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Preparing India for Extreme Climate Events

Mapping Hotspots and Response Mechanisms

Abinash Mohanty

Report | December 2020

India's economic losses due to climate change were the second highest in the world with a loss of Rs 2.7 lakh crore (USD37 billion) — nearly as much as its defence budget in 2018 (German watch, 2020).

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We would like to thank Mr Kamal Kishore, Member, National Disaster Management Authority (NDMA), Government of India, for sharing his time and knowledge with us and motivating us to undertake this study. We would also like to express our gratitude to Mr Animesh Kumar and Ms Iria Touzan, from the United Nations Office for Disaster Risk Reduction, Bangkok, who shared many of their insightful perspectives with us. We thank Dr A. V. P. Prasad, Deputy Director, Indian Space Research Organisation (ISRO), Government of India, and Dr T. Ravi Sankar, Deputy Director and Group Head, National Remote Sensing Centre (NRSC), ISRO, for supporting us with their valuable comments and helping us access base-level maps of the Indian subcontinent.

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"Globally, India is the fifth-most vulnerable country. While the frequency and intensity of extreme events are increasing, we are left with less than a decade to adhere to the Sendai Framework; course correction needs to have a razor-sharp focus on curtailing the compounded impacts of climate extremes. There is no denying that the climate is changing and it is changing fast."

India has witnessed more than 478 extreme weather events between 1970-2019 and most of them occurring after 2005.

Image: iStock

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Acronyms

CRED	Centre for Research on the Epidemiology of Disasters
CGIAR	Consultative Group on International Agricultural Research
CRI	Climate Risk Index
DM	disaster management
DRR	disaster risk reduction
ECMWF	European Centre for Medium-range Weather Forecasting
EM-DAT	Emergency Events Database
ENSO	El Niño south oscillations
ETM	Enhanced Thematic Mapper Plus
GAR	*Global Assessment Report on Disaster Risk Reduction*
GrADS	Grid Analysis and Display System
IGBP	International Geosphere-Biosphere Programme
IMD	India Meteorological Department
IRS	Indian remote-sensing satellites
LULC	land use and land cover
NDMA	National Disaster Management Authority
NOAA	National Oceanic Atmospheric Administration, Government of the USA
NRSC	National Remote Sensing Center, Indian Space Research Organisation
PIB	Press Information Bureau
SREX1-IPCC	*Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, prepared by the Intergovernmental Panel on Climate Change (IPCC)
TM	themat ic mapper
UNDRR	United Nations Office for Disaster Risk Reduction
WHO	World Health Organization
WMO	World Meteorological Organization

The World bank estimates that globally, hydro-met disasters contributed to 90 per cent of disaster loss and damage.

Image: iStock

Executive summary

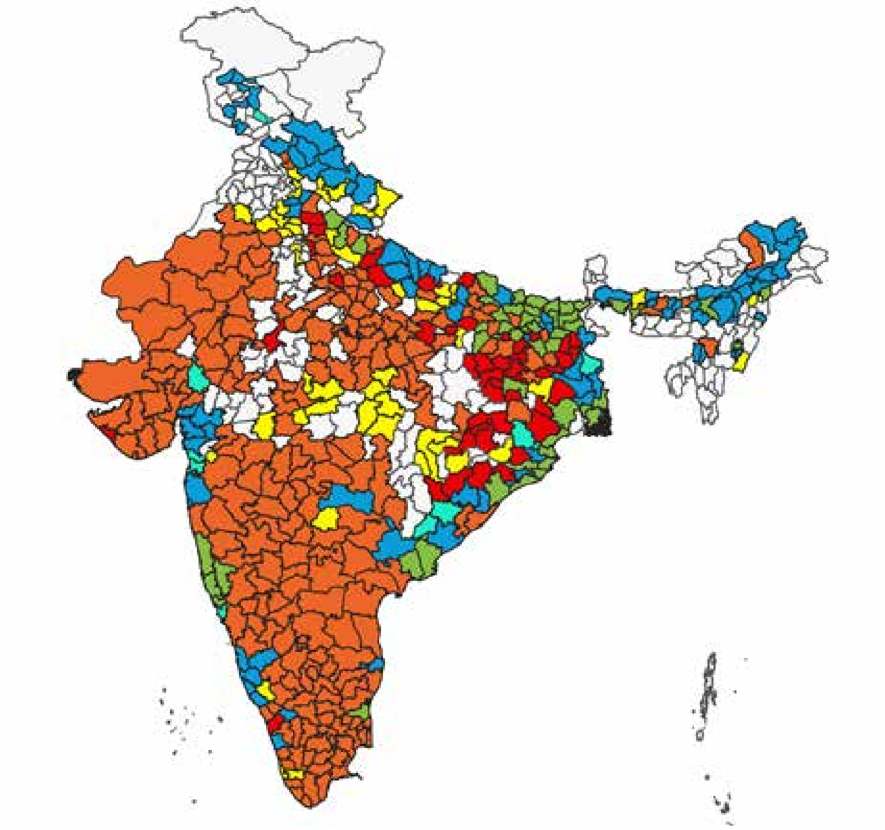
Climate change poses unprecedented challenges to human-made and natural ecosystems as well as to anthropocentric and economic activities. The most obvious evidence, arguably, is the surge in the frequency of extreme events. Extreme weather events resulting from climate change led to 495,000 human deaths across the world in 1999–2018. Further, more than 12,000 extreme weather events led to losses worth USD 3.54 trillion (measured in terms of purchasing power parity or PPP) during this period. Against this backdrop of changing climate, the frequency, intensity, spatial extent, duration, and pattern of weather and climate events are also changing, leading to unprecedented climate extremes (Zhai et al. 2018).

This study provides an micro-level hazard assessment for India at a historical timescale

According to the Climate Risk Index, 2018, India jumped nine places in climate vulnerability rankings and was ranked the fifth-most climate-vulnerable country in the world (German Watch, 2018). Storms are escalating into cyclones, droughts are affecting more than half of the country, and floods of an unprecedented scale are causing catastrophic damage. There is no denying that the climate is changing – and fast.

Global, regional, national, and subnational climate actions are geared toward limiting any further increase in the earth's temperature to 2 °C. However, we must also consider the consequences of this "target" temperature increase, given that the current trends in extreme events are the result of a 0.6 °C rise in the last 100 years (IMD 2019).

This report presents a micro-level hazard assessment of climate extremes in India. Through geospatial, temporal analysis, we provide a detailed assessment of the impact of extreme events at a district level. We use the pentad decadal analysis of extreme events in India (1970–2019) to identify district hotspots and climate change landscape for extreme events (see Figure ES1). The study argues that comprehensive risk assessments at the localised level are the need of the hour and should be undertaken for all districts in India. This study looks at the combined risk of hydro-met disasters and their compounded impacts. As per our analysis, the Indian subcontinent has witnessed more than 478 extreme events since 1970 and an acceleration in their frequency after 2005.

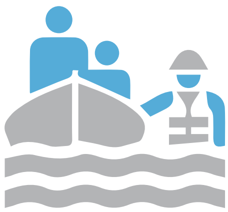


Cyclone   Drought   Flood   Cyclone and drought
Flood and cyclone   Flood and drought

Figure ES1
More than 75 per cent of Indian districts are extreme climate event hotspots

Source: Author's analysis

According to our analysis, India experienced an exponential increase in extreme events during the period 1970–2019, with a marked acceleration in 2000–2019. We considered 2005 the reference year for the pentad decadal analysis primarily because of the availability of attribute base maps for 2005, which we procured from ISRO (Indian Space Research Organisation). However, this study focuses on only hydro-met disasters due to gaps in the data on other phenomena. We developed the district-level roster of extreme events for 1970–2019 in line with Emergency Events Database (EM-DAT) criteria and further updated it using data from the India Meteorological Department (IMD), National Disaster Management Authority (NDMA), Press Information Bureau (PIB), and the Ministry of Agriculture.



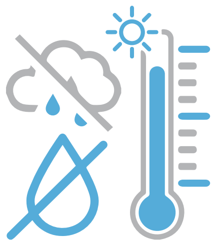
~ 97.51 million people are exposed to extreme flood events in India annually

Our analysis found that floods and droughts have become increasingly common in many regions across various climatic zones in India. Figure ES1 indicates the districts that are extreme events hotspots in India. We infer that in the post-2005 period, at least 55 or more districts in India witnessed extreme flood events year-on-year (≈ 97.51 million people are exposed to extreme flood events in India annually). Increased precipitation levels are triggering a surge in extreme flood events, thereby causing severe damage to infrastructure and disrupting the socioeconomic fabric by causing extensive loss and damage to lives, livelihood and property. Similarly, 79 districts witnessed extreme drought events year-on-year (≈ 140.06 million people are exposed to extreme drought events), and 24 districts witnessed extreme cyclone events yearly (≈ 42.50 million people were exposed to storm surges, intense cyclones, and associated events). In the period 1970–2005, there were 250 extreme events; the post-2005 period witnessed 310 extreme and its associated events (which includes slow onset events like heat waves and cold waves). Frequent floods and droughts pose a severe challenge to food and water security in India. The empirical evidence generated from our analyses coincides with the weakening of monsoons due to rising micro-temperatures. This further can be validated by the fact that states like Maharashtra, Karnataka, and Uttar Pradesh saw severe water scarcity during 2015 due to record-breaking temperatures during summer and weakening monsoons.

Rajkot, Surendranagar, Ajmer, Jodhpur, and Aurangabad, are a few districts where we observed a shift from floods to droughts

We find that the pattern of extreme events is changing across some regions (districts) in India – some drought-prone districts are becoming flood-prone and vice versa. Rajkot, Surendranagar, Ajmer, Jodhpur, and Aurangabad, among others, are a few districts where we observed a shifting trend from floods to drought. A few districts in Bihar, Uttar Pradesh, Odisha, and Tamil Nadu observed the simultaneous occurrence of drought and floods. The trends are alarming and demand a comprehensive risk assessment at the local level, which requires a grid-level climatological analysis to identify the compounded impacts.

Our analysis reveals that microclimatic[1] zones are shifting across various regions (districts) in India. The microclimate zones, categorised according to the Köppen-Geiger classification, are shifting due to climate change. It is important to note that a shift in microclimate zones may lead to severe disruptions across sectors. For instance, every 2°C rise in annual mean temperature will reduce agricultural productivity by 15–20 per cent. Flood- and cyclone-prone districts fall under the category Cwa (monsoon-influenced humid subtropical climate), and drought-prone districts under Bsh (hot semi-arid climate). The flood-based climatic zones are shifting towards Aw tropical, which is characterised by its dry season, thus validating empirically that flood-prone areas are becoming drought-prone. On the one hand, cyclone hot spots are changing from Cwa to Aw tropical climatic zones; on the other, the urban heat island (UHI) effect and increase in sea level are pushing cyclonic disturbances towards warmer regions, as is evident from the climate zone shift. Drought events are becoming more intense, and empirical evidence from the analysis suggests that southern, western, and some parts of central India are becoming increasingly prone to drought.



Maharashtra, Karnataka, and Uttar Pradesh saw severe water scarcity during 2015 due to record-breaking temperatures during summer and weakening monsoons

While the frequency and intensity of extreme events are increasing, we are left with less than a decade to adhere to the *Sendai Framework;* course correction and policy implementation need to have a razor-sharp focus on curtailing the compounded impacts of climate change. Principles of risk assessment must form the core of India's strategy to build resilience. While actions at the global, national, and subnational levels are targeting a well below 2°C limit, it is imperative to outline the chronic challenges that these extreme events pose, especially to the vulnerable sections and sectors. Extreme events are devastating since they are non-linear and disrupt natural and human-made ecosystems. Our analysis suggests some key recommendations that can trigger efforts towards a resilient pathway. Some of them are **developing a comprehensive climate risk atlas, mainstreaming climate risk assessments at all levels across sectors; bridging financing gaps through innovative risk financing instruments; and enhancing resilience and adaptive capacity,** among others. It is time to rethink and reorient our approach to mitigate disaster risks and prepare better for the impending climate uncertainties.

1. A microclimate is a local set of atmospheric conditions that differ from those of surrounding areas. A microclimactic zone (MCZ) refers to a change in climate variables, like temperature, precipitation, etc., leading to effects like UHIs, cloudbursts, hailstorms, and storm surges.

India is leading the global efforts on DRR. It is a signatory to the 'Delhi Declaration on Emergency Preparedness 2019', and *Sendai Framework for Disaster Risk Reduction.* It is also a permanent chair of the CDRI.

Image: iStock

1. Introduction

Countries across the world are increasingly facing economic and social risks due to climate change. Extreme weather events, resulting from climate change, led to 495,000 human deaths across the world in 1999–2018. Further, more than 12,000 extreme weather events led to direct losses of USD 3.54 trillion in terms of purchasing power parity (PPP) in this period. In addition, slow-onset processes like heat wave and cold waves will cause further losses in the future (German Watch 2018). During 2017–18, more than seven million people were displaced in India, Bangladesh, and Nepal due to extreme climate events (Press Information Bureau 2018). There is no denying that the frequency and intensity of extreme events have increased exponentially in India. In 2018, CRI ranked South Asian countries by long-term climate vulnerability thus: Pakistan (5), Bangladesh (7), Nepal (9), India (17), Sri Lanka (22), Bhutan (103), and Afghanistan (NA). In the most-recent CRI ranking, released during COP(Conference of Parties)25, India jumped nine places and was ranked the fifth-most climate-vulnerable country in the world (King et al. 2015). In the past five decades, India has witnessed some catastrophic climate extremes.

During 2017–18, more than seven million people were displaced in India, Bangladesh, and Nepal due to extreme climate events

Trends in climate events are non-linear (Zhai et al. 2018). Given changing climate conditions, the frequency, intensity, spatial extent, duration, and pattern of weather and climate events are also changing. These changing phenomena lead to unprecedented climate extremes (IPCC 2012). Many districts in India are witnessing abrupt trends and patterns. It is not just the frequency of climate events, but the intensity of the associated events that have increased exponentially. These sudden shifts in climate have compound and devastating impacts. Though the scale of climate actions has increased at the regional, national, and subnational levels, at the same time, the impacts of climate change are compounding rapidly. Climate change presents various unprecedented challenges to both human-made and natural ecosystems, including economic and other anthropocentric activities (Garg et al. 2015).

The frequency and intensity of acute hazards (such as droughts) and chronic hazards (such as rising sea levels) is increasing due to the rise in average seasonal temperatures (MGI 2020). Though climate events present major risks for various stakeholders, limited work has been done on identifying these climate risks systemically and holistically at the global, national, sub-national, and even smaller levels. While governments across the globe are stepping up climate actions, individual stakeholders are climate-proofing vulnerable assets. The risk assessments/ evaluation have been limited to understanding the vulnerability of a particular asset, sector, or community through exposure assessment; few studies have focused on the short-term impacts of climate hazards. According to the Global Risk Perception survey, climate-related issues are a major concern in terms of their likelihood, both in short-term and long-term timeframes (WEF 2020).

Many nations have committed themselves to the Paris Agreement, which calls for actions to limit future warming to well below 2°C. At present, however, we have already witnessed global warming of about 1°C and the associated climate catastrophes (Ebi et al. 2018). The increased frequency of catastrophic events is compelling stakeholders to rethink their approach and interpretation of climate events and hazards in order to mitigate risks. The next section provides a chronology of the governance frameworks that discuss rigorous climate risk assessments that are not limited to vulnerability assessments at local downscaled temporal and spatial scales.

1.1 Current disaster risk reduction (DRR) governance frameworks

According to United Nations office on Disaster Risk Reduction (UNDRR), "disaster risk reduction is the concept and practice of reducing disaster risks through methodical efforts to analyse and diminish the pivotal factors of disasters that interrupt the development pathways" (UNDRR 2019). The Sendai Framework for Disaster Risk Reduction (2015–2030), a successor to the Hyogo Framework (2005–2015), is a voluntary, non-binding agreement that brought together 185 countries to act on climate risks through Disaster Risk Reduction(DRR).

The priority actions under the Sendai Framework are:

i. Understanding disaster risk: this includes a multi-sectoral assessment of risk intensity, vulnerability through exposure, and hazard characteristics assessment
ii. Strengthening disaster risk governance to manage disaster risks
iii. Investing in disaster risk reduction for resilience
iv. Enhancing disaster preparedness for effective response and working to "Build Back Better" through recovery, rehabilitation, and reconstruction.

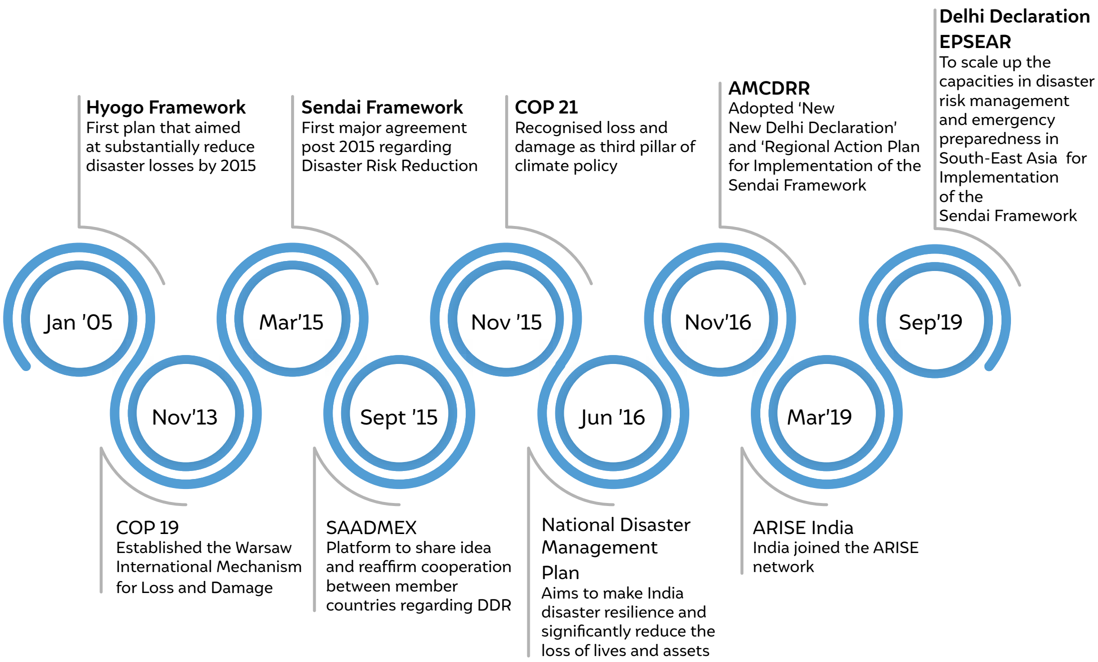


Figure 1
DRR governance framework timelines

Source: Author's compilation

Figure 1 depicts the governance frameworks that recognise climate risk assessment as an important pillar for climate governance at the regional, national, and subnational levels. The Sendai Framework build about upon the disaster risk management mechanisms introduced in the Hyogo Framework and established a new way of estimating "loss and damage" based on the Warsaw mechanism[2]. This systemised disaster risk management in the signatories of the Sendai Framework.

India is a signatory and an active member of these important regional and international treaties in 2019, India also became a signatory to the Delhi Declaration on Emergency Preparedness in the South-East Asia Region. Though the national DRR framework, which is based on the Sendai Framework, envisages precise risk management, very little has been done to mainstream localised risk assessments that climate-proof developmental pathways. India's DRR policies and frameworks were not drafted until August 1999. After the Gujarat earthquake, the Government of India recognised the importance of disaster management (DM) and declared it as a national priority. It further mainstreamed disaster management by setting up a High Powered Committee (HPC) and a National Committee, which established the blueprint for disaster management plans in India (NDMA, 2005). Fiscal provisions were mandated under the then 12th Five-Year Plan, which, for the first time, had a dedicated chapter on disaster management (Ministry of Finance 2012). On December 23, 2005, the Government of India ratified the Disaster Management (DM) Act. The DM Act established the National Disaster Management Authority (NDMA) at the national level, headed by the prime minister, and state disaster management authorities (SDMAs) at the subnational level, headed by the chief ministers of each state. All these governance arrangements aimed at building resilience.

1.2 The state of extreme climate events data in India

Over the past two decades, machine-learning simulations and artificial-intelligence-interfaced machine-learning models have provided comprehensive climate variability and hazard scenario assessments for both the mid-term (2050) and long term (2100) (IPCC 2017). However, these climatological and meteorological analyses do not provide any information on short-term effects. They do not account for historical events, and thereby lack hazard sensitivity indexing.[3] The global assessment framework by GAR also highlights the issue of non-accounting of the sensitivity index of hazards into future climate projections (GAR 2015). One of the preeminent methods of understanding how the climate may change in the future is to study how it has altered in the past based on long-term observational records (IMD 2013). In India, IMD, since its inception, has been the record-keeper of observational climate data. Specific data on various climatic variables from several observatory stations in gridded format are archived by IMD, but it does not have a synchronised repository of historical data on climate events". At a global level, the Emergency Events Database (EM-DAT), developed by the Centre for Research on the Epidemiology of Diseases (CRED), Brussels, with support from the World Health Organization (WHO), has country-specific data sets on various major natural, climatic, technological, and biological events (EM-DAT 2015). However, these data sets have event-specific gaps in frequency, intensity, and areas affected. The data on climate variables (temperature, precipitation, etc.) are quite to up to date both in the observed and reanalysis formats, and various organisations, like the IMD, World Bank, European Centre for Medium-range Weather Forecasting (ECMRWF), National Oceanic and Atmospheric Administration (NOAA), NatCatService,[4] and Dartmouth Flood Observatory, have data sets either in meta or spatial formats. These data sets, however, are complex and need to be simplified to make them accessible to a broader set of stakeholders.

The IPCC acknowledges that data on disasters and disaster risk reduction are lacking at the local level constraining improvements in local vulnerability reduction

2. The COP established the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts (Loss and Damage Mechanism), to address loss and damage associated with impacts of climate change, including extreme events and slow onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change at COP19 (November 2013) in Warsaw, Poland

3. Climate hazard indexing determines the degree of exposure that a particular asset/sector has towards climate hazards. The procedure defined by WMO for any hazard indexing is based on an analysis of historical time series data and information.

4. Munich Re NatCatSERVICE Brakenridge, G. R. Global Active Archive of Large Flood Events. Dartmouth Flood Observatory, University of Colorado. http://floodobservatory.colorado.edu/Archives/index.html (2017).

Any climatological analysis provides precise results if it considers at least a complete set of continuous historical data for a minimum of 30 years; similarly, meteorological analyses require 50 years of continuous historical data (Boccard 2018). Data availability remains a big challenge, but what complicates the scenario is the lack of international consensus on the best practices for mining and collating these data (EM-DAT 2015). SREX-IPCC states that "data on disasters and disaster risk reduction are lacking at the local level, which can constrain improvements in local vulnerability reduction" (2012). The unavailability of data at the local level has hindered informed planning, particularly the lack of information on climate variables attribution and evidence that are visually interpretable and explainable. While climate risk assessments are the need of the hour, localised risk assessments are even more critical. These can inform comprehensive, risk-proof planning, thereby reducing the scale of loss and damage. The available literature strongly recommends institutionalising risk assessments at the local level (Amratunga et al. 2015), and the first step in this is making available robust, validated historical data at the local level. Without accurate and up-to-date data, neither vulnerability nor risk assessments will be effective.

1.3 Research questions

While many studies and analyses of various scenarios have attempted to create a comprehensive, risk-informed decision-making framework at a national level, micro-level data and analysis remains a key research gap globally. The previous sections provided a brief overview of the state of data on both, extreme climate events and climate variables. However, it is evident that sub regional (or district-specific) gridded data is still not available, and barring a few studies at the country level, historical decadal analysis of extreme events is yet to be undertaken. In order to better inform localised climate actions, this study attempts to bridge the current gaps by answering the following research questions through a comprehensive hazard assessment approach. The study attempts to provide a comprehensive overview of the compounded impacts of the combined risks of hydro-met disasters and not just data on particular hazards.

- **What is the pattern and frequency of climate events, and what areas have been affected in the last five decades?**
  Various studies by UNDRR and IPCC have highlighted the importance of understanding the pattern, frequency, and intensity of climate events at the localised level, i.e., beyond the subnational level (UNDRR, Ministerial Charter 2019 and Zhai et al. 2018). Climate change has led to some abrupt trends and patterns in both chronic and acute hazards. This study intends to shed light on the pattern, frequency, and intensity of climate events (such as flood, drought, and cyclones) through pentad decadal analysis, using a gridded exposure sheet.

- **How has the pattern of associated events changed in the last five decades, and how have its impacts compounded?**
  India has contingency plans for specific climate events in adherence to the Sendai Framework. Flood, drought, and cyclone contingency plans are in place, but what is often under-reported is information about the events themselves. This study intends to provide insights into the pattern of these events.

- **How have trends in climate events shifted across sub regions within the country?**
  A long-standing hypothesis is that changing climate is affecting both the macro and microclimate in a specific area, but not enough intertemporal, spatial assessments of climate events have been conducted to validate this hypothesis. Our assessment will provide an insight that the occurrence of climate events is non-linear and that off-late, many districts have shown abrupt shifts in trends. In other words, these shifts in trends will showcase how flood-prone areas have become drought-prone and vice versa.

While climate risk assessments are the need of the hour, localised risk assessments are even more critical

2. Methodology

Image: iStock

For any risk assessment, the first step is a comprehensive hazard assessment (IPCC 2018). Figure 2 depicts the risk function. We use the principles of risk assessment (King et al. 2015) as the guiding principle to develop the methodological approach for a micro-level hazard assessment. The focus of our hazard assessment is to provide fundamental insights on the impacts of climate change on a particular area through the lens of climate extremes. As the IPCC states, the accuracy of any climate extremes study depends on both the quality and quantity of data. We coupled information from globally validated data sheets with data from other sources like the IMD, World Meteorological Organization (WMO), and Press Information Bureau (PIB). The data collated thus is quite comprehensive. There are two key components to our methodological approach: i) the development of a gridded exposure sheet of climate events; and ii) a geospatial analysis of extreme climate events using coarse-grain resolution temporal maps. Each subsection provides a detailed outlay of the hazard assessment by superimposing climatological simulations.

Data: We procured the base maps for the pentad decadal analysis from ISRO at 25 km resolution. For the temporal analysis, we used coarse grain resolution, and for the climate zone analysis, we derived the base Köppen-Geiger classification from the NASA Earth database.

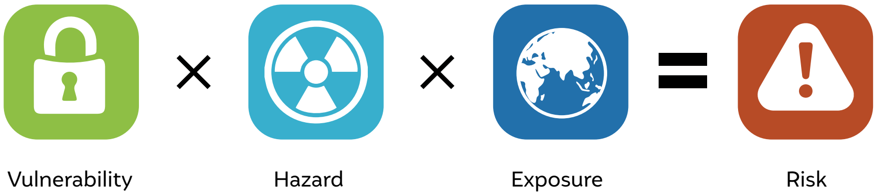


Figure 2
Risk function

Source: UNISDR, 2015

2.1 Development of the gridded exposure sheet

We conceptualise exposure as the occurrence of a particular event in a particular grid, which is characterised by a district boundary. In order to develop the gridded exposure sheet, we prepared a climate events roster using the EM-DAT criteria and template.[5] We further updated the base roster using data from EM-DAT, IMD, WMO, PIB, Ministry of Agriculture, NDMA, Ministry of Finance, and NOAA to develop an India-specific roster of extreme events (or hydromet disasters) and associated events. EM-DAT provides a continuous classification of major climate events reported across the globe since 1900 (see Annexure-I). However, as opposed to Boccard (2018) points out, EM-DAT depicts a country/state-wise catalogue of climatic events. In our study, we consider floods, droughts, and cyclones along with their associated events as the EM-DAT lists them. It is worth noting that any shift in the frequency and intensity trends of extreme events as identified by the EM-DAT would be due to changes in vulnerability and exposure rather than changes in underlying hazards. We present the rationale for our selection of specific extreme events in Section 2.1.1. The main objective of the gridded exposure data sheet is to provide a pentad decadal chronology of extreme climate events during 1970¬–2019. The pentad decadal analysis of the chronology of climate events was undertaken to understand their pattern, frequency, and the districts affected. We used data from the following decades to develop the gridded exposure sheet: i) 1970–79; ii) 1980–89; iii) 1990–99; iv) 2000–09; and v) 2010–2019.

To maintain uniformity across the data set, we formatted the climate events that were added to the base exposure sheet according to EM-DAT criteria.[6] We intend to develop a robust exposure data sheet for future risk assessments. Climate change is a global phenomenon with varied impacts on regional climate zones (CEEW 2015). In order to develop a climate zone gridded exposure data set, we used GrADS[7] for the micro-level analysis. The micro-level analysis was done through downscaling of the climate zones from NOAA earth data set through interpolation and re-gridding. GrADS is widely used for five-dimensional climatological spatial data analysis because its compatible modules can process regular, non-linearly spaced, gaussian, data sets at variable resolutions (Doty et.al, 1995). The GrADS operations have defaults that naturally map to data analysis actions and vice versa. GrADS allows data from different data sheets to be graphically mapped to display the correct spatial

5. In 1988, the Centre for Research on the Epidemiology of Disasters (CRED) launched the Emergency Events Database (EM-DAT). EM-DAT was created with the initial support of the World Health Organization (WHO) and the Belgian government. It contains essential core data on the occurrence and effects of over 22,000 mass disasters in the world from 1900 to the present day. See https://www.emdat.be/.

6. For a disaster to be entered in the EM-DAT, it must fulfill at least one of the following criteria: i) 10 or more people reported killed; ii) 100 or more people reported affected; iii) declaration of a state of emergency; iv) call for international assistance.

7. GrADS, or the Grid Analysis and Display System, is an interactive desktop tool that is used for easy access, manipulation, and visualisation of earth science data. See http://cola.gmu.edu/grads/.

distribution and frequency of extreme events for a given location. We used the masking technique to map regional climate zones, as per the Köppen-Geiger classification. Section 2.2 provides a brief description of the masking technique that further helped us conduct the geospatial analysis. Figure 3 depicts a GrADS-interpreted masking of the region, Gaya, with a hot-summer Mediterranean climate (CSA) Köppen Climate classification and over a pentad average minimum summer temperature in the region. With this methodological approach, we develop an integrated, hazard-specific, and climatology-compatible exposure sheet.

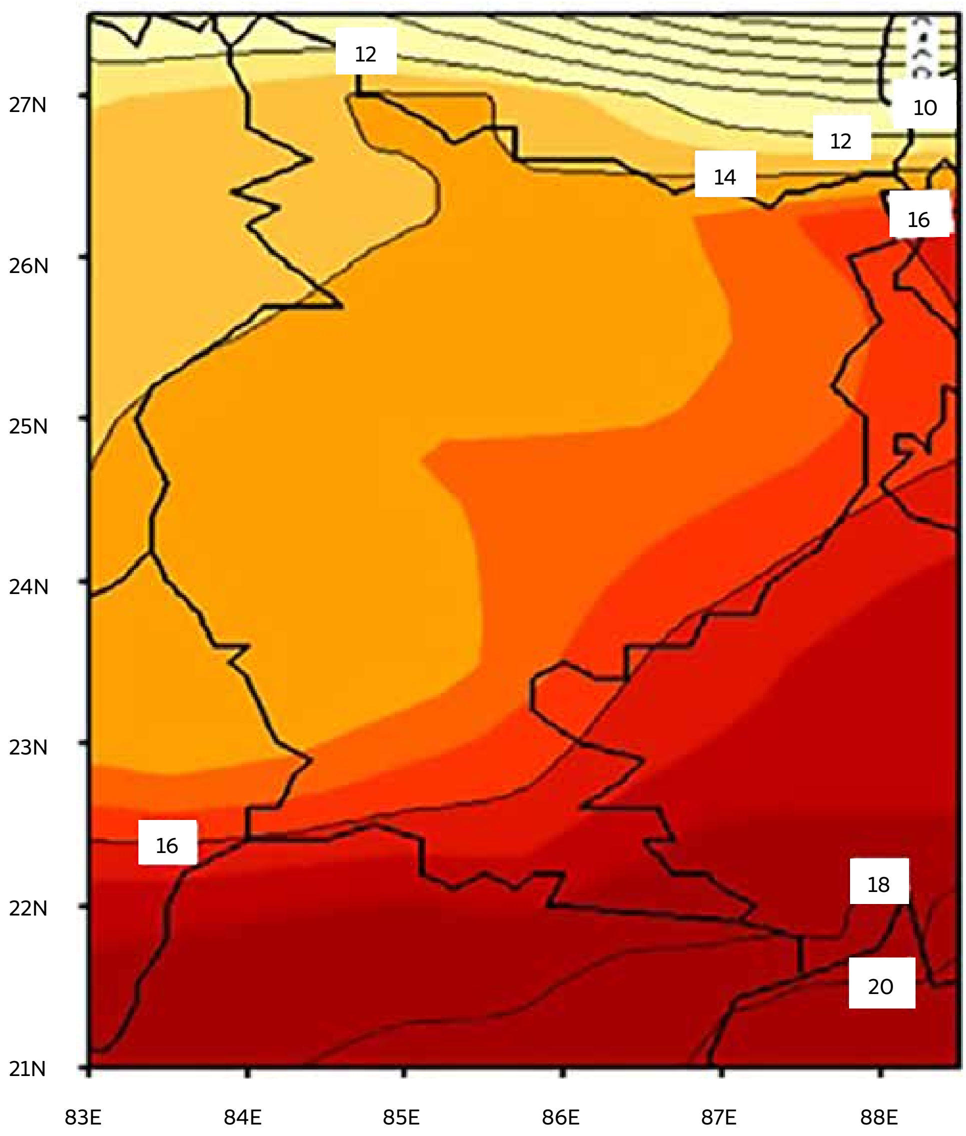


Figure 3
District boundary masking using GrADS on a Köppen-Geiger climate zone

Source: Author's analysis

We developed the gridded exposure data set using the downscaling approach. The downscaling methodology used GrADS and Q GIS for re-gridding and clipping of micro climatic zones superimposition focused on the occurrence of specific primary events (floods, droughts, and cyclones) and their associated events across districts. We estimated a change in the trends and patterns of extreme climate events. We used coarse-grain resolution data to perform temporal analysis, which we will discuss in the next section. Although the coarse-grain resolution is not required for this specific study, it is quite crucial for a comprehensive, localised, micro-level risk assessment using dynamic hazard models (GAR 2017). The gridded exposure data sheet in Figure 4 can be further utilised to carry out asset/sector-based exposure assessments for a similar set of events at a given location. Gridded data sets help both climatological and meteorological inferences at a coarse-grain resolution. This comprehensive gridded exposure sheet can provide an overview of the localised hazard landscape, which can have insightful policy implications at the national, subnational, and regional level.

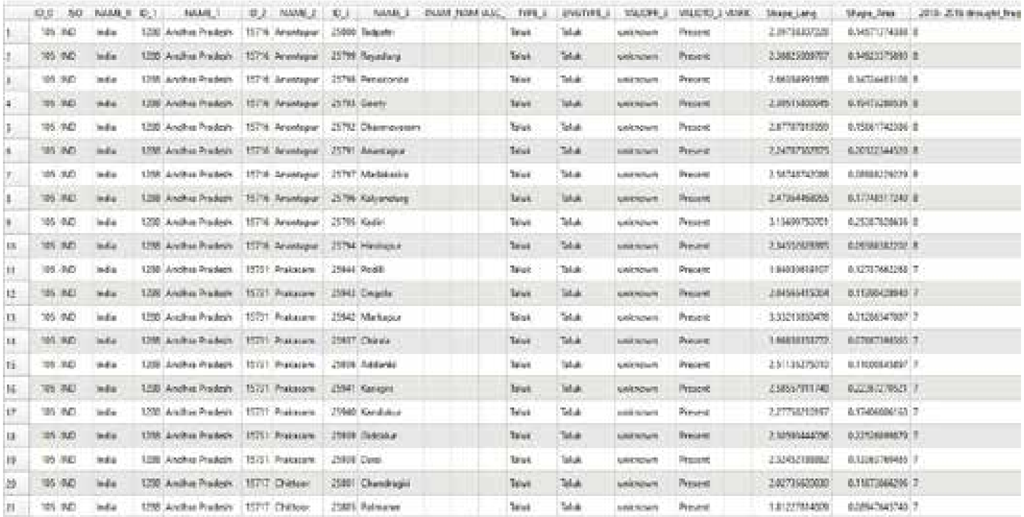


Figure 4
Gridded exposure data sheet for drought

Source: Author's analysis

2.2 Geospatial analysis of extreme climate events using coarse-grain resolution temporal maps

Since the 1990s, visualisation of climatological and meteorological events has gained much attention, with gridded exposure data sheets becoming the basis for hazard assessments. We used baseline thematic maps from the National Remote Sensing Centre (NRSC) and the National Aeronautics and Space Administration's (NASA's) earth data set.[8] The land use and land cover (LULC) classification maps for each decade interval were retrieved at 100-m resolution. According to the Köppen classification, India has six climatic zones: tropical humid, dry, warm temperate, cold, cold snow forest, and highlands. We derived the climate zone classification base maps from global reanalysis shape files modelled by NOAA (Becket al. 2018) and clipped by Q GIS 3.10. We did a pentad decadal rigorous geospatial analysis of the gridded exposure sheet based on its attribution, which includes frequency, districts affected, intensity, and associated events. We provide details of the extreme climate and associated events in the section below. Since we used gridded data, we required consistent, coherent data inputs without outliers or missing values. Some of the data preparation jobs – such as clipping, raster-based math, and associated event analyses – were steered in the desktop environment. We conducted these steps to develop decadal extreme event maps and then recorded specific insights based on changes in micro climatic attribution. We also conducted temporal scale analyses of the maps using Q GIS 3.10 to derive evidence on the changing microclimate. We followed this methodological approach to assess the intertemporal distribution of events.

According to the Köppen classification, India has six climatic zones: tropical humid, dry, warm temperate, cold, cold snow forest, and highlands

8. This data set provides LULC classification products at a 100 m resolution for India at decadal intervals for 1985, 1995, and 2005. We derived the data from Landsat 4 and 5 Thematic Mapper (TM); Enhanced Thematic Mapper Plus (ETM+); multispectral (MSS) data; India remote sensing (IRS) satellites; Resources at Linear Imaging Self-Scanning Sensor-1 or III (LISS-I or LISS-III) data; ground truth surveys; and visual interpretation. We classified the data according to the International Geosphere-Biosphere Programme (IGBP) classification scheme.

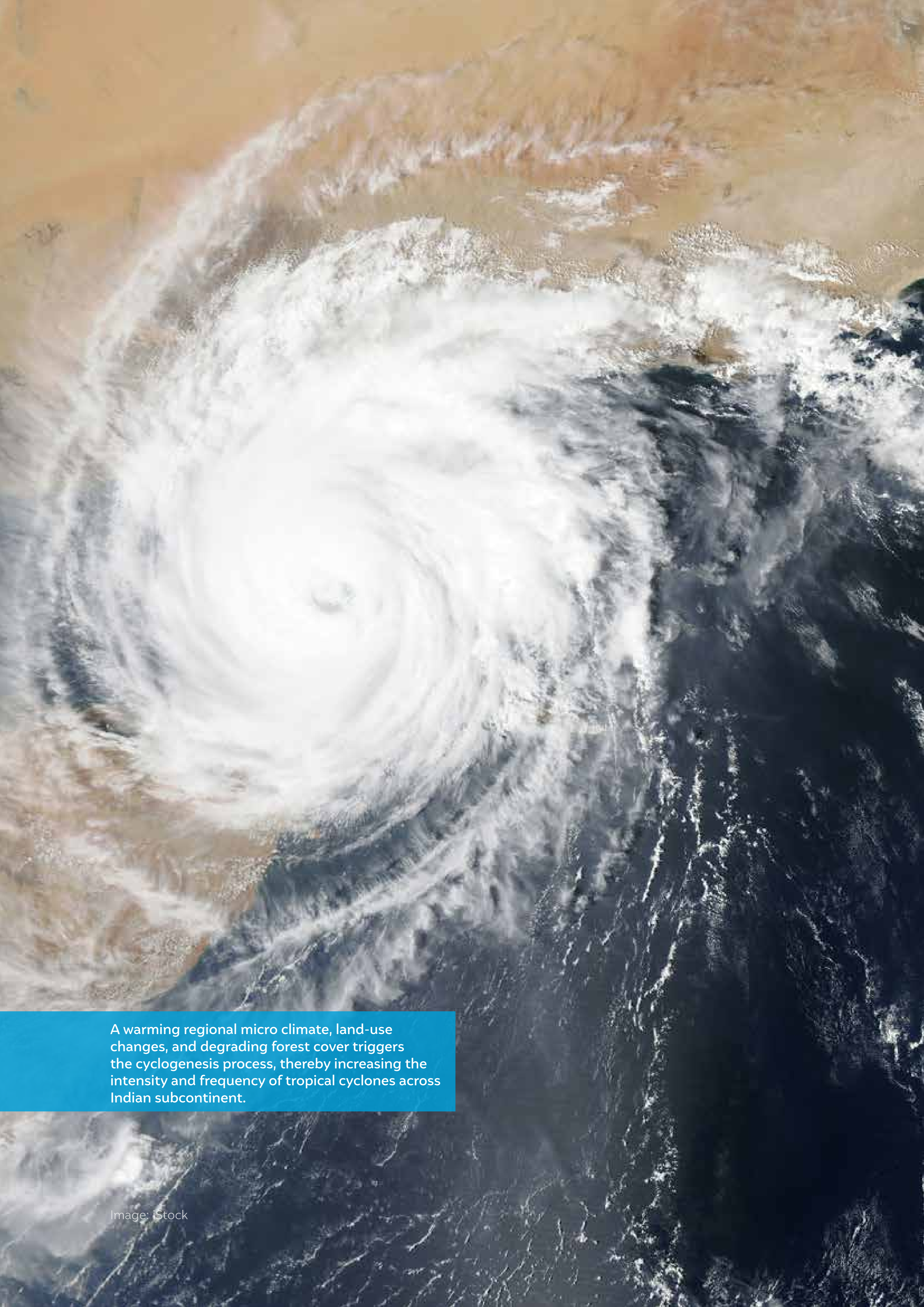
2.3 Scope and limitation

To understand the magnitude of climate change impacts at a localised level, we need a huge set of data to be analysed and modelled. Data classification plays an important role when it comes to climatological and meteorological analysis. There is no international consensus among climate scientists on the classification of extreme climate events, and organisations have different approaches and definitions based on the combinations of weather and geophysical phenomena they encounter. To provide a consistent analysis, we adhered to the classification of EM-DAT, IMD, GFDRR, and WMO for the primary events and their associated events. As we have highlighted in the previous sections, no associated events are considered for droughts. The primary events – flood, cyclone, and drought – are classified as "hydro-met disasters".[9] These disasters are the set of extreme climate events formed by the interaction of the weather with hydrological and climatic processes. The World Bank estimates that globally, hydro-met disasters contributed to 90 per cent of disaster loss (World Bank 2017). This is also true in the case of India. We have not considered slow-onset climatic events like heatwaves, cold waves, and sea-level rise as primary extreme events in our hazard assessment. In the absence of continuous decadal data, we intend to carry out climatological analysis separately to characterise these onset events. This can be regarded as a limitation. Wherever heavy rainfall and rainfall is considered an associated event to floods and cyclones, changes in them are cited based on IMD's declarations. Hence, due to a lack of synchronised data, we did not include a more comprehensive analysis of pattern changes in the scope of the study. We provide details of the primary extreme climate events and their associated events in Table 1. For further detailed definitions and classifications of the extreme climate events, see Annexure-I.

Table 1
Classification of extreme climate events considered in this study

Name of the event	Floods	Drought	Cyclones
Primary disaster subtype	Riverine floods, coastal floods, flash floods, and compounded floods	Meteorological drought, hydrological and agricultural drought	Storm surges and convective storms
Associated event(s)	Extreme rainfall, landslides, hailstorms, cloud bursts, and thunderstorms	NA	Heavy rainfall, floods, hailstorms, cold waves, tornadoes

9. Hydrological and meteorological (or "hydromet") hazards – weather, water, and climate extremes (GFDRR 2018).



A warming regional micro climate, land-use changes, and degrading forest cover triggers the cyclogenesis process, thereby increasing the intensity and frequency of tropical cyclones across Indian subcontinent.

Image: iStock

3. Results and discussion

The risks of climate change are non-linear: while average conditions may change gradually, their impacts can increase rapidly (CEEW 2015). In India, there are four primary seasons i) pre-monsoon (March-May); ii) south-west or summer monsoon (June–September); iii) post-monsoon (October– December); and iv) winter (January–February). These seasons are based on the Köppen classification of climatic zones. We have used these seasonal variables to present our inferences. The abrupt variability of regional climate processes and phenomena, such as El Niño, El Niño Southern oscillations, and warming climate, among others, have together triggered a surge in both the frequency and intensity of extreme climate events (IPCC 2015). The following sections provide a comprehensive hazard landscape of extreme climate events in India in the last 50 years. It aims to establish empirical evidence-based linkage between various climate phenomena and extreme events. Section 3.4 discusses the complexity and non-linearity of trends and patterns at the district level by developing district-level profiling.

CGIAR ranks India first in terms of global flood hotspots, followed by China and the USA

3.1 State of extreme events: flood

Floods are defined as "a general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than-normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods)" (EM-DAT 2015). The state of flood events in India is quite abrupt and non-linear. India has witnessed some devastating floods from the nineteenth century onwards. In our study, we focus on a detailed pentad decadal analysis of flood events, but it is worth having an abridged discussion on pre-1970 flood events.

Extreme flood events are a frequently occurring; year-on-year, trends show that they are multi-faceted compounded events, where the primary event is followed by a string of associated event(s). Section 3.1.2 elaborates on trends in the increase in associated events.

3.1.1 The pentad decadal analysis of extreme flood events

As we have shown earlier, our learnings from the literature suggest that India has been hit chronically by extreme flood events. CGIAR ranks India first in terms of global flood hotspots, followed by China and the USA. This trend is also evident in our micro level analysis. Our analysis of extreme flood events during 1970–2019 showed that 2005 witnessed the highest flood frequency, and a total of 69 districts were affected. In comparison, 2019 registered a total of 16 extreme flood events, which affected 151 districts. Figure 5 illustrates yearly trends in extreme flood events vis-à-vis the districts affected. The pentad decadal analysis shows that there has been an abrupt surge in the number of extreme flood events since 2005. It is notable that between 1970 and 2004, three extreme flood events occurred per year on average, but after 2005, the yearly average rose to 11. Similarly, the yearly average for districts affected until 2005 was 19, but after 2005, it jumped to 55. The year-wise analysis shows how changes in microclimate processes have altered the frequency and pattern of extreme flood events. The next sections provide empirical evidence for the same. Our analysis shows that about 97.51 million people are exposed to extreme flood events in India.

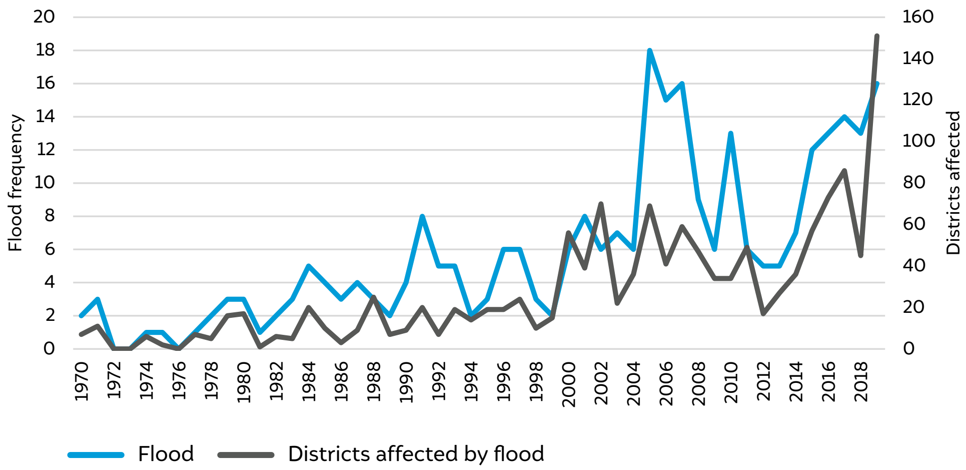


Figure 5
The frequency and number of districts affected by floods has been on the rise since 2005

Source: Author's analysis

The extreme flood events hotspot districts of India are Sivasagar, Dibrugarh, Lakshmipur, Dhemaji, Chennai, Golaghat, West Godavari, and Karimganj, based on both, the frequency and intensity of events. The pentad decadal analysis is represented through temporal scale maps through geospatial analysis. Figures 6–10 depict the decadal district hotspot mapping for flood frequency in the period 1970–2019. The most devastating flood of the decade 1970–79 happened in Saurashtra and Kutch, due to incessant rainfall over Rajkot (De et al. 2005). A total of 54 districts were affected in this decade. Literature-based evidence suggests that the primary cause of flooding during this period was heavy rainfall, which caused riverine floods. The decade of 1980–89 witnessed a series of devastating events in 1981, 1982, and 1988; they affected more than 103 districts. The 1981 Rajasthan floods, resulting from heavy rainfall, affected Jaipur, Tonk, Nagaur, and Sawai Madhopurhar. This decade's flood events were thus due to both heavy and incessant rainfall, which led to coastal and riverine floods.

Table 2
Decadal flood hotspot districts

Decade	District hotspots
1970–79	Dhemaji, Jorhat, Dhubri, Lakhimpur, Dibrugarh
1980–89	Chennai, Barabanki, Dibrugarh, West Godavari, Srinagar, Darbhanga, Dhubri
1990–99	Dhalai, Dibrugarh, Chennai, Srinagar, West Godavari
2000–09	Krishna, Ahmedabad, Patna, West Godavari , Karimnagar, Khammam, Kurnool, Lakhimpur
2010–19	Darrang, Kushinagar, Golaghat, Barpeta , Sivasagar, Dhemaji, Goalpara, Jampuijala

Source: Author's analysis

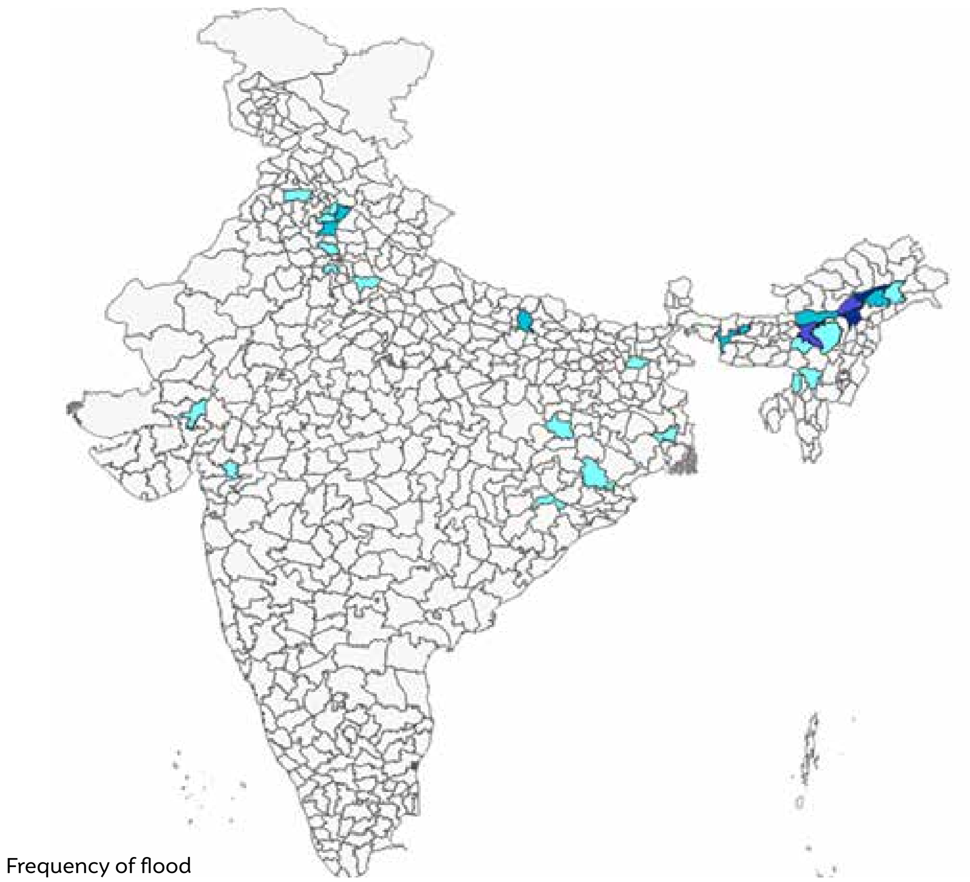


Figure 6
Decadal flood map showing districts affected, 1970–79

Source: Author's analysis

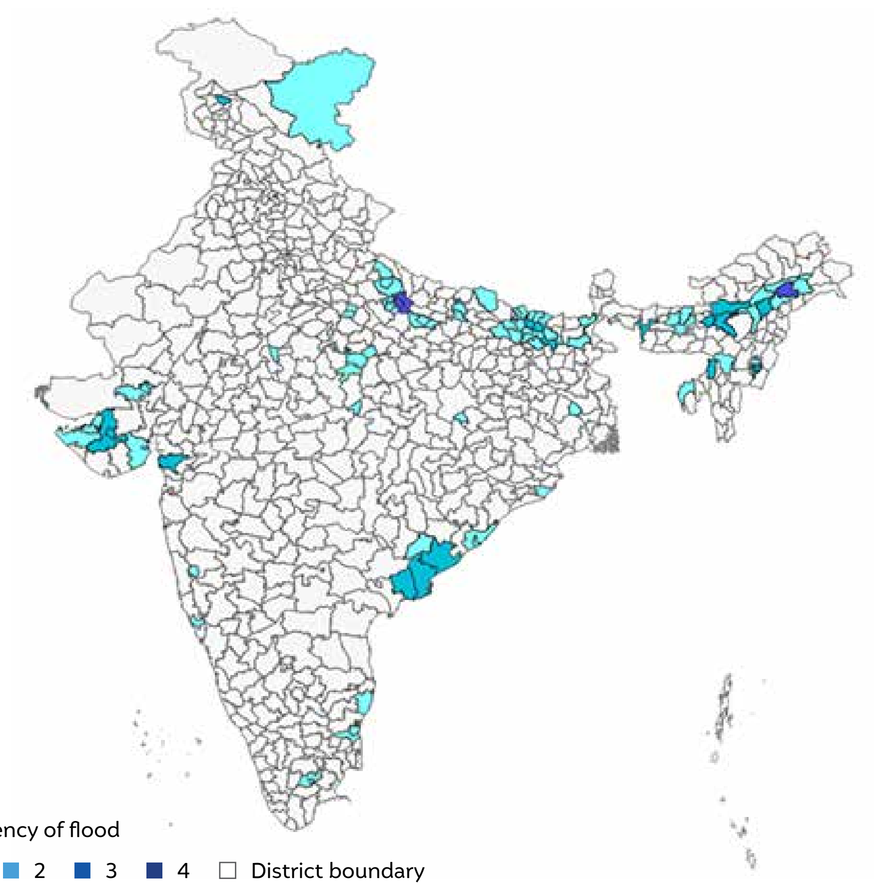
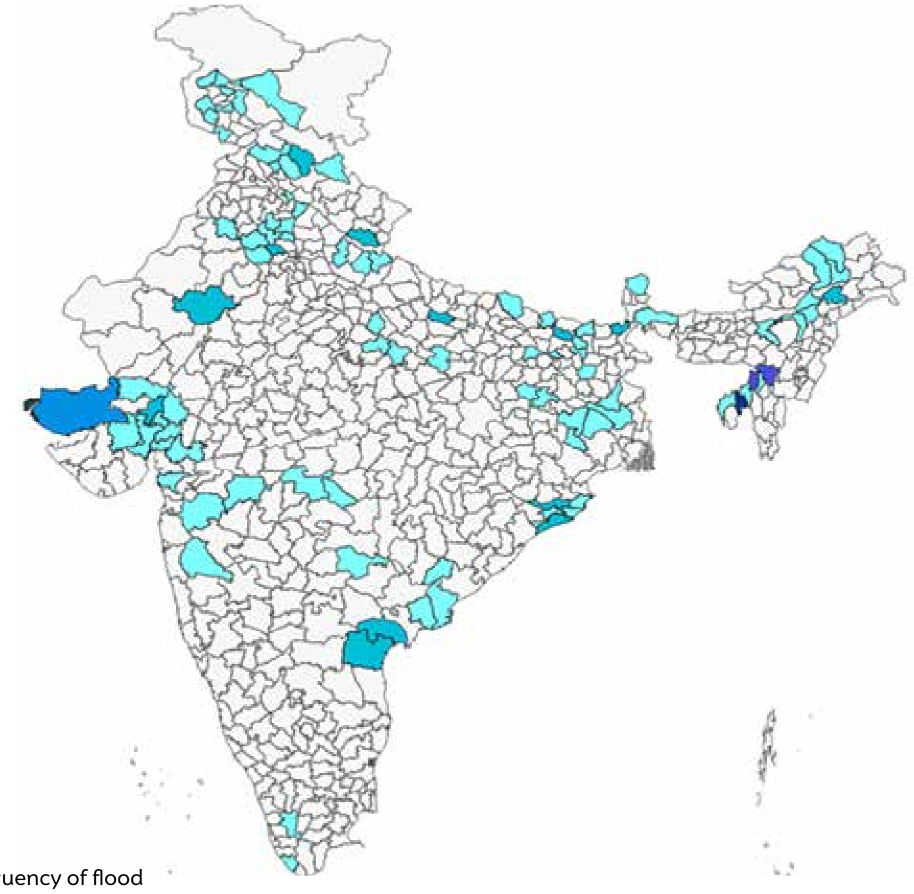


Figure 7
Decadal flood map showing districts affected, 1980–89

Source: Author's analysis

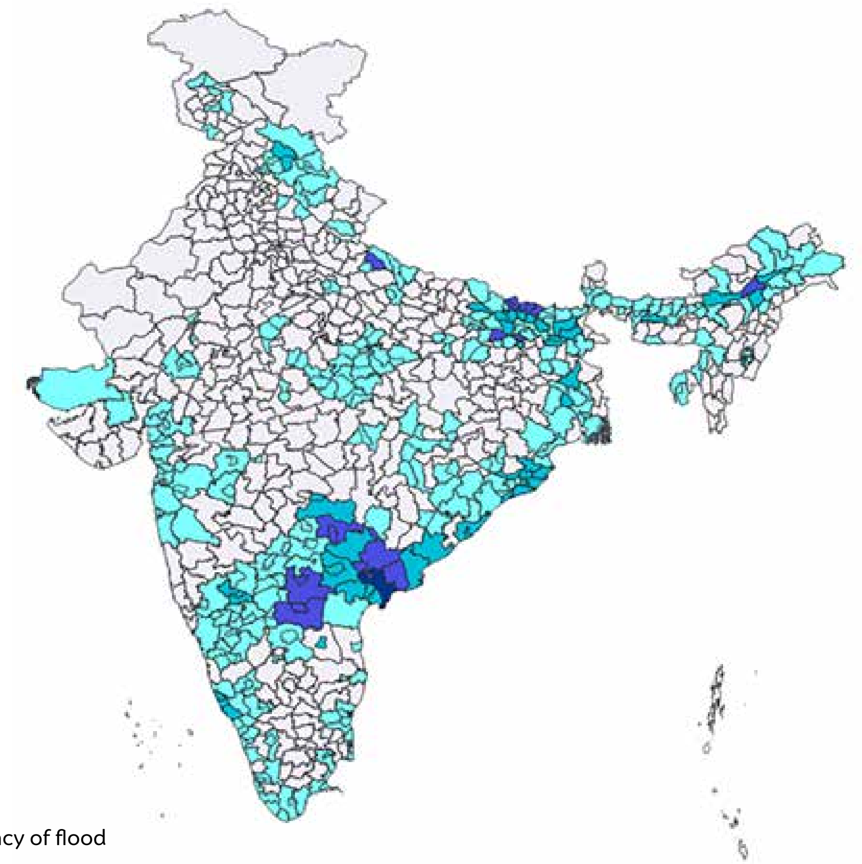


Frequency of flood

1-2 3 4 5 District boundary

Figure 8
Decadal district-affected flood map-1990-99

Source: Author's analysis

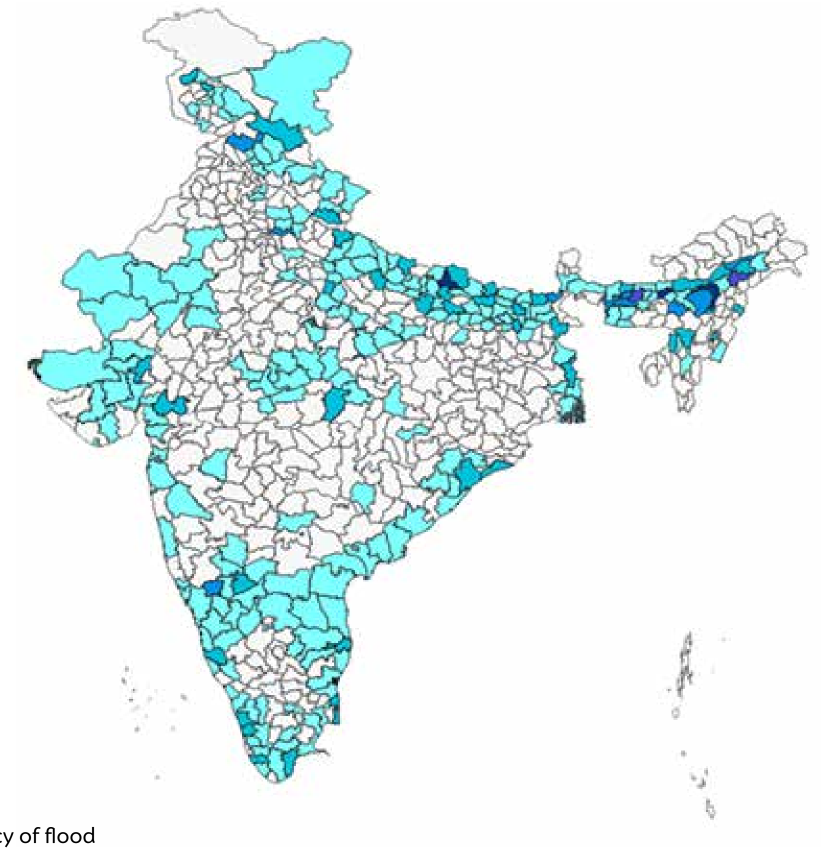


Frequency of flood

1-2 3-4 5-6 7-8 District boundary

Figure 9
Decadal district-affected flood map- 2000-09

Source: Author's analysis



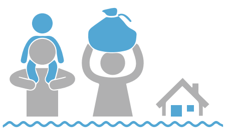
Frequency of flood

1-2 | 3-4 | 5-6 | 7-8 | 9-10 | District boundary

Figure 10
Decadal flood map showing districts affected, 2010–19

Source: Author's analysis

Studies have suggested that glacial melts have compounding effects ranging from sea-level rise to many more phenomena, like heavy rainfall and cloud bursts, which have increased in recent decades. The 1990s witnessed 46 major flood events that affected almost 156 districts. It saw intense cyclonic disturbances due to severe and deep depressions over both the Bay of Bengal and the Arabian Sea, resulting in the intensification of some extreme flood events. Our analysis shows that the decade 2000–2009 showed a spike in extreme flood events and in associated flood events, which affected almost 473 districts. The compounding effects of land subsidence, the urban heat island phenomenon, and sea-level rise due to glacial melts are leading to the intensification of cyclonic disturbances, thus increasing the number of flood events experienced during this decade. The decade of 2000–09 was an outlier in the history of extreme events in India. After 2000, more urban flood events occurred as a result of flawed urban planning, encroaching on wetlands, and deforestation, among others. The devastating 2005 Maharashtra and Bihar floods resulted from changes in the microclimate. A research from IITM shows, urban heat islands over Chennai and Pune triggered sudden cloud bursts; the study further stated that the average rainfall rose from 806 mm to 840 mm over Hyderabad in 2001–02. However, we must acknowledge that urbanisation has led to abrupt "LULC" changes, resulting in changes in micro-climatic dynamics (Roy et.al., 2016). Compared to earlier decades, the frequency of associated flood events increased in the decade of 2010–19. Uttarakhand, Chennai, and Kerala, among others, witnessed the most devastating floods of the decade. This period witnessed compounded flood events due to the occurrence of the following flood subtypes: i) coastal flash floods, ii) riverine flash floods, and iii) coastal-riverine flash floods. The next section discusses our analysis of flood-associated events.



Uttarakhand, Chennai, and Kerala, among others, witnessed the most devastating floods of the decade of 2010-19

3.1.2 Analysis of associated flood events

The previous section provided empirical evidence of extreme flood events in India. The non-linear changes in climate are quite evident; not just the frequency, but the intensity of events is also increasing. Figure 11 depicts a comparative analysis of flood events and associated events. As we stated in Chapter 2, the associated events we consider in this study are: i) landslides; ii) extreme rainfall; iii) hailstorms; iv) thunderstorms; and v) cloud bursts. For the definitions and classifications of these associated events, see Annexure- I.

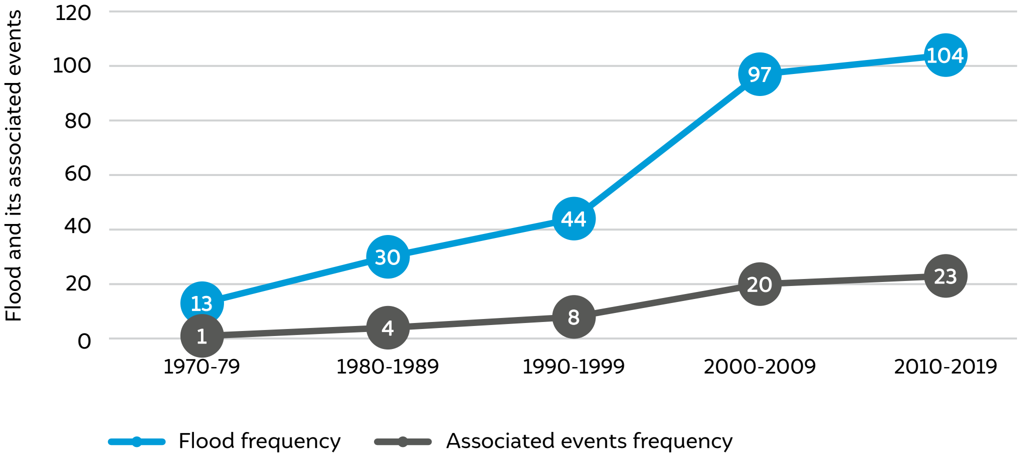
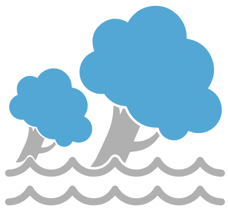


Figure 11
A surge in associated flood events is observed from the decade of 2000-09

Source: Author's analysis

Our analysis suggests that extreme flood events have become more intense in recent decades due to the sharp surge in associated events. According to NDMA, the 2018 floods affected more than 5.1 million hectares of land – which is equal to the size of the state of Punjab. Thunderstorms and hailstorms occur quite frequently in central, northern, north-eastern, and western parts of India (IMD 2017). Hailstorm events were quite rare in the past, but in the recent decades the frequency of hailstorms have shown an abrupt surge (Balasubhramanian 2019), thereby impacting the agricultural sector the most. Usually, hailstorms in India occur during the pre-monsoon season, but along with cloud bursts, post 2005 they are rampantly occurring in central and southern India even until the late monsoon season (WMO 2018). Increasing air temperature and anomalous ground heating have triggered an increase in the intensity of hailstorms and associated events (Ugnar 1999). Apart from microclimate changes, a few broad anthropocentric causes have triggered both flood events and associated events. Land subsidence[10] has created flood zones in low-lying areas, and its impacts are already apparent due to increased sea-level rise(Andreas 2018). Land-use-change-surface[11] and land subsidence increase inundation levels, thereby directly impacting the rate of both coastal and flash floods. While flood management plans need a top-down approach, the containment of associated events needs a bottom-up approach to lower their impact (Kropp et.al 2016).



According to the NDMA, the 2018 floods affected more than 5.1 million hectares of land – which is equal to the size of the state of Punjab

10. Land subsidence is defined as the lowering of the ground level from certain elevation references.

11. Land-use- change surface refers to a change in the use or management of land by humans, which may lead to a change in land cover

3.2 State of extreme events: droughts

Droughts are defined as “an extended period of unusually low precipitation, that produces, a shortage of water, and operationally it is defined as the degree of precipitation reduction that constitutes a drought, that vary by locality, climate and environmental sector” (EM-DAT 2015). The state of drought events in India is of importance for both climatological and political-economic reasons. The impacts of climate change are increasingly being felt across nations (Schipper et.al 2016). India, specifically, is highly vulnerable to the impacts of climate change, since a high share of its population is directly or indirectly dependent on agriculture and its allied sectors for their livelihoods (CEEW 2019). Drought is a very complex extreme event in its morphology. Droughts in India are categorised into three subtypes: i) meteorological drought;[12] ii) hydrological drought;[13] and iii) agricultural drought.[14] Our analysis suggests that drought is a recurring climate event across all climatic zones in India; Section 3.4 provides a climatic zone masking vis-s-vis events hotspots.

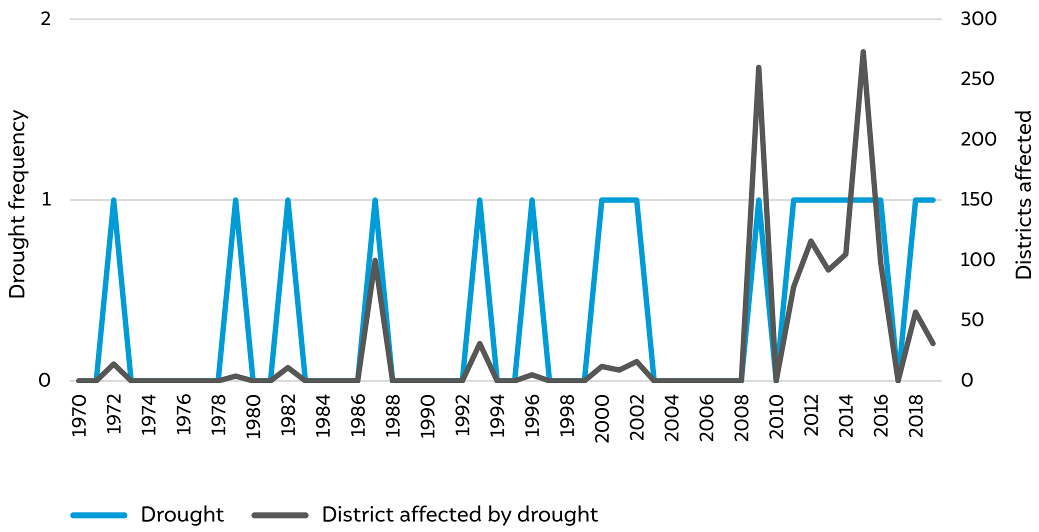


Figure 12
Year-wise extreme drought events

Source: Author’s analysis

Drought events have a long history in India. The year 1918 has been declared the worst drought year (De et. al.,2005). In recent history, drought patterns have undergone an abrupt change. It was recurrent during 1960–1990 (De et al. ,2005)), and in the last 125 years, four country-level droughts have been reported. Droughts in the early twentieth century caused considerable loss of life and property due to famine and scarcity of food (De et al. 2005). Studies suggest that droughts in 1870–1990 were associated with warm ENSO (El Niño south oscillation) events. However, recently, the pattern has been triggered by land-use changes, urban heat island effects, and changes in precipitation levels. Figure 12 depicts drought frequency and the number of districts affected by drought, across years. The increased frequency of droughts is likely to have a multi-dimensional ripple effect across sectors.

12. Meteorological drought is defined as the deficiency of precipitation from expected or normal levels over an extended period of time.
13. Hydrological drought is defined as deficiencies in surface and subsurface water supplies, leading to a lack of water for normal and specific needs.
14. Agricultural drought is usually triggered by meteorological and hydrological drought, and occurs when soil moisture and rainfall are inadequate during the crop growing season, causing extreme crop stress and wilting.

3.2.1 The pentad decadal analysis of extreme drought events

Drought events have been well managed in recent years, resulting in lesser loss and damage, as India is striving to be a food-secure nation. It is a slow-onset seasonal phenomenon, but its area of impact could be large. Our analysis also suggests the same. Until 2005, the number of districts affected by drought was six, but after 2005, this figure rose to 79. Figures 13–17 depict the decadal districts mapping vis-à-vis drought frequency, which was higher in the central, western, and northern peninsula, as compared to other parts of India. The number of districts affected by drought has grown exponentially. Compared to the previous decade, 1980–89 showed an exponential rise in the number of districts affected to 111. Drought-affected district hotspots of India are Rajkot, Anantapur, Aurangabad, Barmer, Bijapur, Churu, Jaisalmer, and Jodhpur.

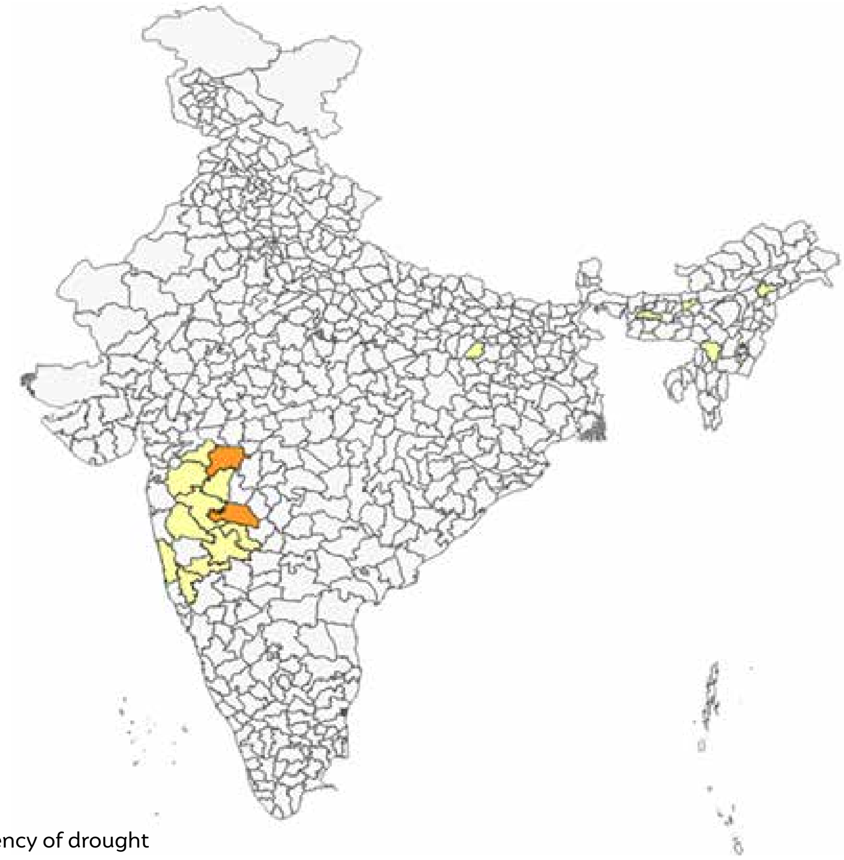
Similarly, the decades 2000–09 and 2010–19 saw a sharp increase in the number of districts affected by agricultural droughts. Drought-like conditions prevailed in many parts of the country during this time. In 1970–79, India witnessed the severe 1972 drought. Our analyses suggest an interesting trend – until 1966, droughts occurred at regular intervals and at high frequency, which was not the case later. Bid, Jalgaon, Pune, Nashik, and Aurangabad were the most affected districts in 1970–79. Moderate droughts dominated this decade.

Decade	District hotspots
1970–79	Bid, Jalgaon, Aurangabad, Shivasagar, Ratnagiri
1980–89	Jalgaon, Rajkot, Anantapur, Chittoor, Churu, Thiruvananthapuram, Ujjain, Varanasi
1990–99	Rajkot, Banaskantha, Surendranagar, Ahmedabad, Bhavnagar, Jamnagar, Patan, Kutch
2000–09	West Siang, Surendranagar, Rajkot, Bikaner, Ajmer, Barmer, Bhilwara, Nagaur, Churu
2010–19	Anantapur, Bijapur, Chittoor, Chikkaballapur, Gulbarga, Hassan, Ahmednagar, Aurangabad, Bagalkot

Table 3
Drought hotspot districts

Source: Author's analysis

TThe decade 1980–89 recorded a surge in the occurrence of moderate drought events, barring a severe drought in the year 1987 which affected 49.2 per cent of the total population(WMO 2003),. The most affected districts of the country in this decade were Nashik, Pilbhit, Thiruvananthapuram, Ujjain, and Varanasi, among others. The trend of irregular rainfall characterised the decade. Our analyses, validated by empirical evidence from the WMO, highlights that the decade of 1990–99 was climatologically important because of the El Niño effect on Indian droughts. The average July rainfall was notably down by about 51 per cent compared to 1980–89, but the increase in rainfall in August compensated for it, and the average seasonal rainfall was the same in both decades. This resulted in a moderate or drought-like condition over the subcontinent. The most drought-affected districts of the decade were Rajkot, Ahmedabad, Banaskant, Bhavnagar, and Jamnagar, among others.

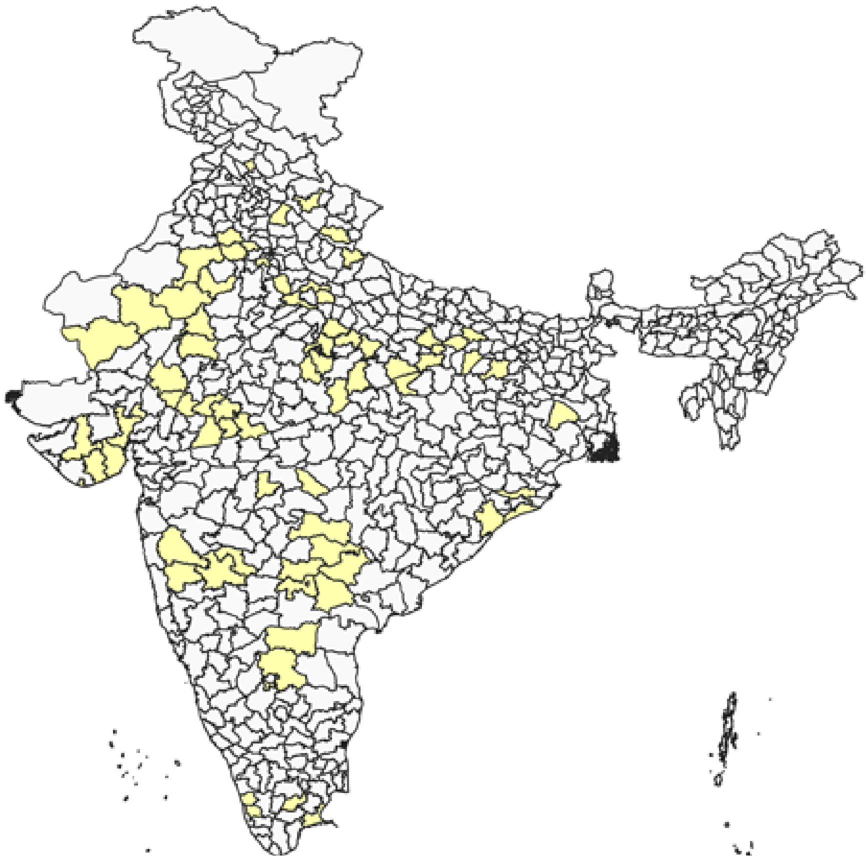


Frequency of drought

1 2 District boundary

Figure 13
Decadal drought map of districts affected, 1970-79

Source: Authors' analysis

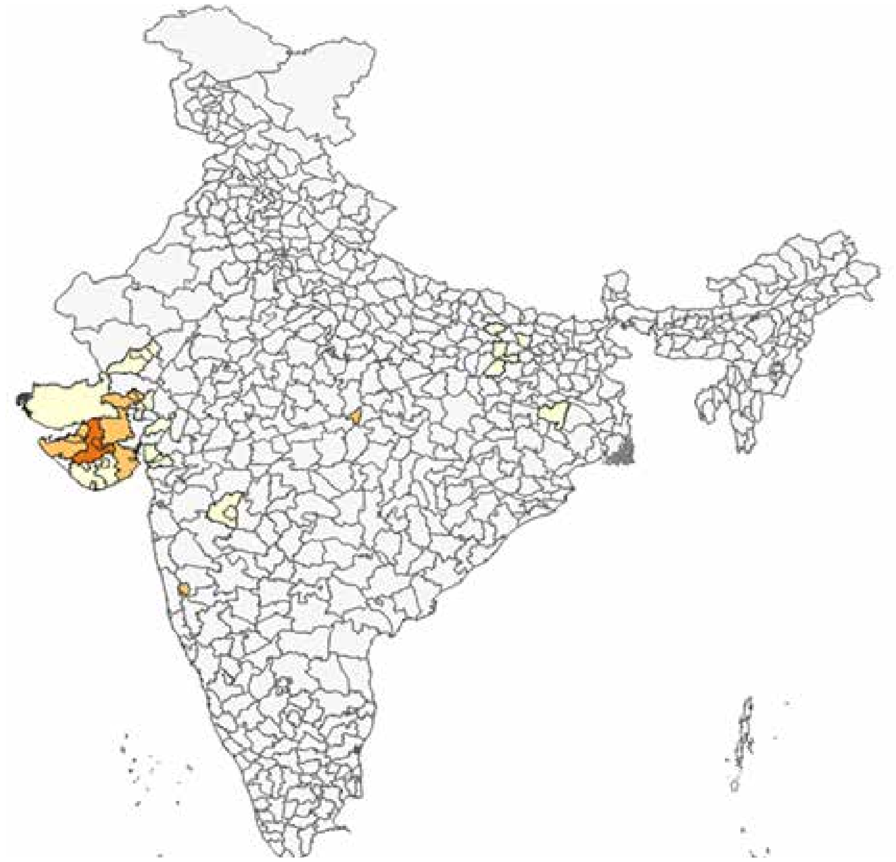


Frequency of drought

1 District boundary

Figure 14
Decadal drought map of districts affected, 1980-89

Source: Authors' analysis

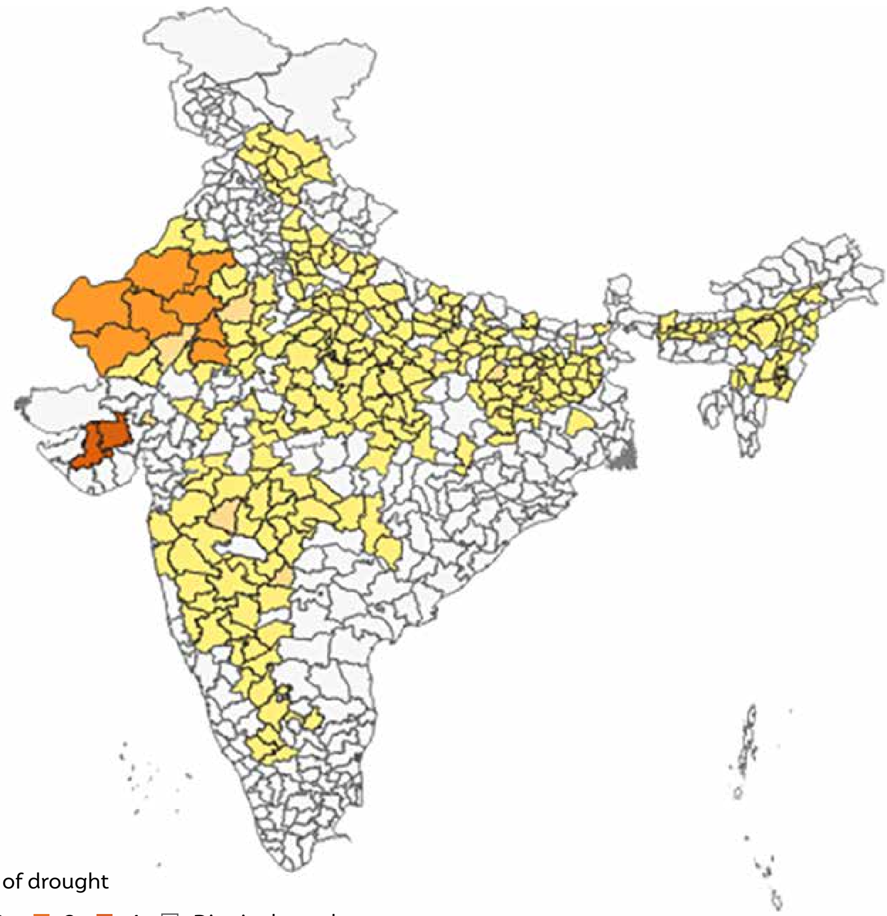


Frequency of drought

1 2 3 District boundary

Figure 15
Decadal drought map of districts affected, 1990–99

Source: Author's analysis

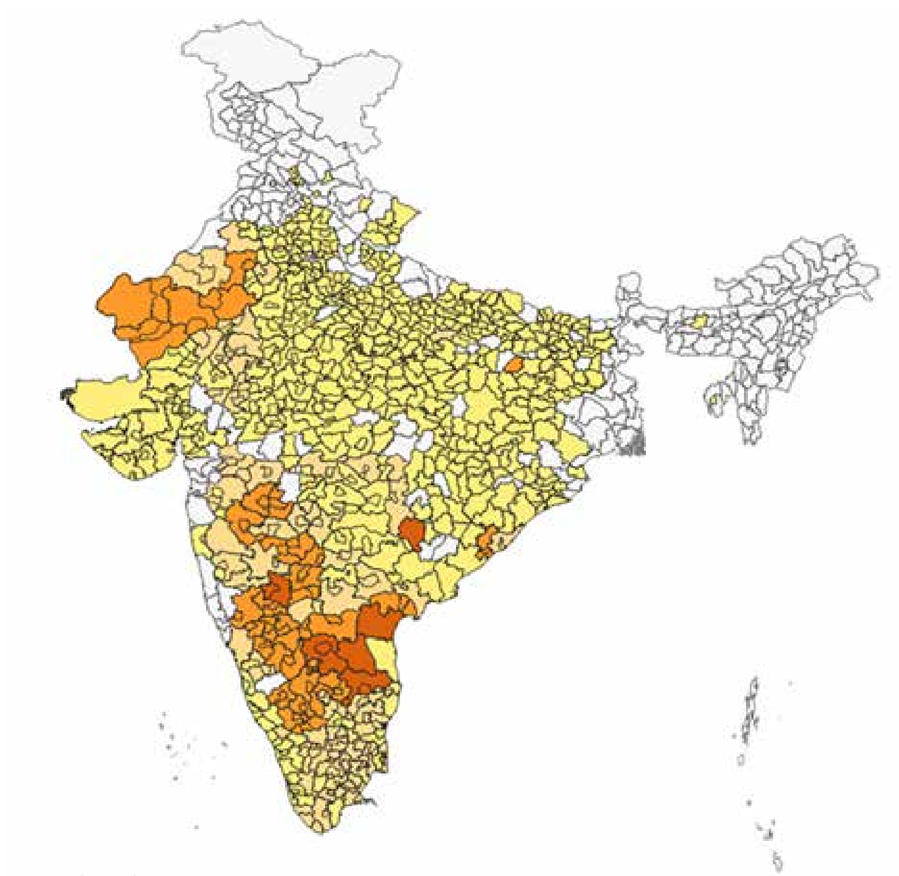


Frequency of drought

1 2 3 4 District boundary

Figure 16
Decadal drought map of districts affected, 2000–09

Source: Author's analysis



Frequency of drought

1-2 3-4 5-6 7-8 District boundary

Figure 17
Decadal drought map of districts affected, 2010–19

Source: Author's analysis

Climatological and meteorological linear relationships could be established between the drought events and the annual average rainfall until the decade of 1990–99. The decade of 2000–09 witnessed some erratic drought patterns, and the annual number of districts affected surged to 30. As per the IMD, in 2001, 25 per cent of the country, and in 2002, 29 per cent, was affected by moderate drought (IMD 2005). The seasonal rainfall during the summer monsoon in 2002 was below 19 per cent of the average (De et al. 2005), thereby causing the first country-level drought since 1987 (IMD 2005). The chronology of ENSO disturbances validates the erratic surge of drought events in the decade. Repeated failure of summer monsoons and surge in droughts prompted the IMD to change short-term weather forecasting (Ray et.al 2013). The most affected districts of the decade were West Siang, Rajkot, Surendra Nagar, Nagpur, and districts of central Rajasthan. The decade 2010–19 was in the news for both the drought events and the political economy around it. The farming community was highly impacted by the rise in drought events. In May 2016, the Supreme Court of India asked the then central government to revise the *Drought Manual of 2009* and formulate a national plan on drought management. This direction led to the revision of the drought manual, wherein droughts were reclassified as "Normal", "Below-Normal", "Above-Normal", "Deficient-Year", and "Large-deficient Year" compared to the old classification of "Calamitous", "Severe", and "Moderate". The average number of districts affected by droughts during 2010–19 increased to 85 after this recategorisation of droughts. While the intensity of damage in terms of loss of life has reduced to nearly zero, droughts continue to affect agrarian economies on a large scale. With the growing El Niño disturbances and microclimatic changes, droughts will only increase the uncertainties related to agriculture and rural livelihoods.

With the surge in El Niño disturbances and micro climatic changes, droughts will only increase the uncertainties related to agriculture and rural livelihoods

3.2.2 Associated drought events analysis

Drought, described as a slow-onset process, is usually not associated with any other major climatic events apart from famines and heat waves, as per EM-DAT. In the pre-1990 era, however, drought was associated with famine – a major non-climatic event. Although EM-DAT associates heat waves with droughts, a high-resolution climatological analysis is required to derive a robust inference, and EM-DAT currently does not have archived historical heat stress data. A climatological analysis is beyond the scope of this study. Considering the reported association of famines with drought and its varying definitions, we have not considered any specific associated events in relation to drought. Various studies have cited that droughts occurred quite frequently alongside famines in the pre-1970 era, and since our pentad decadal analysis is for 1970–2019, we have not considered any associated drought events in the study. Globally, droughts account for 22 per cent of the total loss and damage caused by major extreme climate events, but the death toll recorded is around 3 per cent (De et al. 2005). Studies suggest that there is a rise in heatwave conditions, but all heatwave conditions do not necessarily lead to drought or drought-like situations.

Pre-2005, cyclones would, on an annual average, affect 8 districts in India. Post-2005, this number has increased to 28

3.3 State of extreme events: cyclone (tropical cyclones)

The nomenclature of cyclones differs based on their location and the climatological and meteorological processes that trigger the event. They are classified under tropical storms. **A cyclone is defined as "a tropical storm originating over tropical or subtropical waters. Cyclones are characterised by a warm-core, non-frontal x-scale disturbance with a low-pressure centre, spiral rain bands, and strong winds.** Depending on their location, tropical cyclones are referred to as hurricanes (Atlantic, Northeast Pacific), typhoons (Northwest Pacific), or cyclones (South Pacific and the Indian Ocean)" (EM-DAT 2015). Our analysis includes the classification of tropical cyclones. Globally, over 90 tropical cyclones occur worldwide per year (Jonathan et al. 2013), and in the case of India, the current average frequency is a little higher than three (Figure 18). In the pre-2005 era, eight districts were affected on average annually, but post-2005, this number increased to 28. It is worth noting that cyclones are often transboundary phenomena, and cause loss of life and damage across boundaries. The Bombay cyclone in 1948 was one of the most disastrous cyclones in the pre-1970 era.

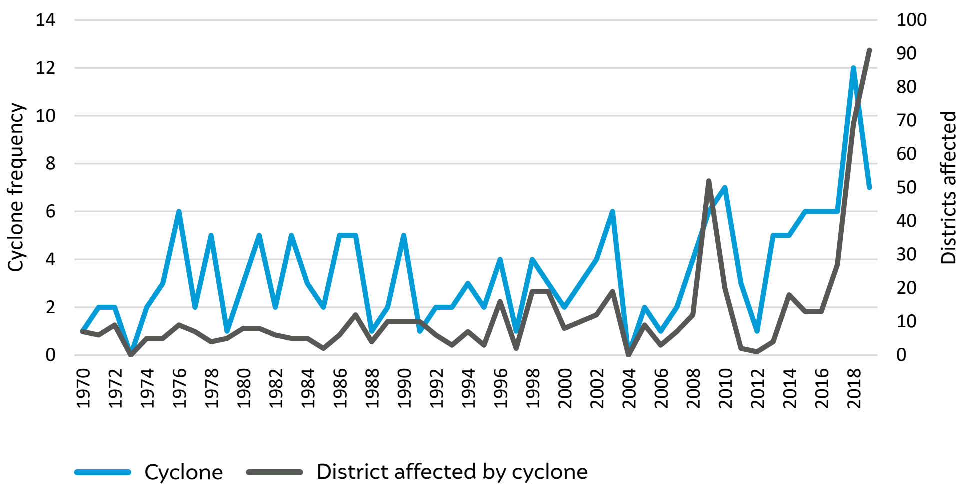


Figure 18
The frequency and number of districts affected by cyclones has been on the rise since 2005

Source: Author's analysis

The primary indicator of a warming ocean is increase in the sea surface temperature (SST), which is also one of the primary variables for the formation and intensification of tropical cyclones (Gary et al. 1979). The frequency of tropical cyclones is dependent on the humidity in the atmosphere and pre-existing disturbances (Jonathan et al. 2013). The ENSO and Madden Jullian oscillation (MJO) have an impact on tropical cyclones (Camargo et al. 2007). Tropical cyclones in India are primarily the result of the ENSO phenomenon. In India, the maximum number of tropical cyclones occurs between November and May (Singh et al. 2000). Our analysis suggests that Puri, Chennai, Nellore, North 24 Parganas, Ganjam, Cuttack, East Godavari, and Srikakulum are the cyclone district hotspots of India. While the extent of loss and damage to lives, livelihood and properties does not seem to be decreasing with time, adequate evacuation plans and strategic management have resulted in reduced loss of life (CEEW, 2015). As per the IMD, the most disastrous cyclone recorded till date is the 1999 super-cyclone. In the last century, more than four severe cyclones made landfall in the Paradeep port, of which two were in October, during the post-monsoon season (Sridharan et al. 2002).

Puri, Chennai, Nellore, North 24 Parganas, Ganjam, Cuttack, East Godavari, and Srikakulum are India's cyclone hotspot districts

3.3.1 The pentad decadal analysis of cyclone events

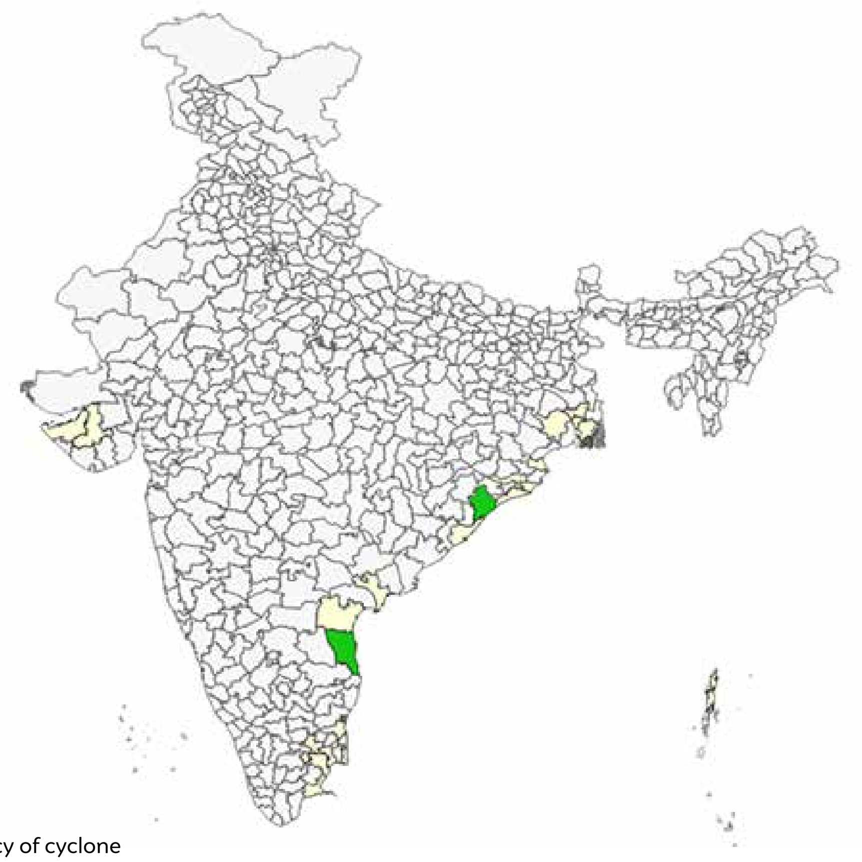
As we have stated earlier, the literature suggests that India's coastline is highly vulnerable to intensified tropical cyclones (IMD, 2018). Figures 19–23 depict districts most affected by decade during 1970–2019. The decade 1970–79 recorded a total of 24 cyclones, and the average number of districts affected was six. Some of the most affected districts in this decade were Gopalpur, Nellore, Srikakulam, Baleswar, Guntur, Kolkata, and Puri, among others. The cyclone of 1971, which made its landfall in Paradeep, Odisha, caused more than 10,000 deaths, and the storm surge height was recorded to be around 7.20 feet (IMD 1980). The other major event of the decade was the 1977 cyclone in Andhra Pradesh that made its landfall in Chirala; its storm surge height was 16.12 feet, and it caused almost 10,000 deaths (De et al 2005). A total of 57 districts were affected in this decade. The Bay of Bengal was the epicentre of cyclone events in this decade.

Our analysis reveals that the frequency of cyclones over the Bay of Bengal varied across the decades. The decade 1980–89 recorded a total of 33 major cyclone events, which affected 66 districts. This decade saw the highest number of cyclonic storms. The 1999 super-cyclone has dominated the history of cyclonic events in India, though 1990–99 decade also witnessed some major tropical cyclones, cyclonic storms, and monsoon depressions. However, the frequency of tropical cyclones and monsoon depressions forming over the region has decreased with time. The average number of districts affected in the decade was 10, but a few districts, such as Puri, Chennai, Cuttack, East Godavari, and Jamnagar, have been witnessing cyclones every alternate year. West Bengal, Odisha, and Andhra Pradesh have been prone to disturbances in recent decades (Mahapatra et al. 2018) due to changes in the microclimate. In 2000–09, North Goa, Puri, Kolkata, Amreli, and Baleshwar were the most affected districts. Cyclonic storm (CS) Phyan, which impacted the coastline of Gujarat and Maharashtra in 2009, was one of the most significant cyclone events in the decade, because of the changing course of disturbances from the Bay of Bengal to the Arabian Sea. The decade saw some major cyclonic storms and tropical cyclones that affected a total of 132 districts. Our analysis suggests that the compounded events started intensifying from this decade, i.e., cyclonic storms were followed by substantial rainfall, flooding, and landslides. The decade witnessed the catastrophic tsunami at the Andaman and Nicobar Islands, which caused maximum deaths. In 2010–19, the frequency and intensity of cyclonic storms increased. The decade saw 58 severe cyclonic storm events that affected 258 districts. Some of the most affected districts of the decade were East Imphal, Deoghar, Cuttack, and North 24 Parganas. Strategic evacuation planning resulted in low casualties, but infrastructure and livelihood loss remain a matter of grave concern.

Decade	District hotspots
1970–79	Gopalpur, Nellore, Masulipatna, Paradip, Tamil Nadu
1980–89	Puri, Paschim Medinipur, Chennai, Ganjam, Srikakulam, North 24 Parganas, Banka, Cuddalore, Cuttack
1990–99	Puri, Cuttack, Chennai, East Godavari, Jamnagar, Baleshwar, Guntur, Srikakulam, West Godavari
2000–09	Cuttack, Kolkata, North Goa, Puri, Krishna, East Godavari, Amreli
2010–19	Imphal East, Sri Potti Sriramulu Nellore, Deoghar, Araria, Ratnagiri, Ranchi, Bareilly, Bijnor, Moradabad

Table 4
Cyclone hotspot districts , 1970-2019

Source: Author's analysis



Frequency of cyclone

1 2 District boundary

Figure 19
Decadal cyclone map showing districts affected, 1970–79

Source: Author's analysis

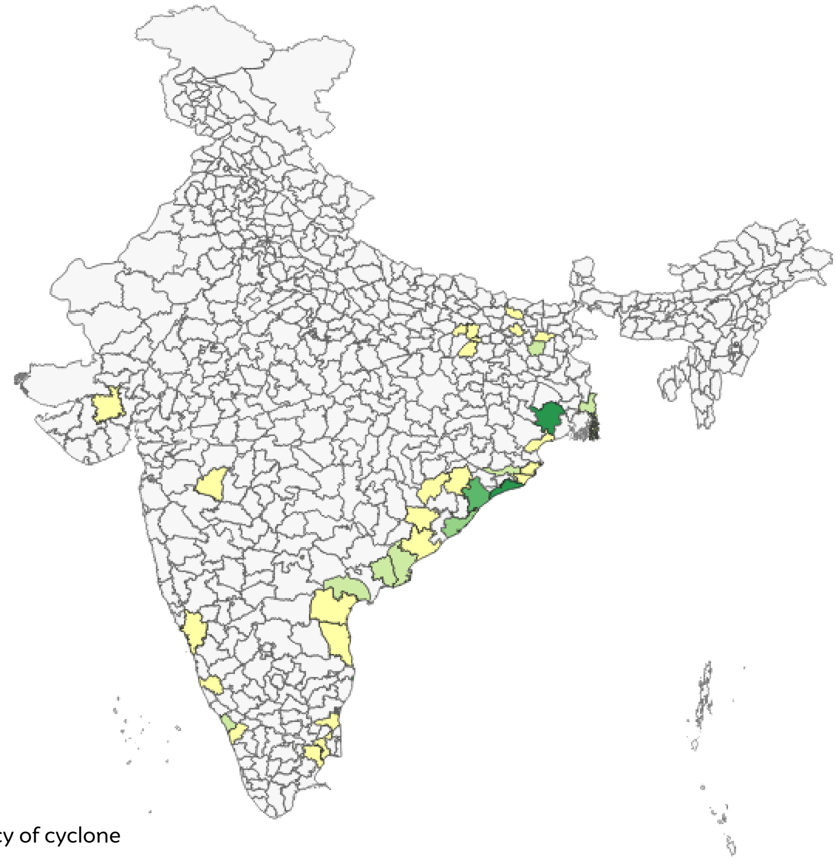


Figure 20
Decadal cyclone map showing districts affected, 1980-89

Source: Author's analysis

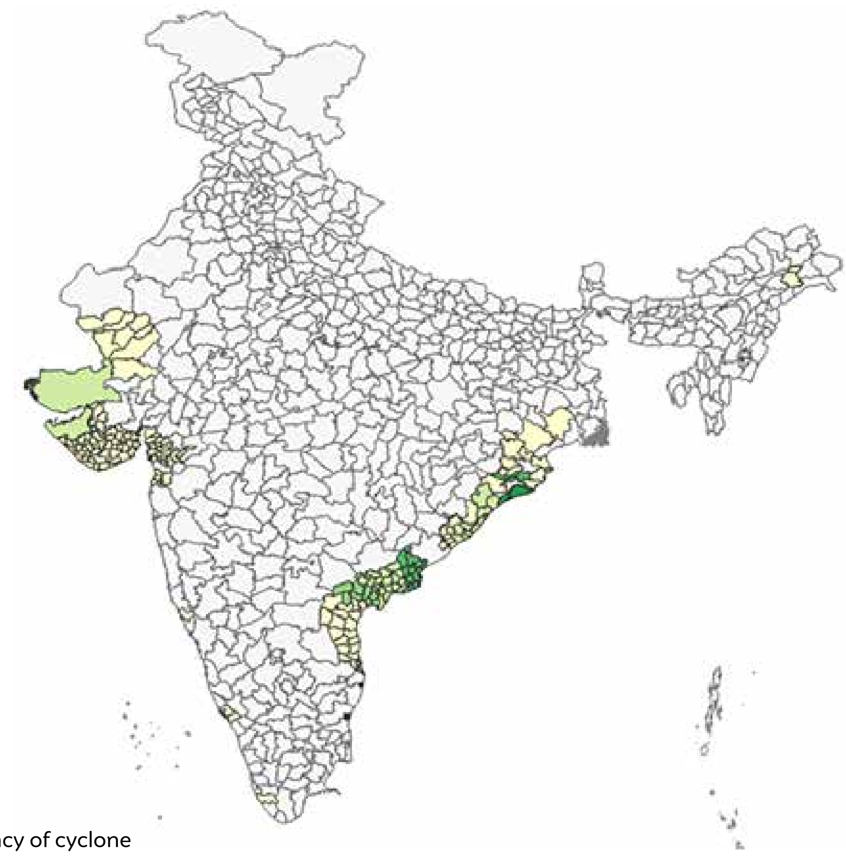
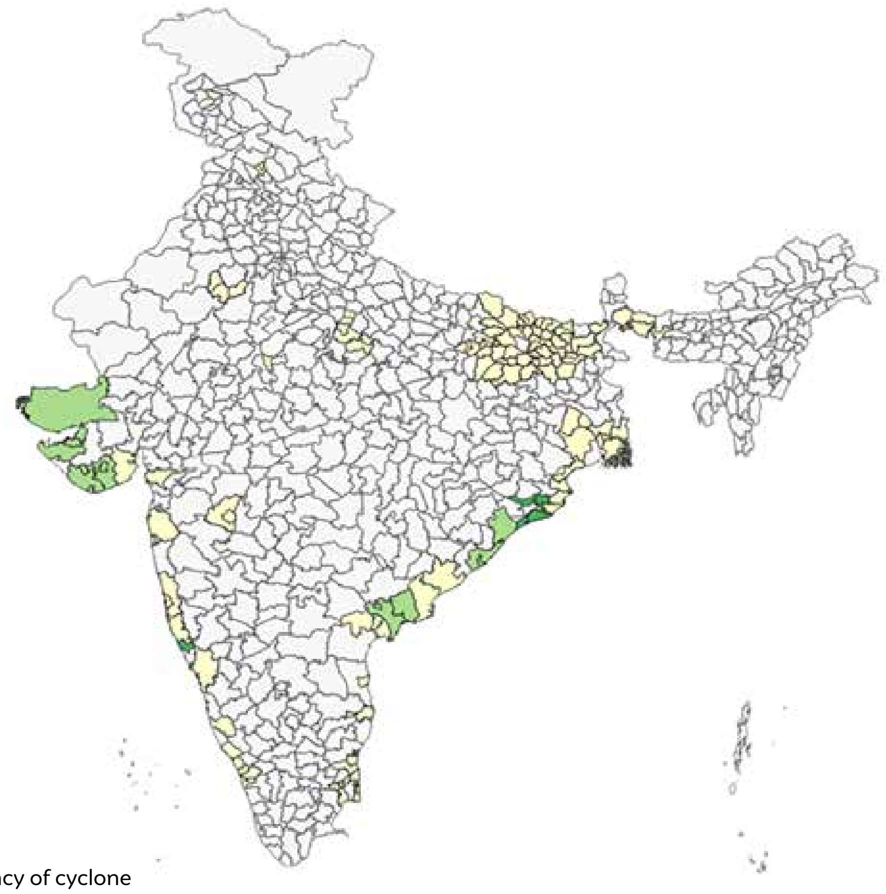


Figure 21
Decadal cyclone map showing districts affected, 1990-99

Source: Author's analysis

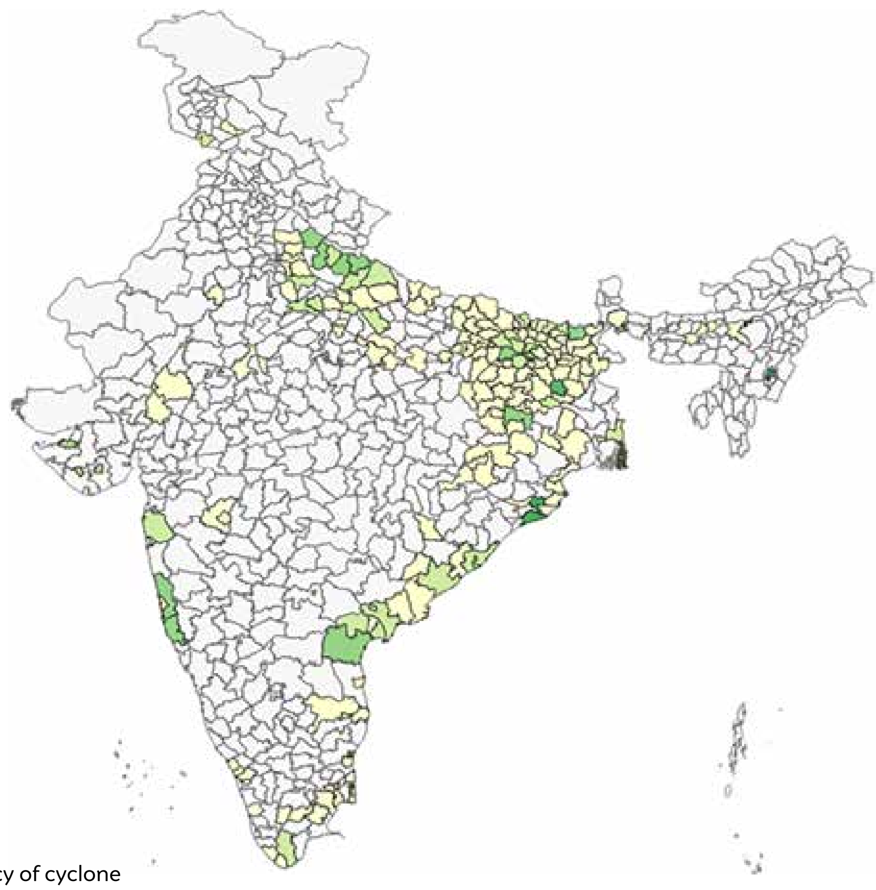


Frequency of cyclone

1 2 3 District boundary

Figure 22
Decadal cyclone map showing districts affected, 2000-09

Source: Author's analysis



Frequency of cyclone

1 2 3 District boundary

Figure 23
Decadal district-affected cyclone map: 2010–19

Source: Author's analysis

3.3.2 Analysis of associated cyclone events

Cyclone events involve complex climatological phenomena and often have a compounding effect based on the topography and morphology of the microclimate. A cyclonic storm formed due to a monsoon depression may lead to extreme rainfall/hailstorms/floods/thunderstorms. Tropical cyclones often make landfall for a day or two and maintain their peak wind speed for a limited time; however, their effects continue in the form of associated events. Figure 24 depicts the frequency of cyclone events vis-à-vis associated events for 1970–2019.

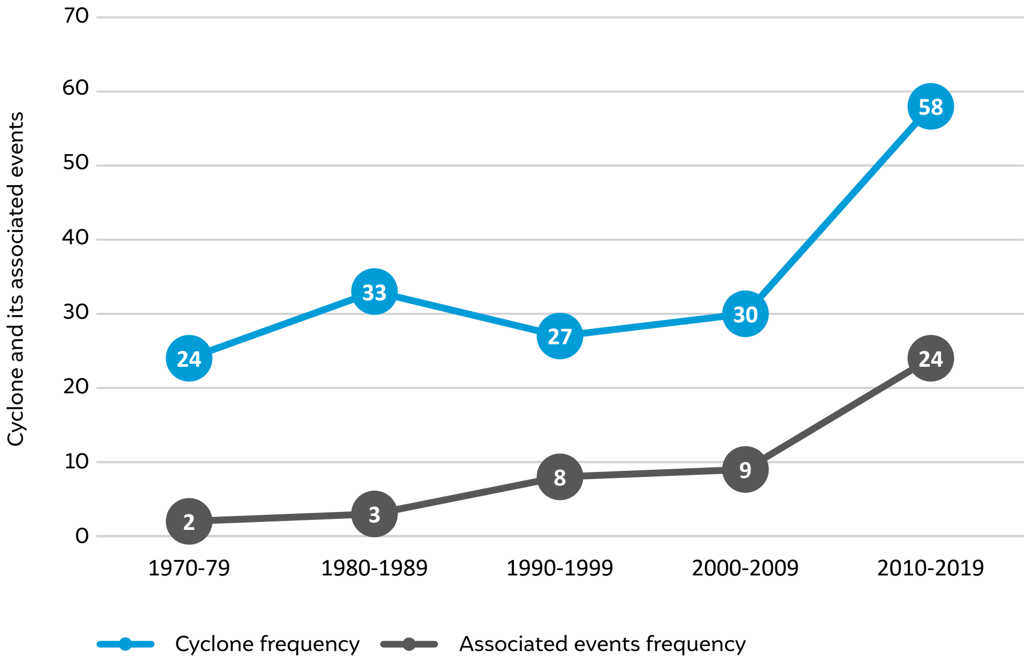


Figure 24
The decade of 2010-19 has witnessed an exponential surge in associated cyclone events

Source: Author's analysis

Our analysis suggests that the east coast of India witnessed a greater number of cyclones than the west coast. It is notable that along with the coastline districts, there is a trend of deflection across the central regions. The cyclogenesis[15] process, which is induced by changes in the sea-surface temperature and coastal surface temperature, has been accelerating, hence resulting in intense cyclones along the coastlines, deflected towards warmer central regions. The compounding effect of cyclones is more severe than that of any other climatic event owing to the amount of loss and damage that it causes. A warming regional microclimate, land-use changes, and degrading forest cover triggers the cyclogenesis process. Studies suggest that an increase in sea surface temperature leads to an increase in the diameter of the cyclone, which in return intensifies the cyclone. The number of storms with more than 100 mm of rainfall in a day is reported to have increased by 10 per cent per decade (UNEP, 2009).

Similarly, an increase in the coastal surface temperature leads to an increase in entropy, which deflects the cyclone to the warmer regions across the coast, thereby inducing a faster cyclogenesis process over these warmer oceans. These effects are now being increasingly witnessed over other regions in the country. Districts like Araria, Bareilly, Patna, and Gorakhpur, among others, are experiencing more frequent and intense cloudbursts, followed

15. Cyclogenesis is the development or strengthening of an area of low pressure in the atmosphere, resulting in the formation of a cyclone.

by flash floods. A report by IPCC that tracks the trajectory of cyclones suggests that increased and uneven temperatures generate increased suction that forces cyclonic disturbances to deflect from their natural path towards warmer regions. The pattern is evident over the Indian Ocean, which is reported to have warmed by 0.6 degrees since 1960 – the largest warming among the tropical oceans (Mishra et al. 2014). There is enough empirical and cardinal evidence to prove that the changing climate is intensifying the course of climatic events, thereby making them extreme. Cyclones are part of natural processes that cannot be avoided, but the extent of loss and damage can be mitigated.

3.4 State of extreme events: India's changing landscape of climate risks

In this study, we intend to provide insights into the impacts of climate change on the frequency and intensity of high-impact, extreme events, primarily hydromet disasters. While the impacts are evident, some patterns of extreme events need urgent attention. Our district-level hazard assessment provides us with a detailed view of the changing climate. Our analysis provides evidence that it is not just the extremity of the climate events that is increasing both in scope and impact; relatively, it's very basic nature is also changing. Figure 25 depicts the extreme events district hotspots of India. India is exposed to increasingly frequent floods, droughts, and cyclones. According to the NDMA, 12 per cent and 68 per cent of India's total land area is exposed to floods and drought, respectively. Eighty per cent of the total coastline is exposed to cyclones and tsunamis. India is witnessing associated events corresponding to that of the heatwaves, cold waves, extreme rainfall, landslides, and avalanches as a new normal. The flood hotspot zones are formed by the districts along the Indo-Gangetic plains and Brahmaputra Valley. The frequency of floods and droughts has increased year-on-year due to changes in the microclimate and surface temperature.

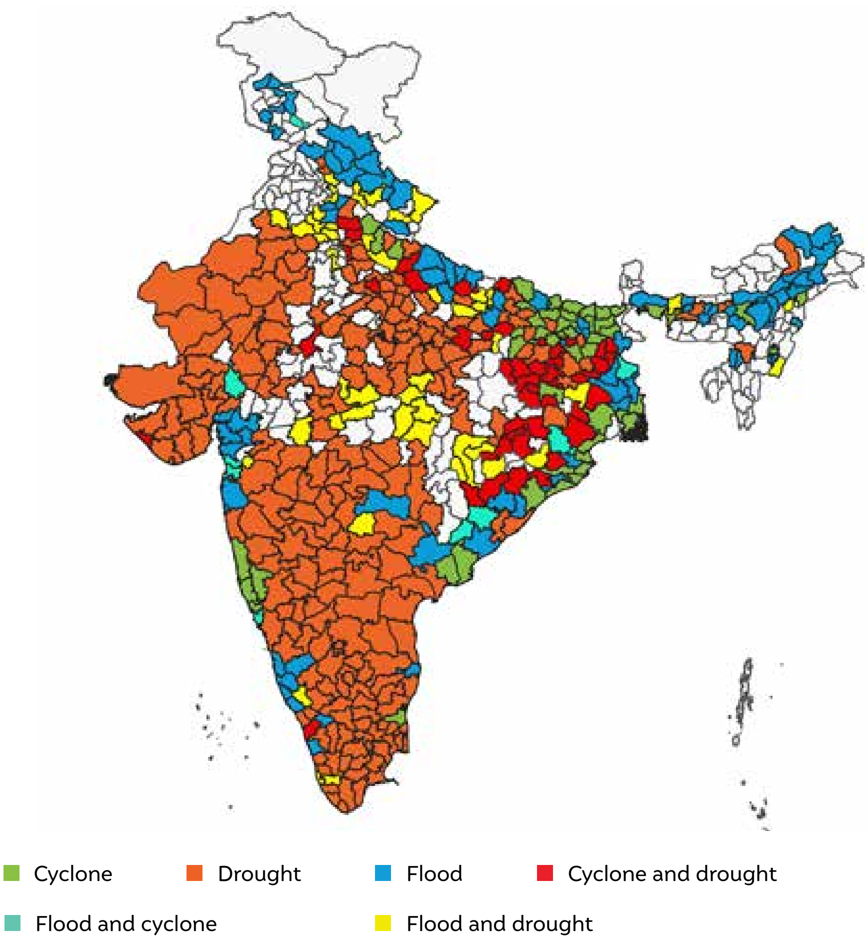


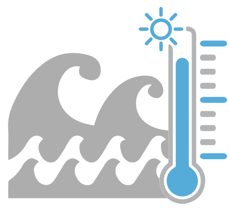
Figure 25
More than 75 per cent of Indian districts are extreme climate events hotspots

Source: Author's analysis

As we discussed earlier, since 2000–09, we have observed a surge in extreme climate events. The primary reasons for the surge are i) land-use changes ii) the urban heat island (UHI) phenomenon,[16] and iii) land subsidence (UNEP 2009). A detailed analysis of microclimate changes is beyond the scope of this study. In the following sections, we map the causal factors for the increase in the frequency and intensity of extreme climate events. Land-use changes lead to an increase in the impervious layer, thereby inversely affecting natural drainage. Hence, the surplus flow is increased through surface runoff. The complex interaction between the UHI and rain-bearing clouds pushes up the convected clouds towards down-wind (or downward) rainfall, resulting in high-intensity localised rainfall. The UHI thus triggers urban flooding. In coastal regions, as we have highlighted in Section 3.4.2, an increase in sea surface temperature and coastal surface temperature has not only intensified cyclones, but also other associated phenomena, like cloud bursts, monsoon depressions, and cold waves. While roughly 68 per cent of the country suffers drought or drought-like situations, the rest of the country is witnessing flooding events. Temperature increase have significant adverse impacts on sensitive ecological regions. For example, the decadal rise in temperature over the Himalayan region is around 0.4 °C higher than the global average, as reported by the WMO. These macroclimatic shifts lead to the rise of sudden events like glacial lake outburst floods (GLOF) and inundation due to sea-level rise (SLR). The other important classification of land-use changes attribution is land subsidence; studies suggest that land subsidence is one of the primary reasons for SLR (Boccard et al. 2018, Woodruff et al. 2018). Woodruff et al. have suggested that a one-metre rise in sea level can potentially inundate 5,763 km in India (2018).

3.4.1 Changing patterns of extreme events

Our geospatial analysis at the temporal scale provides empirical evidence that trends and patterns in climate events are changing, thereby increasing the vulnerability of exposed communities and assets. The analysis infers a shifting pattern in terms of extreme events across the Indian districts. Many of the flood prone districts are becoming drought prone and vice-versa (Figure 27). The section (3.4.2) below provides a depiction of the changing climate through these shifts.



An increase in sea surface temperature and coastal surface temperature has intensified cyclones and associated phenomena, like cloud bursts, monsoon depressions, and cold waves

We have undertaken a pattern shift analysis for floods and droughts. Our study provides district-level insights on the changing trends in these specific extreme events based on frequency and intensity. Droughts were concentrated in the northern peninsula, eastern India, and western India, but the pattern is shifting towards flooding in some districts of these regions. The number of districts that have experienced a shifting trend from floods to droughts is higher than that of districts that have shifted from drought to floods. Some of the districts that have seen a reverse trend (floods to droughts) are Srikakulum, Cuttack, Guntur, Kurnool, Mahbubnagar, Nalgonda, and Paschim Champaran, among others. South India is experiencing an increasing shift towards drought in states like Andhra Pradesh, Tamil Nadu, and Karnataka. Our analysis provides empirical evidence that southern, western, and some parts of central India are increasingly experiencing a drought/drought-like situation. Rajkot, Surendranagar, Ajmer, Jodhpur, and Aurangabad, among others, are some districts that have shown a flood-to-drought trend. Our findings suggest that drought events are becoming more intense across the Indian subcontinent.

16. An urban heat island or UHI is an urban or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities.

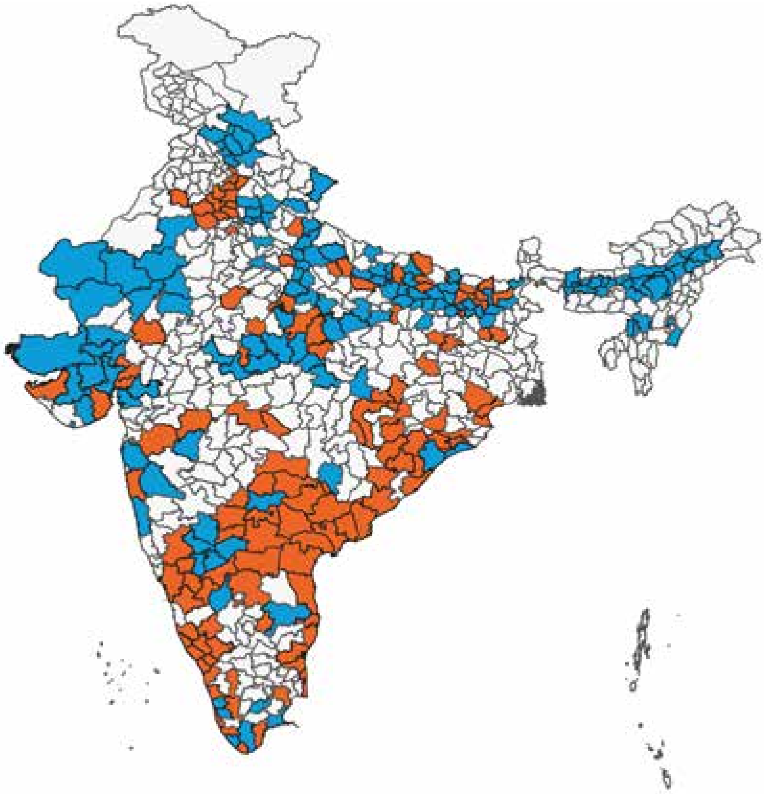


Figure 26
The changing pattern of extreme events are witnessed by more than 40 per cent of Indian districts

Source: Author's analysis

Contrary to the trends stated above, a few districts witnessed a mix of both events. Geospatial masking analysis shows the simultaneous occurrence of both droughts and floods in some parts. A small number of districts in Bihar, Uttar Pradesh, Odisha, and Tamil Nadu witnessed the simultaneous occurrence of droughts and floods. These trends are alarming and demand a comprehensive risk assessment at the local level through a detailed, grid-level climatological analysis to identify their compounded impacts.

3.4.2 Mapping the changing patterns of climate zones

As we highlighted earlier in Chapter 2, through GrADS, we mapped extreme events hotspots to discuss changes in microclimates across climate zones (see Figure 28) to trigger a discussion around the changing microclimate. A coarse-grain resolution climatological analysis can provide a granular overview of both the changing micro and macroclimate. However, we have attempted to provide empirical evidence on changing microclimatic zones. Figure 29 depicts the mapping of climatic zones based on the Köppen classification vis-à-vis extreme events district hotspots in India. Many scientists have adopted the methodological approach of providing empirical evidence of climatic zone variations (Hylke et al. 2018), but the representation of climate zones vis-à-vis extreme event hotspots is an attempt to understand the pattern of change across Köppen climate zones. The Indian subcontinent is divided into six climatic zones and 15 subtypes (Table 4). Each climatic zone and its subtype has a specific definition. There are not many studies on the mapping of extreme climate events and climate zones, so we have considered the Köppen classification subtypes distribution as the baseline reference scenario based on the temporal analysis maps of NASA.

Our analysis shows that flood and cyclone districts fall under the category Cwa[17] (monsoon-influenced humid subtropical climate), and drought districts under category Bsh[18] (hot semi-arid climate). The characteristic features of these classifications are detailed in Annexure-II (Hylke et al. 2018). The geospatial analysis at a temporal scale suggests that these changing patterns represent changes in microclimatic zones. The flood hotspot districts are shifting towards the Aw tropical climate,[19] which confirms our findings that flood-prone areas are becoming drought-prone. The cyclone extreme events hotspots are shifting across to the Aw tropical climatic zone. As we discussed in Section 3.3.2, the UHI phenomenon and rising sea surface temperatures and coastal surface temperatures are pushing cyclonic disturbances towards warmer regions, as is evident from the climate zone shift. The extreme drought events hotspots are moving towards the Bwh[20] desert climate zone, based on which we can infer that drought events are becoming more intense – and hence our findings in Section 3.4.1 are validated. These findings hint at a more comprehensive microclimatic zone mapping and assessment, which can provide a base for more risk-informed planning and decision-making to build the resilience of the vulnerable sectors and sections of the population.

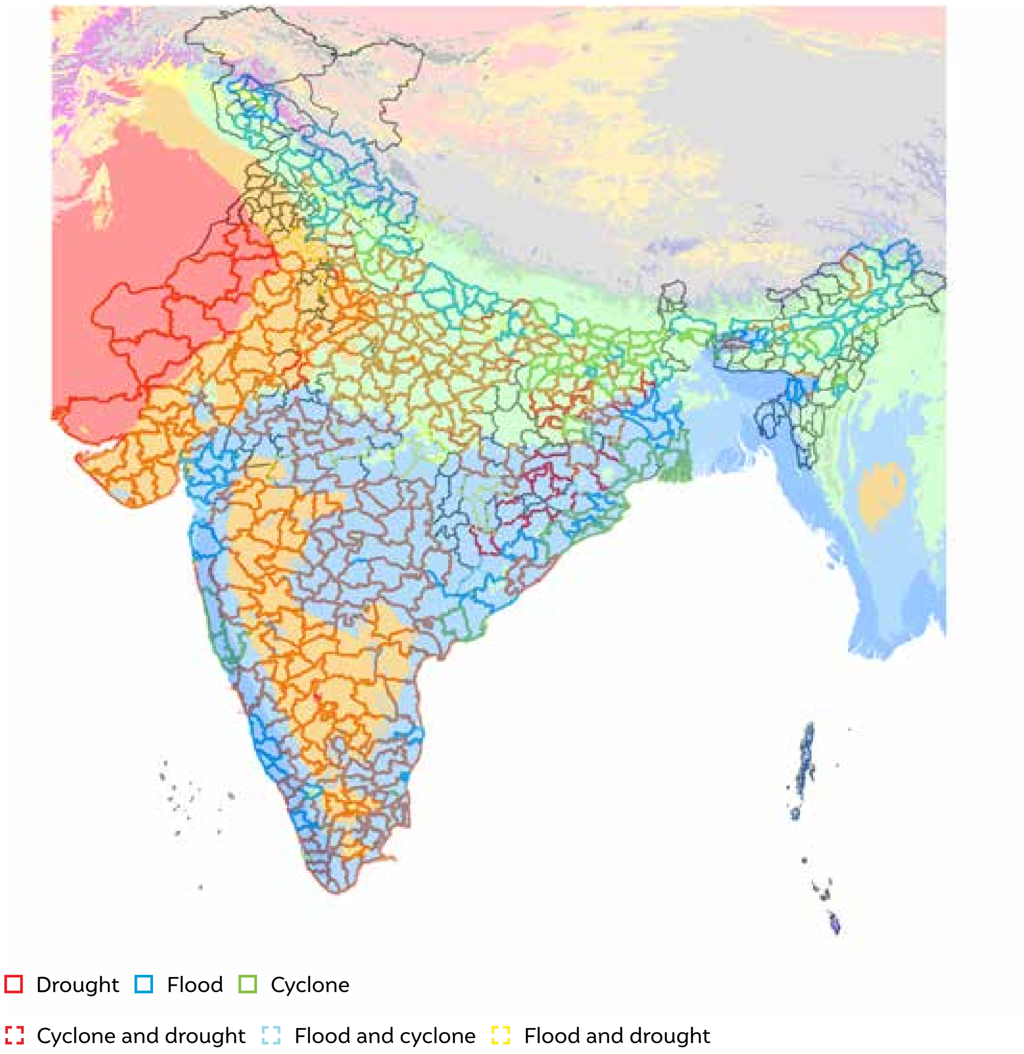


Figure 27
Extreme climate vis-a-vis climate zones

Source: Author's analysis

17. Cwa zones have at least ten times as much rain in the wettest month of summer than in the driest month of winter.
18. Bsh climates tend to have hot – sometimes extremely hot – summers and warm to cool winters, with some to minimal precipitation.
19. Aw climates have a pronounced dry season, with the driest month having precipitation of less than 60 mm.
20. In a Bwh desert climate zone, there is an excess of evaporation over precipitation. The typically bald, rocky, or sandy surfaces in desert climates hold little moisture, and the little rainfall they receive evaporates.

Table 5
Köppen classification of climatic zones

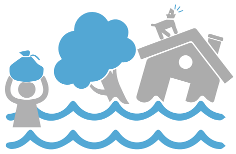
Source: Beck et. al 2018

Numeric value	Colour	Köppen-Geiger classes	Class description	Subclass	
1		Af	Tropical	Rainforest	
2		Am		Monsoon	
3		Aw		Savannah	
4		Bwh	Arid	Desert	hot
5		Bwk			Cold
6		Bsh		Steppe	hot
7		Bsk			Cold
8		Csa	Temperate	Dry summer	Hot summer
9		Csb			Warm summer
10		Csc			Cold summer
11		Cwa		Dry winter	Hot summer
12		Cwb			Warm summer
13		Cwc			Cold summer
14		Cfa		No dry season	Hot summer
15		Cfb			Warm summer
16		Cfc			Cold summer
17		Dsa	Cold	Dry summer	Hot summer
18		Dsb			Warm summer
19		Dsc			Cold summer
20		Dsd			Very cold winter
21		Dwa		Dry winter	Hot summer
22		Dwb			Warm summer
23		Dwc			Cold summer
24		Dwd			Very cold winter
25		Dfa		No dry season	Hot summer
26		Dfb			Warm summer
27		Dfc			Cold summer
28		Dfd			Very cold winter
29		Et	Polar	Tundra	
30		Ef		Frost	

4. Conclusion

Image: iStock

India is one of the most vulnerable countries globally, and its exposure to climate change impacts is increasing by the year. Our analysis suggests that more than 575 districts in India are exposed to compounded impacts of hydro-met disasters. This study provides evidence of changing climate at the district level by highlighting the morphology of extreme climate events through the analysis of historical time series. One key learning from this study is that the traditional approach of vulnerability assessments needs to be enhanced for a comprehensive risk assessment. Adhering to the principles of risk assessment remains central to any risk-assessment process, and it should be applied to the broadest possible extent (CEEW 2015). This should help us understand the segments of risk assessment – hazard assessment, vulnerability assessment, and compounded events assessment – in detail (Omar et.al 2014). For example, until now, most discussions of extreme climate events did not include the mapping of associated events and processes that compound the effects. The key recommendations from our work focus on five aspects: developing a climate risk atlas; developing an integrated emergency surveillance system; mainstreaming risk assessment; enhancing the adaptive and resilience capacity; increasing the participatory engagement of all stakeholders in the risk-assessment process; and integrating local, subnational, and national plans.



More than 575 districts in India are exposed to compounded impacts of hydro-met disasters

4.1 Developing a climate risk atlas (CRA)

Our hazard assessment study clearly demonstrates that identifying the combined risks at a high resolution would enhance preparedness and enable climate-proofing of policies and plans. Our analysis further suggests that post 2005 more than 310 extreme events and its associated events have caused devastating impacts and it is important to project the climate risks in short term time scale. The climate risk atlas (CRA) will provide a base to understand, identify, and quantify hazards arising from specific climate risks across various sectors and elements through risk metric modelling, thereby generating evidence to build resilient communities, countries, and regions in a short term time scale which considers micro climatological assessments as well. The CRA will be a risk-informed decision-making toolkit on the cloud computing interface along with dynamically analysed high-resolution maps. It will help quantify the impacts of climate risks through downscaled risk rating indices for various sectors. The CRA will further help in climate-proofing the critical, emergency, transportation, and allied sectoral infrastructures.

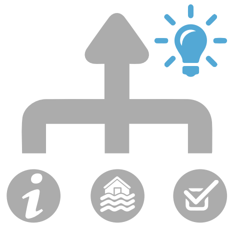
4.2 Developing an integrated emergency surveillance system (IESM)

Effective preparedness is a long-term, integrated, and multifaceted approach to disaster and emergency management. It strengthens governance frameworks and community preparedness, and systematically builds resilience and adaptation (CEEW 2020). Our analysis suggests that more than 80 per cent of Indian sub-continent is exposed to hydromet disasters and hence its surveillance is imperative. The hazard assessment can further supplement the development of a nationwide, centralised, structured, and real-time digital disaster/emergency surveillance and management system. The Ministry of Home Affairs could scale up the basic surveillance and tracking system of the national Integrated Disease Surveillance Programme (IDSP) database and the state disaster management authorities (SDMA) to serve the entire range of emergency preparedness activities in the nation, which can be supplemented by both vulnerability and hazard assessment outputs.

The UN-IASC states that USD 1 invested in preparedness saves USD 2 for future disaster recovery and response

4.3 Mainstreaming risk assessment at all levels

As we highlighted earlier, climatological or meteorological studies need to have continuous, validated, and high-resolution historical data to undertake comprehensive risk assessments. A risk assessment helps us to set a limit to preparedness. While risks are uncertain, the preparation can be certain and well in the ambit of collective action to reduce possible damage. Risk assessments need to have a razor-sharp focus on some of the direct, indirect, transitional, and emerging risks that both chronic and non-chronic hazards pose to the most vulnerable communities and sectors. The first step of any risk assessment is risk identification, i.e., identifying the risks at a localised, regional, sectoral, and cross-sectoral level. Risk identification should also focus on the extent of loss and damage at the secondary (agricultural and labour productivity, industrial value, forced migration, and damage to biodiversity, the ecosystem, etc.) and tertiary (revenue and conflicts due to resource scarcity) levels. Risk assessments at the least possible downscaled level should have a description of the common language of the problem. Risk identification needs to inculcate climatological and meteorological processes at both the macro and microclimate levels, through loss precedence curve identification for each hazard and region.



The approach by which adaptive and resilience capacity can be built is based on what we know, what can happen, and what can be done

4.4 Enhancing the adaptive and resilience capacity

Our analysis suggests that the micro climatic zone shifting trend, impending that drought prone areas are becoming flood prone and vice–verse. This changing pattern would require an enhanced adaptive and resilience capacity to climate proof lives, livelihoods and investments. There is limited capacity at the implementation level of disaster risk reduction plans. The approach by which we build adaptive and resilience capacity should be based on what we know, what can happen, and what can be done. Appropriate standard operating procedures (SOPs) should be formulated and strictly enforced in planning and designing. These should be coupled with operational training at the grassroot level to enhance resilience. The state- and district-level disaster plans list various training and capacity-building programmes. The mainstreaming of disaster risk reduction in developmental project planning can mitigate loss and damage if matched with high-resolution exposure assessment. This adaptive capacity training should not just be focused on government functionaries but also on masons, architects, designers, and other relevant frontline stakeholders.

4.5 Increasing participatory engagement of all stakeholders in the risk assessment processes

A global study on risk assessment by CEEW in 2015 highlighted the importance of participatory engagement, and this engagement holds the key to building resilience. Any risk assessment should include policy and decision-makers right from the inception of the process, thereby ensuring that problems are identified and solutions are feasible. (CEEW 2015). The ambit of risk assessments should involve public policy, economic, insurance, and industry partners, apart from climate scientists, who have a core mandate of risk-informed planning at different levels. Often, the risk-assessment process tends to marginalise the those affected by climatic shifts. The communities might not have scientific expertise, but they embody traditional management practices, and these are low-hanging fruits that can be harnessed at the community level with less financial implications. Mitigation, adaptation, and resilience-building efforts should not work in silos; instead, the approach should be to understand the co-benefits of mitigation and adaptation. The inclusion of co-benefits and hazard sensitivity functions in long- and short-term risk projections can fetch better results.

4.6 Integrating risk assessments into local, subnational, and national-level plans

As we are approaching the completion of the first phase of the Sendai Framework, it is essential to understand that dedicated plans, while important, have often led to duplication in terms of work and financial allocation. In India, the plans range from national disaster plans to the state and district disaster plans from a DRR purview. Similarly, for climate actions, we have the NAPCC (National Action Plan on Climate Change) at the national level and the SAPCC (State Action Plan on Climate Change) at the state level. Our analysis further suggests that more than 1.09[21] billion people are currently exposed to extreme and its associated climate events. The plans don't consider national level or state level risk assessments during its planning nor implementation (Mcbean et.al 2012). These plans needs to mainstreamed and integrated at all levels. All of these plans look at mitigating risks and building resilience with a different set of actors and parameters. Further mitigating loss and damage calls for an integrated approach, where there should be convergence across actions, and the standards for evaluating them should be the same. The integrated approach should include both sectoral and socioeconomic indicators.

21. Considering average district population to be 1.09 million as per Census, 2011.

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Annexures

Annexure-I

Glossary

Affected
People requiring immediate assistance with basic survival needs such as food, water, shelter, sanitation, and immediate medical assistance during a period of emergency.

Airburst
The explosion of a comet or meteoroid within the earth's atmosphere without striking the ground.

Animal accident
Human encounters with dangerous or exotic animals in both urban and rural developments.

Ash fall
Fine, unconsolidated volcanic debris (less than 4 mm in diameter) blown into the atmosphere during an eruption; can remain airborne for long periods of time and travel considerable distances from the source.

Avalanche
A large mass of loosened earth material, snow, or ice that slides, flows, or falls rapidly down a mountainside under the force of gravity.

- Snow avalanche: Rapid downslope movement of a mix of snow and ice.
- Debris avalanche: The sudden and very rapid downslope movement of an unsorted mass of rock and soil. There are two general types of debris avalanches: a cold debris avalanche usually results from an unstable slope suddenly collapsing, whereas a hot debris avalanche results from volcanic activity, leading to slope instability and collapse.

Biological hazard
A hazard caused by exposure to living organisms and their toxic substances (e.g., venom or mold) or the vector-borne diseases that they may carry. Examples include venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents such as parasites, bacteria, or viruses (e.g., malaria).

Climatological hazard
A hazard caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability.

Coastal erosion
The temporary or permanent loss of sediments or landmass in coastal margins due to the action of waves, winds, tides, or anthropogenic activities.

Coastal flood
Higher-than-normal water levels along the coast caused by tidal changes or thunderstorms that result in flooding, which can last from days to weeks.

Cold wave
A period of abnormally cold weather. Typically, a cold wave lasts two or more days and may be aggravated by high winds. The exact temperature criteria for what constitutes a cold wave vary by location.

Collapse
An accident involving the collapse of a building or structure; it can either involve industrial structures or domestic/non-industrial structures.

Complex disasters
Major famine situation for which the drought was not the main causal factor.

Convective storm
A type of meteorological hazard generated by the heating of air and the availability of moist and unstable air masses. Convective storms range from localised thunderstorms (with heavy rain and/or hail, lightning, high winds, and tornadoes) to meso-scale, multi-day events.

Crop failure
Abnormal reductions in crop yield such that it is insufficient to meet the nutritional or economic needs of the community.

Death
The number of people who lost their lives because the event that happened.

Derecho
Widespread and usually fast-moving windstorms associated with convection/convective storms. Derechos include downbursts and straight-line winds. The damage from derechos is often confused with the damage from tornadoes.

Disaster
A situation or event that overwhelms local capacity, necessitating a request to the national or international community for external assistance (definition considered in EM-DAT); an unforeseen and often sudden event that causes great damage, destruction, and human suffering. Though often caused by nature, disasters can have human origins.

Disaster event
A disaster that meets EM-DAT criteria and which is recorded in EM-DAT. A disaster event can affect one country or several [see “country-level disaster”]. In the case of the latter, the disaster event will result in several country-level disasters being entered into the database. A disaster event will always have a unique DISNO identifier.

Disease
Either an unusual, often sudden, increase in the number of incidents of an infectious disease that already existed in the region (e.g., flu, E. coli) or the appearance of an infectious disease previously absent from the region (e.g., plague, polio).

Drought
An extended period of unusually low precipitation produces a shortage of water for people, animals, and plants. Drought is different from most other hazards in that it develops slowly, sometimes even over years, and its onset is generally difficult to detect. Drought is not solely a physical phenomenon because its impacts can be exacerbated by human activities and water supply demands. It is therefore often defined both conceptually and operationally. Operational definitions of drought, meaning the degree of precipitation reduction that constitutes a drought, vary by locality, climate and environmental sector.

Earthquake
Sudden movement of a block of the earth’s crust along a geological fault and associated ground shaking.

El Niño
("Little child" in Spanish): Anomalous warming of ocean water resulting from the oscillation of current in the South Pacific, usually accompanied by heavy rainfall in the coastal region of Peru and Chile and reduction of rainfall in equatorial Africa and Australia.

Epidemic
Either an unusual increase in the number of cases of an infectious disease, which already exists in the region or population concerned, or the appearance of an infection previously absent from a region.

Estimated damage
The amount of damage to property, crops, and livestock. In EM-DAT, estimated damage is recorded in US$ ('000). For each disaster, the registered figure corresponds to the damage value at the moment of the event, i.e., the figures are shown true to the year of the event.

Explosions
Explosions involving buildings or structures. It can either involve industrial structures.

Extra-tropical storm
A type of low-pressure cyclonic system in middle and high latitudes (also called mid-latitude cyclone) that primarily gets its energy from the horizontal temperature contrasts (fronts) in the atmosphere. When associated with cold fronts, extratropical cyclones may be particularly damaging (e.g., the European winter/windstorm, Nor' easter).

Extreme winter conditions
Damage caused by snow and ice. Winter damage refers to damage to buildings, infrastructure, traffic (especially navigation) inflicted by snow and ice in the form of snow pressure, freezing rain, frozen waterways etc.

Famine
Catastrophic food shortage affecting large numbers of people due to climatic, environmental, and socio-economic reasons.

Flash flood
Rapid inland floods due to intense rainfall. A flash flood describes sudden flooding with short duration. In sloped terrain, the water flows rapidly with high destruction potential. In flat terrain, the rainwater cannot infiltrate into the ground or run off (due to the small slope) as quickly as it falls. Flash floods are typically associated with thunderstorms. A flash flood can occur at virtually any place.

Flood
A general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than-normal levels along the coast and in lakes or reservoirs (coastal flooding), as well as ponding of water at or near the point where the rain fell (flash floods).

Fog
Water droplets that are suspended in the air near the earth's surface. Fog is simply a cloud that is in contact with the ground.

Food shortage
Lack of alimentation bases.

Forest fire
A type of wildfire in a wooded area.

Geophysical disasters
Events originating from solid earth.

Geophysical hazard
A hazard originating from solid earth. This term is used interchangeably with the term geological hazard.

Glacial lake outburst
A flood that occurs when water dammed by a glacier or moraine is suddenly released. Glacial lakes can be at the front of the glacier (marginal lake) or below the ice sheet (subglacial lake).

Hail storm
Storm with hailstones as a dominant type of precipitation. The size of the hailstones can vary between pea size (6 mm) and softball size (112 mm), and therefore cause considerable damage.

Hazard
Threatening event, or probability of occurrence of a potentially damaging phenomenon, within a given time period and area.

Heatwave
A period of abnormally hot and/or unusually humid weather. Typically, a heatwave lasts two or more days. The exact temperature criteria for what constitutes a heatwave vary by location.

Homeless

Number of people whose houses were destroyed or heavily damaged and therefore need shelter after an event.

Hurricane
Large-scale closed circulation system in the atmosphere above the western Atlantic with low barometric pressure and strong winds that rotate clockwise in the southern hemisphere and counter-clockwise in the northern hemisphere. Maximum wind speed of 64 knots or more [See "cyclone" for the Indian Ocean and South Pacific and eastern Pacific and "typhoon" for the western Pacific].

Hydrological hazard
A hazard caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater.

Injured
People suffering from physical injuries, trauma, or an illness requiring immediate medical assistance as a direct result of a disaster.

Insured losses
Insured losses are those that are covered by the insurance sector and paid directly to the owner of the damaged or destroyed property or crops and livestock or the primary insurance company (in case of reinsurance).

Landslide
Any kind of moderate to rapid soil movement, including lahar, mudslide, or debris flow. A landslide is the movement of soil or rock controlled by gravity, and the speed of the

movement usually ranges between slow and rapid, but not very slow. It can be superficial or deep, but the materials have to make up a mass that is a portion of the slope or the slope itself. The movement has to be downward and outward with a free face.

Lightning
Hazards/losses caused by a lightning stroke. Lightning is an atmospheric discharge of electricity, which typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms.

Meteorological disasters
Events caused by short-lived/small to mesoscale atmospheric processes (in the spectrum from minutes to days).

Rain
Water vapour condenses in the atmosphere to form water droplets that fall to the earth.

Risk
Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability.

Sandstorm/Duststorm
A sandstorm/duststorm typically occurs in arid or semi-arid regions if high wind speeds cause the transportation of small particles like sand or fine clastic sediment by saltation and/or suspension (e.g., in deserts).

Scrub fire
Fires in scrub or bush that cause extensive damage. They may be sparked by natural causes such as volcanic eruptions or lightning, or they may be caused by arsonists or careless smokers, by those burning wood, or those clearing a forest area.

Shockwave
A shockwave carries energy from a disturbance through a medium (solid, liquid, or gas); it is similar to a wave, though it travels at a much higher speed. It can be a type of extraterrestrial hazard caused by an explosion (airburst) or the impact of meteorites, which can generate energy shockwaves capable of shattering glass, collapsing walls, etc.

Storm surge
An abnormal rise in sea level generated by a tropical cyclone or other intense storms.

Subsidence
Subsidence refers to the sinking of the ground due to groundwater removal, mining, dissolution of limestone (e.g,. karst, sinkholes), extraction of natural gas, and earthquakes.

Tornado
A violently rotating column of air that reaches the ground or open water (waterspout).

Total affected
In EM-DAT, it is the sum of the injured, affected, and homeless after a disaster.

Tropical storm
A tropical storm originates over tropical or subtropical waters. It is characterised by a warm-core, non-frontal synoptic-scale cyclone with a low-pressure centre, spiral rain bands, and strong winds. Depending on their location, tropical cyclones are referred to as hurricanes (Atlantic, Northeast Pacific), typhoons (Northwest Pacific), or cyclones (South Pacific and the Indian Ocean).

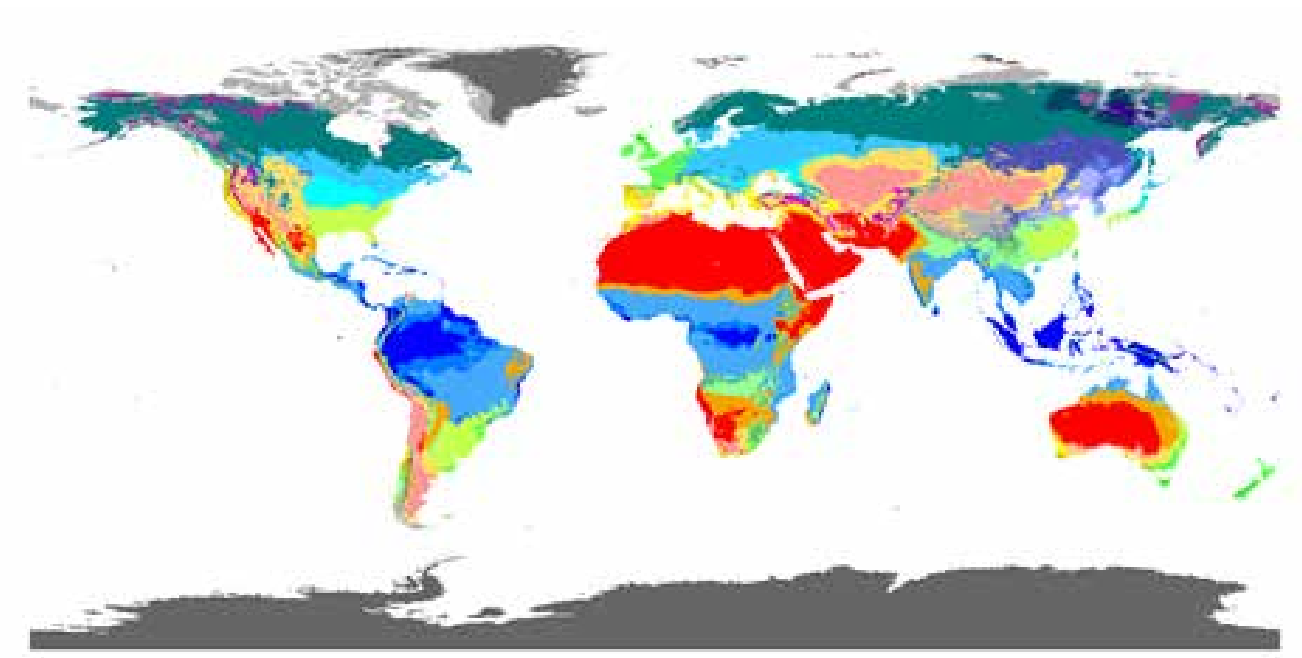
Tsunami
"Wave in the port" in Japanese; a series of waves (with long wavelengths when travelling across the deep ocean) that are generated by a displacement of massive amounts of water through underwater earthquakes, volcanic eruptions, or landslides. Tsunami waves travel at very high speed across the ocean, but as they begin to reach shallow water, they slow down and the wave grows steeper.

Typhoon
Large-scale closed circulation system in the atmosphere above the western Pacific with low barometric pressure and strong winds that rotate clockwise in the southern hemisphere and counter-clockwise in the northern hemisphere. Maximum wind speed of 64 knots or more [See "hurricane" for the western Atlantic and eastern Pacific and "cyclone" for the Indian Ocean and South Pacific].

Vulnerability
Degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon.

Annexure-II

Köppen-Geiger Climate Zone Classification



Source : Hykle et.al 2018

Numeric value	Colour	Köppen-Geiger classes	Class description	Subclass	
1		Af	Tropical	Rainforest	
2		Am		Monsoon	
3		Aw		Savannah	
4		Bwh	Arid	Desert	hot
5		Bwk			Cold
6		Bsh		Steppe	hot
7		Bsk			Cold
8		Csa	Temperate	Dry summer	Hot summer
9		Csb			Warm summer
10		Csc			Cold summer
11		Cwa		Dry winter	Hot summer
12		Cwb			Warm summer
13		Cwc			Cold summer
14		Cfa		No dry season	Hot summer
15		Cfb			Warm summer
16		Cfc			Cold summer
17		Dsa	Cold	Dry summer	Hot summer
18		Dsb			Warm summer
19		Dsc			Cold summer
20		Dsd			Very cold winter
21		Dwa		Dry winter	Hot summer
22		Dwb			Warm summer
23		Dwc			Cold summer
24		Dwd			Very cold winter
25		Dfa		No dry season	Hot summer
26		Dfb			Warm summer
27		Dfc			Cold summer
28		Dfd			Very cold winter
29		Et	Polar	Tundra	
30		Ef		Frost	

The risk-assessment process needs to include those affected by climatic shifts. The communities embody traditional resource management practices that can be harnessed at the community level with less financial implications.

Image: iStock

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