to Electricity (Percent)	Young Age Dependency
Gross National Savings Per Capita (USD PPP)	Lack of Access to Clean Cooking Fuels (Percent)	Old Age Dependency
Mean Years of Schooling	Fixed Broadband Subscriptions per 1,000 Persons	Gender Disparity in Adolescent Fertility
School Life Expectancy from Primary to Tertiary Education	Mobile Cellular Subscriptions Per 1,000 Persons	Gender Disparity of Mean Years of Schooling
Net Volume of Official Development Assistance Received Per Capita (USD PPP	Prevalence of Undernourishment	Gender Disparity of School Life Expectancy from Primary to Tertiary Education
Net Volume of Personal Remittances Received Per Capita (USD PPP)	Average Dietary Energy Supply Adequacy	Gender Disparity of Labour Force Participation Rates

4. Vulnerable Populations Due to Violence, Conflicts and Disasters	5. Vulnerable Populations Due to Diseases and Epidemics
Refugees, Asylum Seekers, Returned Refugees and Other Displaced (Total and Percent)	Prevalence of HIV and AIDS
Internally Displaced Persons Due to Natural Disasters (Total and Percent)	Prevalence of Tuberculosis and Respiratory Diseases
Internally Displaced Persons Due to Violence and Conflict (Total and Percent)	Prevalence of Neglected Tropical Diseases and Malaria
	Prevalence of Other Infectious Diseases

Source: Bündnis Entwicklung Hilft (Alliance Development Works) (2022).

Appendix Table 1(b): WRI Indicators and Sub-indicators of Lack of Coping Capacities

1. Recent Societal Shocks	2. State and Government	3. Health Care Capacities
Population Affected by Disasters in The Last 5 Years (Total and Percent)	Control of Corruption	Medical Doctors and Practitioners Per 1,000 Persons
Population Killed in Conflicts in The Last 5 Years (Total and Percent)	Rule of Law	Nurses and Midwives Per 1,000 Persons
	Government Effectiveness Political Stability and Absence of Violence and Terror	Maternal Mortality Rate Child Mortality Rate
		Hospital Beds Per 1,000 Persons
		Current Health Expenditures Per Capita (USD PPP)

Source: Bündnis Entwicklung Hilft (Alliance Development Works) (2022).

Appendix Table 1(c): WRI Indicators and Sub-indicators of Lack of Adaptive Capacities

1. Education	2. Research	3. Long-Term Health and Deprivation Effects
Government Expenditure on Primary and Secondary Education Per Capita (USD PPP)	Government Expenditure on Research and Development Per Capita	Years Lost Due to Unsafe Water and Sanitation Sources
Number of Teachers in Primary and Secondary Education Per 1,000 Students	Personnel in Research and Development Per 1,000 Persons	Years Lost Due to Particulate Matter Air Pollution
Gross Enrolment Rate in Primary and Secondary Education	Gross Enrolment Rate in Tertiary Education	Years Lost Due to Child and Maternal Malnutrition
		Children Without Third DTP Dosage (Percent)
		Children Without Third Polio Dosage (Percent)
		Children Without Second Measles Dosage (Percent)

Source: Bündnis Entwicklung Hilft (Alliance Development Works) (2022).

Appendix Table 2(a): ND-GAIN Vulnerability Indicators

Sector	Exposure	Sensitivity	Adaptive Capacity
Food	Projected change of cereal yields	Food import dependency	Agriculture capacity (Fertilizer, Irrigation, Pesticide, Tractor use)
	Projected population change	Rural Population	Child malnutrition
Water	Projected change of annual runoff	Fresh water withdrawal rate	Access to reliable drinking water
	Projected change of annual groundwater	Water dependency ratio	Dam capacity
Health	Projected change of deaths from climate change induced diseases	Slum population	Medical staffs (physicians, nurses and midwives)
	Projected change of length of transmission season of vector- borne diseases	Dependency on external resource for health services	Access to improved sanitation facilities
Ecosystem services	Projected change of biome distribution	Dependency on natural capital	Protected biomes
	Projected change of marine biodiversity	Ecological footprint	Engagement in International environmental conventions
Human Habitat	Projected change of warm period	Urban concentration	Quality of trade and transport-related infrastructure
	Projected change of flood hazard	Age dependency ratio	Paved roads
Infrastructure	Projected change of hydropower generation capacity	Dependency on imported energy	Electricity access
	Projection of Sea Level Rise impacts	Population living under 5m above sea level	Disaster preparedness

Source: Chen et al. (2015)

Appendix Table 2(b): ND-GAIN Readiness Indicators

Economic Readiness	Doing business			
Governance Readiness	Political stability and non-violence	Control of corruption	Rule of law	Regulatory quality
Social Readiness	Social inequality	ICT infrastructure	Education	Innovation

Source: Chen et al. (2015)

Appendix Table 3: Indicators used in the UN MVI (along with corresponding scores for India)

Domains	Vulnerability Indicators	Resilience Indicators
Economic	(i) Trade openness (NA) (ii) Merchandise and services export concentration (24.06) (iii) Instability of export revenue (18.38) (iv) Food and fuel import dependency (22.64)	(i) Lack of Connectivity (27.30) (ii) Population Smallness (0) (iii) Lack of Gross fixed capital formation (31.25) (iv) Production concentration index (15.14)
Environmental	(i) Victims of natural hazards (54.84) (ii) Damages related to natural hazard (37.77) (iii) Rainfall shocks (67.12) (iv) Temperature shocks (51.83) (v) Low elevated coastal zones (3.04) (vi) Drylands (50.38)	(i) Lack of Renewable internal freshwater resources (55.38) (ii) Lack of Crop land (74.84) (iii) Lack of Tree cover (77.44)
Social	(i) Victims of epidemics (0.43) (ii) Regional Conflict-related death (excluding own country's data) (18.25)	(i) Low Dependency ratio (35.08) (ii) Low Population density (100)

	(iii) Regional Homicide	(iii) Lack of basic sanitation
	(excluding own country's data) (9.39)	services (46.75)
	(iv) Refugees from abroad (2.54)	(iv) Low Under-5 mortality (31.41)
		(v) Low Years of schooling (57.60)
		(vi) Low Proportion of seats held by women in national parliaments (74.41)

Note: Figures in brackets are Vulnerability Indicators scores and Lack of Resilience Indicators scores for India (Source: https://www.un.org/ohrlls/content/mvi-preliminary- country-scores. Accessed 12.06.2023.)

Appendix Table 4: Number of districts in each state in different Quartiles of the Vulnerability indices

States	Number of districts in the state	Number of districts in Quartile I	Number of districts in Quartile II	Number of districts in Quartile III	Number of districts in Quartile IV
Andhra Pradesh	13	3 (23.08%)	6 (46.15%)	3 (23.08%)	1 (7.69%)
Arunachal Pradesh	14	0 (0.00%)	2 (14.29%)	5 (35.71%)	7 (50.00%)
Assam	27	25 (92.59)	0 (0.00%)	1 (3.70%)	1 (3.70%)
Bihar	38	31 (81.58%)	7 (18.42%)	0 (0.00%)	0 (0.00%)
Chhattisgarh	18	0 (0.00%)	3 (16.67%)	6 (33.33%)	9 (50.00%)
Goa	2	0 (0.00%)	0 (0.00%)	1 (50.00%)	1 (50.00%)
Gujarat	23	0 (0.00%)	12 (52.17%)	9 (39.13%)	2 (8.70%)
Haryana	21	1 (4.76%)	1 (4.76%)	6 (28.57%)	13 (61.90%)
Himachal Pradesh	12	0 (0.00%)	0 (0.00%)	0 (0.00%)	12 (100.00%)
Erstwhile Jammu and Kashmir	22	8 (36.36%)	6 (27.27%)	3 (13.64%)	5 (22.73%)
Jharkhand	24	15 (62.50%)	8 (33.33%)	1 (4.17%)	0 (0.00%)
Karnataka	30	1 (3.33%)	13 (43.33%)	9 (30.00%)	7 (23.33%)
Kerala	14	0 (0.00%)	5 (35.71%)	8 (57.14%)	1 (7.14%)
Madhya Pradesh	50	15 (30.00%)	11 (22.00%)	8 (16.00%)	16 (32.00%)
Maharashtra	35	6 (17.14%)	13 (37.14%)	10 (28.57%)	6 (17.14%)
Manipur	9	3 (33.33%)	5 (55.56%)	1 (11.11%)	0 (0.00%)
Meghalaya	7	0 (0.00%)	0 (0.00%)	3 (42.86%)	4 (57.14%)
Mizoram	8	1 (12.50%)	0 (0.00%)	3 (37.50%)	4 (50.00%)
Nagaland	11	0 (0.00%)	2 (18.18)	2 (18.18%)	7 (63.64%)
Orissa	30	10 (33.33%)	9 (30.00%)	8 (26.67%)	3 (10.00%)
Punjab	20	0 (0.00%)	0 (0.00%)	7 (35.00%)	13 (65.00%)
Rajasthan	33	0 (0.00%)	5 (15.15%)	17 (51.52%)	11 (33.33%)

Sikkim	4	0 (0.00%)	0 (0.00%)	3 (75%)	1 (25%)
Tamil Nadu	32	5 (15.63%)	6 (18.75%)	11 (34.38%)	10 (31.25%)
Telangana	9	2 (22.22%)	1 (11.11%)	3 (33.33%)	3 (33.33%)
Tripura	4	0 (0.00%)	2 (50%)	1 (25%)	1 (25.00%)
Uttar Pradesh	70	17 (24.29%)	31 (44.29%)	16 (22.86%)	6 (8.57%)
Uttarakhand	13	0 (0.00%)	1 (7.69%)	4 (30.77%)	8 (61.54%)
West Bengal	19	10 (52.63%)	4 (21.05%)	4 (21.05%)	1 (5.26%)

Source: Department of Science and Technology (2020: Table 7, page 36).