# Mapping India's exposure to climate change: a district level study

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*Exposure is a key component in determining climate risk; however, inconsistencies around its conceptualization have been relatively less explored. This article first makes a case for studying exposure as a crucial factor in understanding the consequences of climate change and highlights the fact that exposure is a necessary factor in understanding both vulnerability and adaptation. It then goes on to trace the regional differences in exposure to climate change in India, and identifies the most climate change-affected districts in the country.*

**Keywords:** Climate change, exposure, extreme events, long-term climate variations, vulnerability.

AN area's vulnerability to climate change is typically understood in terms of the pre-existing conditions in the region that make it vulnerable to external shocks[1]. This approach does not emphasize the nature of climate change the region will likely face. As a result, it tends to ignore the variability in the effects of climate change in a large and diverse country like India. This article seeks to develop this larger picture by focusing on exposure to climate change rather than vulnerability. It does so by first exploring the concept of exposure to climate change. It then traces the variability in the exposure across India. This leads us to the identification of the districts that are most exposed to climate change.

## Exposure: a conceptual background

Climate change has varyingly been defined as 'A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and, which is in addition to natural climate variability observed over comparable time periods' by the United Nations Framework Convention on Climate Change (UNFCCC)[2] and as 'A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer' by the Intergovernmental Panel on Climate Change (IPCC)[3]. The former definition by UNFCCC focuses on the cause of climate change by attributing it to anthropogenic factors. Such conceptualization emphasizes the need for mitigation. The latter definition, on the other hand, focuses more on the process of change without delving into its causes. This conceptualization makes a case for exposure as a key determinant of climate change.

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The term 'exposure' in scientific discourse related to climate change has varied over time. Earlier, when climate change discussions were more centered around mitigation efforts, the term exposure was used more in the context of health (exposure of crops to ozone and air pollution due to greenhouse gas emissions) and economic consequences (fuel price volatility) of climate change[3,4]. Later, when the focus on adaptation gained prominence, exposure was used in the context of exposure of a nation or region to climate stress. The conceptualization of the term by IPCC has also been inconsistent over the years, leading to limited focus being paid to the concept in climate change studies.

The earliest definition of exposure was given by IPCC in the third assessment report[5] as 'The nature and degree to which a system is exposed to significant climatic variations'. However, in the fourth assessment report[6], exposure was defined as a component of vulnerability, sensitivity, and adaptive capacity, which led to the loss of its exclusivity. In the fifth assessment report[7], again exposure was considered a separate entity when it was defined as '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'. This definition has been retained in the sixth assessment report as well[8].

In the fifth assessment report, we not only see a delinking of exposure from the definition of vulnerability, but also a delinking of hazard from exposure. This shift in the definition of exposure from the mere existence of climate variability and extreme events to the presence of people and related systems in exposed places or settings has added a spatial aspect to the concept of exposure[1]. The introduction of the spatial element is crucial for understanding the uneven effects of adaptation to climate change at the local level. However, while the spatiality of exposure is an important factor in determining the effect of climate change, in this article, we revert to the earlier conceptualization of exposure in terms of exposure to significant climatic variations.

## Choosing exposure over vulnerability

Vulnerability is an internal property of a system, while exposure is the external element that affects a system. As discussed earlier, exposure was considered one of the components of vulnerability by IPCC's fourth assessment[6], while in the later report[7], it was eliminated from the definition. This delinking made vulnerability independent of exposure, making it completely a function of pre-existing factors. Such a definition does not account for the nature of the external threat and its effects on a system, thus leaving this question unaddressed: vulnerability to what?

While vulnerability is a necessary measure of climate risk, it might not be sufficient because a system that could be exposed may not always be vulnerable, but to be vulnerable to climate change, it is necessary to be exposed[8]. It is thus important to consider the nature of the external threat or exposure for two reasons. Firstly, the variations in climate differ on local scales, so the nature of climatic threats also varies across geographies[9]. For instance, the experience of people in a flood-affected area would contrast with that of a drought-affected region, or the effect of flood in a hilly region would be different from that in a coastal region. The nature of climate variations and local geographies thus determine people's experience of climate change as well as their responses to it. In effect, the specific situation created by the local differences in the experience of climate change needs to be considered for any effective climate change assessments. Understanding exposure may thus serve as a prerequisite in exploring vulnerability while enabling pathways to enquire about the existing and emerging autonomous reactions to manage the impacts of climate change at the local level.

Secondly, vulnerability to climate change is defined as the 'propensity or predisposition to be adversely affected'[10], focusing on adverse effects. This attaches the concept of vulnerability to the negative consequences of climate change. However, many impacts or responses to climate change may be either adverse or beneficial depending upon the magnitude of change experienced, the nature of the affected system, and the specific contexts related to different factors involved[11]. For example, in the Nordic nations, climate change has reduced snow security for cross-country skiing, but the rising temperature has benefits in terms of longer growing seasons for agriculture and more potential for hydropower[12]. So, to assess the overall impact of climate change on a community or society, it is important to consider both the negative and positive impacts of climate change, which could further help inform improved adaptation strategies. This requires a component of analysis that is value-neutral (this is also highlighted by IPCC[11]), a criterion satisfied by the component of exposure.

## Identifying indicators to study exposure

As climate is a multivariate concept, we need to narrow it down to specific indicators of exposure that represent climate change for a given region or location. These indicators are referred to by the IPCC Sixth Assessment Report[13] as climate impact-drivers (CIDs) which are the physical climate system conditions including means, events and extremes. Climate indicators may be categorized into three levels[14]: Type 1 with single variables (temperature, precipitation, etc.) and the associated extreme of those variables (heat waves, cold waves, droughts and floods); Type 2 with complex climate phenomena representing numerous weather events such as hurricanes, tornadoes etc.; and Type 3 including the most complex phenomena which require the measurements of various factors such as air pollution, agricultural and ecological drought, ocean acidity, etc. The single variables (temperature, precipitation) signify long-term changes in climate, while the associated extremes, as well as the complex climate phenomena-related events, signify extreme events. Exposure involves changes in the long-term climatic conditions as well as the variability in magnitude and frequency of extreme events[15].

Long-term climate variability, as well as extreme variations, affect and disrupt many aspects of society directly or indirectly. For instance, rising average temperatures could increase air conditioning costs and affect the spread of diseases; increased frequency and intensity of heat waves may damage some crops and increase illnesses and deaths among vulnerable populations. Increasing precipitation can replenish water sources but may not support certain crops. Extreme rainfall events and cyclones can cause loss of life, damage property, displace population, and temporarily disrupt essential services like telecommunications, transportation, water supplies and energy[16]. A combination of multiple climate drivers, like the simultaneous occurrence of droughts and heat waves or cyclones and floods, lead to compound extreme events[13] that further contribute to social and environmental risks.

Unlike extreme weather events, changes in the long-term trends of the climate are subtle yet apparent. As these long-term changes are imperceptible, people who experience them become the first responders and adapt to them well before science detects them or governments respond to them. Extreme events garner more responses by virtue of their overt nature. While both long-term changes and extreme events are found to impact people and societies, the research and policy-making on these two aspects have mostly remained separated (as also pointed out by Burton[14]). But, with growing climate extremes, long-term variations and compounding of extreme events, it becomes important to take an integrated approach to study the combined effect of multiple climate change indicators. This becomes even more important for shaping local adaptation strategies by considering the combined effect of diverse climatic indicators.

For India, the indicators of climate change deemed most pertinent have been highlighted in several reports. IPCC's Sixth Assessment Report[13] forecasts that sea level rise, erratic monsoons, intense heat waves, and tropical cyclones will be persistent in the Indian sub-continent in the forthcoming years. The future climate predictions of the Indian region have signalled changes in the mean, variability, and extremes of key climatic parameters, including surface temperature and precipitation, monsoons, tropical cyclones, temperature variations in the Indian Ocean, and sea level, and the melting of Himalayan ice caps. As per a report by the Ministry of Earth Sciences[17], the climate change indicators in the Indian region are temperature (both land and ocean), precipitation (including monsoon), droughts and floods, sea level rise in the Indian Ocean (especially the northern part of the ocean), cyclones, and the Himalayan cryosphere. From this report, we drew out seven climatic events that have a pan-Indian appearance. These include long-term trends in changing temperature and changes in rainfall patterns, followed by climate events based on these long-term trends like rising heat wave trends, increase in droughts and floods, as well as extreme events such as extreme rainfall events and cyclones.

## District level exposure to multiple climatic events

To map the districts affected by multiple climatic events, we developed a three-stage matrix. This matrix was developed based on the data assembled from available secondary sources holding information on exposure to climatic events. The stages of the matrix were developed based on the attributes of a climate parameter as well as its spatio-temporal dynamics and variations in magnitude. When a district was found exposed to a climatic parameter/event with a significant (either increasing or decreasing) trend, then that district was assigned with the value 1, and the districts with no significant trend were marked with the value 0. The three stages of the matrix and the results are explained below.

### *Stage 1: Key indicators*

In the first stage of the matrix, key indicators, namely temperature (maximum and minimum) and precipitation, were taken into account. The long-term variability in these two parameters could indicate wider variations in the overall climate and validate the existence and the effects of other associated climatic events impacted by these variations. Studying the fluctuations in temperature and precipitation is considered crucial in climate studies as these fluctuations can alter both hydrological and environmental processes[18]. The thresholds considered while mapping long-term trends in temperature and precipitation were:

- *Rainfall:* District-wise trends in rainfall were secured from the study named 'observed rainfall variability and changes'[19], coordinated by Indian Meteorological Department (IMD) involving daily rainfall data from 1989 to 2018 for each state. In the matrix, we have marked the districts showing increasing or decreasing trends at a 95% significance level.
- *Temperature:* The analysis of long-term trends in the annual average maximum and minimum temperatures at the district level was enabled by the data from the maps developed by the Climate Prediction and Monitoring Group of the IMD. These maps represented trends in temperature based on the historical data ranging between the period 1901 and 2015 (ref. 20). The districts with significant departure either positive or negative (at 95% significance level) from the average annual maximum/minimum temperature (normal) (1981–2010), were utilized in the matrix.

Though many districts in the country were exposed to one or two of the key parameters analysed in stage one of the matrix, we found that only 78 districts were affected by changes in all these three parameters of rainfall, maximum temperature and minimum temperature.

### *Stage 2: Associated climatic events*

Expanding from the results of stage one, we explored the exposure of the above-noted 78 districts to associated extreme climatic events. At this stage, the matrix accommodated events like floods, droughts and heat waves, based on the fact that their occurrence was largely sensitive to variations in the climatic parameters which were part of the first stage. Precipitation variability garners evidence towards the response of the hydrological cycle to global warming and the associated effects. It also relates to arid and wet events like droughts and floods. Temperature exceeding a certain threshold for a prolonged time leads to heat waves.

- *Floods:* The data representing the magnitude of incidence and intensity of floods at the district level were derived from the website named thinkhazard.org, a screening tool developed and maintained by the Global Facility for Disaster Reduction and Recovery (GFDRR)[21]. This screening tool represents the intensity, frequency, and susceptibility of a hazard in the form of probabilistic data while informing the user about the probable frequency at which a particular location may experience a hazard. The probabilistic hazard data is mainly provided in the form of three categories: low, medium, and high, depending upon a hazard's damaging intensity and frequency threshold. The matrix represents the districts with a higher probability of the incidence of the hazard with a higher damaging threshold and lower end of the return period.
- *Heatwaves:* Representng district-level heatwave trends in the matrix was facilitated by extrapolating the data provided by Pai *et al.*[22] for 103 stations in the country.

We extrapolated this data to the districts that those stations belonged to. The above study[22] used the normal climatological value for the base period of 1971–2000 and analysed the daily maximum temperature data of 103 stations distributed all over the country for the period 1961–2010.

- *Droughts:* The data on increasing drought trends in India was based on the study on the long series monthly rainfall data of 640 districts for 115 years (1901–2015)[23]. This study uses the standardized precipitation index (SPI) to analyse drought trends. The districts showing a significant decreasing trend in cumulative SPI were considered part of this analysis, and the significance level was 95%.

At the end of stage 2 analysis, out of 78 districts carried over the former stage one, 10 districts in the country were found to be exposed to 5 out of all 6 parameters, i.e. 3 parameters from the previous stage, viz. rainfall, maximum temperature and minimum temperature, and 3 more parameters from the current stage namely floods, droughts and heatwaves. Those 10 districts were Nagaon, Cachar and Darrang in Assam state, Pathanamthitta and Kozhikode in Kerala, Chandel in Manipur, Kanpur Nagar, Bareilly and Kaushambi in Uttar Pradesh, and Uttarkashi in Uttarakhand state.

### *Stage 3: Extreme events*

The final stage of the matrix was done on a supplementary basis to consolidate the districts with higher exposure. Extreme rainfall events and cyclones are highly complex phenomena and are episodic in nature. Their trends for the 10 districts narrowed down earlier were probed, and the associated criteria utilized in the process were as follows:

- *Extreme rainfall events:* District-wise annual extreme rainfall events data were derived from the IMD report[24] on 'extremes of temperature and rainfall'. The dataset provided by the report was till the year 2012. For the data after 2012, the annual climate summary reports published by IMD[25] were referred to. The rainfall event with the highest magnitude, which has ever been recorded at a particular station for 24 h, was considered in the matrix, as extreme rainfall events may not maintain any specific long-term trends.
- *Cyclones:* As for the long-term trends in the cyclones were concerned, similar to floods, the data was obtained from the web portal of thinkhazard.org, developed by GFDRR[21]. The districts with a higher probability of the prevalence of this hazard with a higher damaging threshold and lowest return period were included in the matrix.

The results of the matrix pointed that out of 10 districts, 2 districts – Cachar and Kozhikode were exposed to both extreme rainfall events as well as cyclones, while the districts such as Nagoan, Pathanamthitta, Chandel, Kanpur Nagar, and Bareilly were affected by at least one of these extreme events.

### *Limitations with data*

As mentioned earlier, the data on district-level trends were collected from various sources due to the country's lack of prevailing district-level studies. The secondary data collated from different sources were from dissimilar time frames; for instance, the rainfall trends for the districts of Manipur were for the period 1901–2000 (ref. 26), the temperature trends for the districts of Uttar Pradesh were from 1971 till 2013 (ref. 27), and the temperature trend of Sikkim was from 1978 to 2009 (ref. 28). Other issues included climate trends originally calculated for agro-climatic zones of the states which had to be extrapolated to the corresponding districts. This was done with the temperature trends for the districts of Madhya Pradesh for the period 1951–2013 (ref. 29). For the state of Tripura, the temperature data was available for only two stations of Agartala and Kailashahar for the period 1969–2014 (ref. 30). The district-level annual minimum temperature for the state of Himachal Pradesh was for the period 1951–2013 (ref. 31). The data on temperature for states like Arunachal Pradesh, Mizoram and Nagaland were not available.

## Results

The analysis of key climate indicators at the district level gives us an understanding of regional differences in the experience of climate change in India. We found that five districts had been affected by six types of climate variations and extremes, while three others affected by five types (Figure 1). The districts of Cachar (Assam) and Kozhikode (Kerala) have been identified as the most exposed to climate change, as each of them experienced variations in three long-term climate trends and witnessed four kinds of extreme events. This compounding of multiple climate variations and extremes puts these locations at high climatic risk. These districts can further be studied to understand the spatial variations in exposure to climate change at even finer scales, in line with the IPCC fifth assessment report's conceptualization of exposure. As exposure is a pre-requisite to climatic vulnerability, this study gives a starting point to do more focused vulnerability assessments in these regions.

## Conclusion

The focus on exposure highlights the regional differences in the experience of climate change in India. The diverse geographies and climate zones create conditions unique to a location which tends to uphold the differential traits of

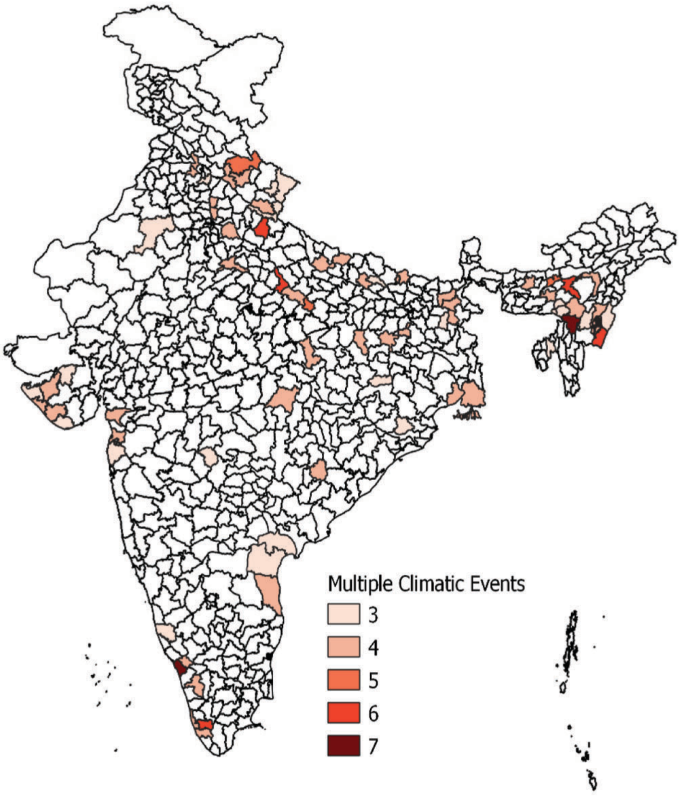


**Figure 1.** Multiple climatic events: district level exposure.

exposure and has implications for the kinds of responses generated to deal with their consequences – whether adverse or beneficial. The significance of exposure lies in the fact that it is a value-neutral concept that gives us a picture of climate change as it is, thus giving us a starting point to understand the effects of climate change in its entirety. Vulnerability to climate change cannot be studied by excluding the actual impacts of climate change, and thus exposure becomes a crucial element in filling this gap. Further, exposure to extreme events has been the primary focus in the field of disaster risk. However, exposure to variations in long-term trends of temperature and rainfall has the potential to fundamentally alter the way people live, work and eat, but people and communities are largely left to adapt to these changes on their own. Prioritizing these indicators of exposure is thus important to study autonomous adaptations at the local level, which can further help inform planned adaptation strategies.

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