Environmental Science and Technology

CS9.428

Course Project

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Project Report submitted on the topic

Exploring Climate Change and Environmental Disasters in India

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Date Of Submission
18th November 2024

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1. Introduction:

1.1 Literature Survey:

1.1.1 India and Climate Change

Climate change is one of humanity's biggest issues at hand and extends to cross-generational limits and boundaries to having wider and more long-lasting effects. Its root cause pertains to the buildup of greenhouse gasses in the atmosphere. One very striking aspect of climate change is that of global warming, which signifies an exceptional rise in average temperatures of both the Earth's surface and the oceans over the past few decades.
Scientific evidence now shows that human activities since the mid-18th century have led to a dramatic increase in the concentration of key GHGs, namely carbon dioxide, methane, and nitrous oxide, all far exceeding pre-industrial levels.

Climate change is said to impact disadvantageous population groups in an even greater way since it exacerbates vulnerability to environmental hazards. Other peoples at the greatest risk are developing ones because they lack power as well as adaptive capacity, thus incapable of keeping pace with the challenges from high sea levels or recovering after the damage has been inflicted. This threatens sustainable development significantly.

1.1.2. Temperature

The surface air temperature of India warmed appreciably over the last hundred years, with a strong acceleration during the last few decades. Observational analysis depicts the mean annual warming of 0.15°C per decade between 1986 and 2015 with the largest warming rate being that of the pre-monsoon season (March to May). This global-scale change is also in agreement but also highlights regional variations within India associated with local climatic and geographical factors.

This warming has impacts that unevenly vary through seasons and regions. The temperatures have risen more steeply in Northern India compared to the southern peninsula, especially during the pre-monsoon and post-monsoon seasons. While the anomalies in temperature are higher, urban areas and semi-arid areas in the northwest have faced worse heatwaves and their corresponding health impacts. The frequency of cold days and nights has declined sharply during this period, reflecting the change in the dynamics of temperatures.

Projections include that this warming will continue, with mean temperatures likely to rise by 1.39–4.44°C by the end of the 21st century, depending on greenhouse gas emission scenarios. Such changes are expected to be more severe in northern and semi-arid regions, with an increase in frequency, intensity, and duration of heatwaves in the pre-monsoon season. These changes underpin the urgent need for climate adaptation focused on vulnerable regions and sectors.

1.1.3. Precipitation

The rainfall climate, economy, and means of livelihood of India have an important role to play because it depends mainly on the rain for most of its water resources as well as major agricultural activities. However, the occurrences of extreme rainfall events over the last decades have increased drastically, drastically disrupting it with effects in various sectors. Although these EREs are usually typical of the phenomenon that characterizes thunderstorms, cloudbursts, and monsoon depressions, the impact on society, the environment, and the economy cannot be overlooked. Indian subcontinent precipitation patterns experience variability in the spatio-temporal space induced by such factors as topography, atmospheric circulation, and climate change, which makes them a bit complicated to analyze and predict.

The monsoon season accounts for the lion's share of yearly rainfall over India from June to September. However, its distribution pattern is highly irregular; sometimes, a particular region may experience many decades of drought, while another would be experiencing flash floods. The analysis of the record of rainfall over the last 72 years by India's Meteorological Department reveals an increasing trend in the mean intensity of daily rainfall during EREs, especially in central and southern India. The events of 2018 Kerala floods are symptomatic of how such changes can lead to devastating effects, most of which usually involve regional climate change, land-use changes, and urbanization. High-resolution climate models indicate that global warming tends to enhance the convective feedback mechanisms and hence leads to more localized and intense rainfalls that increase the danger of flash floods and landslides.

The unique geographical features of the Himalayas and particularly of India's Himalayan region and the Western Ghats have considerable implications for rainfall dynamics, with the Himalayas often acting as a bar to atmospheric circulation and introducing scenarios conducive for heavy rainfall and cloudbursts, at times resulting in flash floods and landslides. Similarly, the Western Ghats are also prone to events of intense rainfall due to their steep topography. Although improvements in the prediction of meso-scale events in terms of numerical weather are significant for the more recent model generations of WRF, predicting the occurrence and intensity of such an event remains challenging. It is something that requires an interdisciplinary approach integrating high-resolution modeling capabilities, enhanced observation systems, and a better understanding of the interactions between natural variability and climate change.

1.1.4. Environmental Disasters in India

1.1.5. Floods

Introduction to Floods

Floods in India are periodic and disastrous, every year many parts of the country get affected by Floods. According to the National Disaster Management Authority (NDMA), over 40 Mha ha of land in India is prone to flooding. The

Ministry of Jal Shakti (MoJS) reported that the recent estimate on flood prone area in the country is 49.15 Mha, out of which Assam, Bihar, Odisha, Uttar Pradesh and West Bengal are largely affected. These floods have a severe impact on life, property, and infrastructure, to prevent and decrease the effects of Floods, it requires a combined effect from the government organizations, civil society, and individuals. The Indian government has taken measures to improve disaster management, early warning systems, and flood control infrastructure that include the construction of dams, embankments, and other flood control structures specifically to mitigate the impact of floods through different State & Central disaster management support organizations.

Fig[source]

Causes of Floods [Source]

1. **Natural Causes:**
   a. **Heavy Rainfall:** The primary cause of floods in India is heavy rainfall, especially during the **monsoon season** from June to September.
      i. **Intense and erratic rainfall** can exceed the soil's absorption capacity or overwhelm drainage systems, leading to floods.
   b. **Melting of Glaciers: Melting snow and glaciers** in mountainous regions due to rising temperatures can increase river and stream water levels, resulting in downstream flooding.
      i. For example: **Glacial lake outburst** flood killed around 14 in **Sikkim** more than hundred people were missing.
   c. **Cyclones and Storms: Cyclones and storms** can generate strong winds and heavy rainfall, particularly affecting coastal regions.

        i. For instance, **Cyclone Michaung** in December 2023 caused intense rain and flooding that killed around 13 people.
    d. **River Overflow:** Flooding can occur when a river's water level exceeds its capacity due to excessive inflow from upstream or diminished outflow downstream.
        i. In 2023, the **Yamuna River** overflowed due to heavy rains in Himachal Pradesh and Haryana, overwhelming the barrages in Delhi and causing flooding in several areas along the river.

2. **Man Made Causes:**
    a. **Unplanned & Rapid Urbanisation**: Unplanned urbanization and shooting up of slums on the outskirt of urban centers add to flood havoc in case of heavy rainfall.
        i. The **2020 floods in Hyderabad and Chennai in 2015,** thousands of houses were submerged, reminding of how rapid urbanization is making cities prone to urban floods.
        ii. Another fine example is Gurugram which has a persistent problem that haunts it every monsoon season – severe flooding.
    b. **Concretisation:** The **rapid concretisation** due to use of **asphalt and concrete** has increased impervious surfaces that do not absorb rainwater, leading to **increased surface runoff.**
        i. As a result, during heavy rainfall, water accumulates quickly, overwhelming drainage systems and contributing to localized flooding.
    c. **Encroachment of Water Resources**: Construction and **development activities in riverbeds and floodplains** can severely disrupt the natural flow of rivers and **encroachment of lakes and ponds.**

   i. For example, encroachment activities in lakes of urban centers like **Bhopal and Chennai** have increased flooding instances in these cities.

d. **Deforestation:Forests** play a crucial role in absorbing rainfall and facilitating ground water recharge.

   i. **Deforestation** leads to reduced soil's capacity to retain water, leading to **greater surface runoff** which carry excess water into rivers and streams, raising the risk of flooding.

e. **Dams and Barrages: Dams and barrages** are built to manage water flow and generate hydroelectric power, but heavy rain and poorly managed reservoirs can pose significant risks.

   i. For instance, alleged poor management of water in **Mullaperiyar dam** in **Tamilnadu and Kerala border** area caused floods in 2018.

f. **Unsustainable Mining Practices**: Mining operations can disrupt the landscape, leading to **soil erosion and sedimentation** in nearby rivers.

   i. This **sediment** accumulation reduces the carrying capacity of rivers, while **mining** activities can alter natural drainage patterns, increasing the risk of water accumulation.

g. **Climate Change**: Human activities that contribute to climate change are altering weather patterns worldwide. Increased temperatures can lead to more **intense and unpredictable rainfall,** raising the potential for flooding events.

h. **Poor Drainage Systems:** In many urban and rural areas, due to **siltation and clogging** by solid waste, drainage infrastructure is inadequate to handle heavy rainfall.

   i. **Poorly designed** or maintained drainage systems can cause significant flooding, even during moderate rain events.

ii. For Example: **Improper urban planning** and ineffective drainage solutions lead to **waterlogging** in cities like Delhi.

One of the major contributing factors to Floods in India is its Geography. The NRSC & ISRO's Flood Affected Area Atlas presents specific issues that floods pose in varied regions.

Overview-Areas Prone to Floods in INDIA[Source]

S. No.	State	No. of Districts Affected	Flood Affected Area (Ha)
1	Andhra Pradesh	24	738200
2	Arunachal Pradesh	5	3373
3	Assam	35	2464958
4	Bihar	38	3976861
5	Chhattisgarh	12	12029
6	Delhi	7	5848
7	Gujarat	16	517770
8	Haryana	9	67852
9	Jammu & Kashmir	10	43022
10	Jharkhand	2	2966
11	Karnataka	26	280156
12	Kerala	10	79377
13	Madhya Pradesh	30	210809
14	Maharashtra	20	233590
15	Manipur	9	88352
16	Meghalaya	2	8787
17	Odisha	23	1424313
18	Punjab	15	142692
19	Rajasthan	10	155144
20	Tamil Nadu	24	552010
21	Telangana	14	102318
22	Uttar Pradesh	72	2662942
23	Uttarakhand	2	7604
24	West Bengal	20	1969750
TOTAL		435	15750723

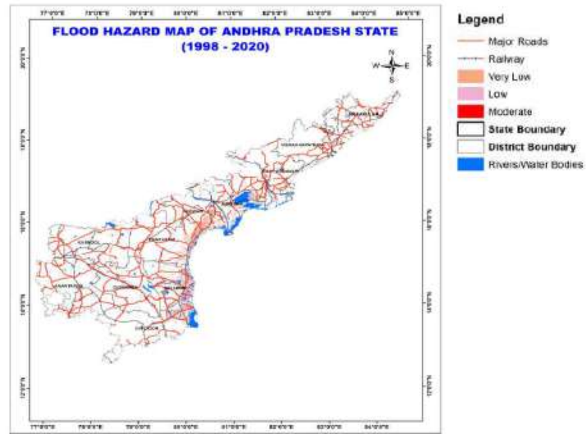
Flood affected area (Ha)	No. of Districts Affected
>2,00,000	12
1,50,000 -2,00,000	11
1,00,000 - 1,50,000	34
50,000 - 1,00,000	50
25,000 - 50,000	48
10,000 - 25,000	66
5,000 – 10,000	52
1,000 – 5,000	76
100 – 1,000	86
Total	435

The table shows that flooding significantly impacts various Indian states, with Uttar Pradesh, Bihar, and Assam experiencing the largest affected areas. A total of 435 districts are impacted, covering over 15 million hectares. While some states, like Uttar Pradesh, face extensive flooding across many districts, others, such as Arunachal Pradesh and Delhi, have smaller affected areas. The data highlights the widespread and varied severity of floods across India, reflecting both geographical vulnerabilities and the scale of flood events.

Analysis Of Majorly affected States [Source]

1. Andhra Pradesh

In Andhra Pradesh, floods primarily occur due to the over-flowage of rivers like Krishna and Godavari. For years, many major flood activities have been held in this state and nearly in every flood incidence, the coastal districts including East Godavari and West Godavari are the primary affected ones.



Floods in Andhra Pradesh are caused by cyclonic storms, heavy rains, and overflowing river water. Major regions that get affected are Godavari, Krishna, Vamsdhara, and Sabari. Flooding is very common during post-monsoon months, from October to December, mainly because of cyclones in Bay of Bengal. Major events include Cyclones Laila in the year 2010, Hudhud in the year 2014, and Titli in the year 2018. Due to Heavy rainfalls and the increasing water level, riverine floods such as the Krishna flood in 2009 and the Godavari flood in 2006 increased.

S. No	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 29th Jul -12th August 2005 , 19th - 22nd Sep 2005 due to rise in water levels in Tungabhadra, Krishna Rivers.	10
2	2006	Floods in Godavari & Sabari rivers during 5th – 18th Aug 2006	3
3	2007	Floods occurred during 4th June 2007 due to heavy rains as a result of depression in Bay of Bengal and also during 4th week of October 2007 due to heavy rains.	6
4	2008	Floods occurred during 7th -13th August, 18-19th Sep, 29th -30th Nov 2008 due to heavy rains	5
5	2009	Floods occurred during first week of 4-7th, October, 2009 due to heavy rainfall. Floods Heavy rains in the catchments of Krishna, Tungabhadra rivers during the first week of October 2009 affecting Kurnool town due to backwaters of the Srisailam dam and unprecedented inflows.	4
6	2010	The low pressure developed in the Bay of Bengal on 17th May, 2010 turned into a Cyclonic Storm called "Laila". ; and Floods occurred due to heavy rainfall during the 1stweek of September 2010, 1st week November 2010.	3
7	2012	Rains due to cyclone NILAM during first week of November 2012.	6
8	2013	Floods in last week of October due to heavy rains under the influence of low-pressure and north-east monsoon	4
9	2014	Cyclone HUDHUD made a landfall on 12thth October, 2014 on the coast of Andhra Pradesh, near city of Visakhapatnam	1
10	2015	Floods due to heavy rains	5
11	2018	Floods were reported due to heavy torrential rains during 2nd week of October, 2018 (12-13th Oct) under the influence of Cyclone Titli. Further due to impact Cyclone Phethai (21st Dec 2018)	4
12	2019	Floods were reported in due to heavy rains during August, 2019 due to rise in water levels in Godavari and Krishna Rivers.	4
13	2020	Floods were mapped in the state of Andhra Pradesh 4 times during August, October and in November 2020	8
14	2021	Heavy rains are reported 4th week of July, 4th week of September, Nov, 2021 due to multiple depressions formed in Bay of Bengal. The Coastal areas suffered due to the influence of Cyclones - Jawad, Gulab and Yaas.	
15	2022	Heavy rains are reported during 14th –28 July 2022, 12th Aug-28th Aug, 12-14th Sep 2022 and rise in water levels in Godavari and Sabari rivers.	7

AP experienced many Floods between 2005 and 2022. Amongst them, Sri Potti Sriramulu Nellore and Bapatla faced the worst experience so far. Most of the damages along the coast are caused by cyclone-induced floods, Visakhapatnam have been severely affected during events like Cyclone Hudhud.

2. Assam

Assam is facing the severe problem of flooding. This state has approximately. 78,000 sq. km of land, divided into two regions such as the Brahmaputra and Barak Valleys that are more prone to flooding. The world's largest river besides the Nile is the Brahmaputra River, which comes all the way from Tibet and has more than 30 tributaries, including such rivers as Subansiri, Manas, and Dhansiri, which swell in monsoon season. Deforestation, excess siltation, and lack of proper river bank maintenance increase the risk of floods through runoff and Heightened levels in the river. In 2002, there was disastrous flooding that took place from 8 July to 31 July at hundreds of villages in the state. Huge floods had occurred in Nowgong district in 2007, while in September 2012 floods touched several districts and caused severe structural damage.

3. Bihar

Bihar is known for floods, especially from the Kosi basin. Often called the "Sorrow of Bihar". The north Bihar plains are highly susceptible to flood, where the Kosi River caused immeasurable damage. Since the river emanates from the Nepal Himalayas and enters India as it passes through north Bihar, its confluence with the Ganga River causes significant flooding. The flood situation is further deteriorating in Bihar with major parts of this state land, 37.24% (35.06 lakh ha), under flood extent between 1998 and 2019. Flood hazard maps developed from satellite remote sensing data classify locations

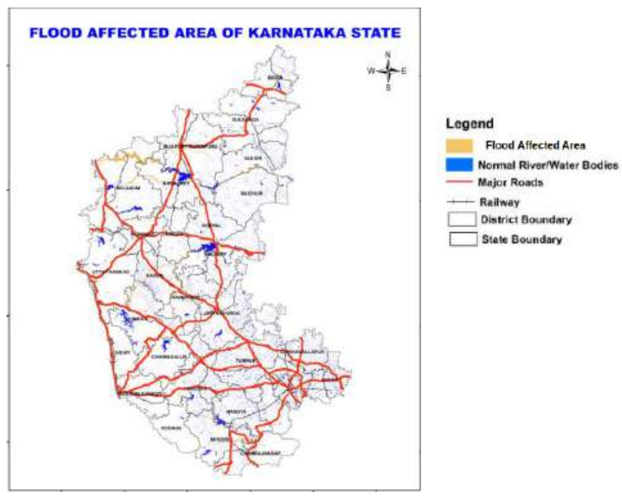
	Year	Description of the flood event	Districts affected
1	1998	Flood occurred with the new breaches in the embankments of rivers Gandak, Kosi and its tributaries during Jul-August , 1998	13
2	2003	Flood occurred in 3 spells during 30th June – 25th July , 05th – 28th August, 11th -21st August 2003	7
3	2004	Floods occurred during 22nd Jun – 31st July 2004 due to rise on water levels in rivers of Burhi Gandak, Bagmati, Adhwara, Gandak, Kamla Balan and Mahananda.	22
4	2005	Floods occurred during 21st July – 9th Sep 2005 due to heavy rainfall in Nepal Catchments due to which rise in water levels in Bagmati at Benibad, Ganga, Burhi Gandak, Bagmati, Adhwara Group, Kamala Balan, Kosi and Mahananda.	17
5	2006	Floods occurred in 3 spells during 10-15th Jun, 3-26th July, 13-15th Sep 2006 due to rise in water level in Ganga, Sone, Punpun, Bagmati, Burhi Gandak, Kamlabalan and Mahananda rivers.	39
6	2007	Floods occurred during 20-25th Jun, 10th -12th Oct due to rise in water levels in Burhi Gandak, Bagmati, Adhwara, Gandak, Kamla Balan and Mahananda rivers	36
7	2008	The breach in the eastern embankment of Kosi river near Kusaha village in Nepal on 18th August, 2008 led to extensive flooding in northern districts of Bihar	25
8	2009	Floods occurred during 29th July – 10th Oct 2009 due to rise in water levels in Kosi, Gandak, Budhi and Bagmati flooding after the Bagmati river breached its embankment.	
9	2010	Floods occurred during 29th July – 10th Oct 2009 due to rise in water levels in Kosi, Gandak, Budhi and Bagmati; The Saran embankment, under severe strain from the rising Gandak River, breached near Semaria in North Bihar's Gopalganj district	37
10	2011	Floods occurred during 2nd Jul – 9th Oct 2011 due to rise in water levels in Kosi, Mahananda, Gandak, Bodhi and Bagmati rivers.	18
11	2012	Floods occurred during 18th Jul – 25th Jul and 20th Sep -25th Sep rise in water levels in Kosi, Bagmati, Ghaghra rivers	38
12	2013	Floods occurred during 13th Jul – 11th Sep 2013 due to rise in water levels Kosi river at Basua in Supaul, Mahananda	37
13	2014	Floods occurred during 17-27th Aug 2014 due to rise in water levels in Kosi, Ghaghra, and Ganga	37
14	2016	Floods occurred during 27th Jul – 10th Sep due to rise in water levels Kosi, Ghaghra, and Ganga	36
15	2017	Floods occurred during Jul-Sep , 2018 due to rise in water levels Kosi, Ghaghra, and Ganga	38
16	2018	Floods occurred during 13th -30th August, 8-25th Sep 2018 due to rise in water levels in Mahananda, Bagmati and Kamalabalan rivers	38
17	2019	Floods occurred during 11th Jul -22nd Aug , 20th Sep – 11th Oct due to rise in water levels in Mahananda, Bagmati, Kamla Balan,River Adhwara,Burhi Gandak,Kosi and Gandak river levels.	34
18	2020	Floods occurred due to rise in water levels in Kosi, Bagmati, Gandak and Ganges rivers	39
19	2021	Floods occurred during 17th Jun -22nd Oct due to rise in water levels in River Gandak, Mahananda, Parman, Kamla, BurhiGandak, Kosi, Bagamati, Adhwara and Kamalabalan rivers.	35
20	2022	Floods occurred during 25th Jul – 20th Oct 2022 due to rise in water levels Ganga, Kosi, Adhwara group and Bagmati rivers.	33

that have either high frequency and low magnitude of floods or vice versa. The use of flood hazard zonation will help in risk demarcation and contribute in floodplain management, rescue planning, and promoting flood-tolerant crops.Major flood events also happened during the period 1998, 2003-2022 where many districts have been affected of which Purba Champaran, Madhubani, and Darbhanga suffered most. Cumulative flood inundation maps indicate an impact of 39.76 lakh ha; of those 21 districts have more than 100,000 ha affected.

4. Karnataka

Floods in Karnataka are caused mainly by the heavy monsoon rains, which then affect the coastal and northern regions. The most affected areas will be the Krishna and Bhima river overflows across the district, most prominently in Belagavi and Kalaburagi.

There have been major floods in 2005, 2009, 2013, 2019, 2020, and 2022. The heaviest rainfall was during August and September. Floods of this magnitude have badly affected districts like Belgaum, Shimoga, Bagalkot, and Davangere, which suffered badly in terms of infrastructure and agricultural damages. The total flood-affected area in Karnataka is estimated to be 280,156 hectares, with Belgaum at the top position, followed by Shimoga and Bagalkot.



5. Gujarat

Gujarat is one of the western states in India, with 1,600 km of coastal area, having a different climatic condition from very wet to arid. Like

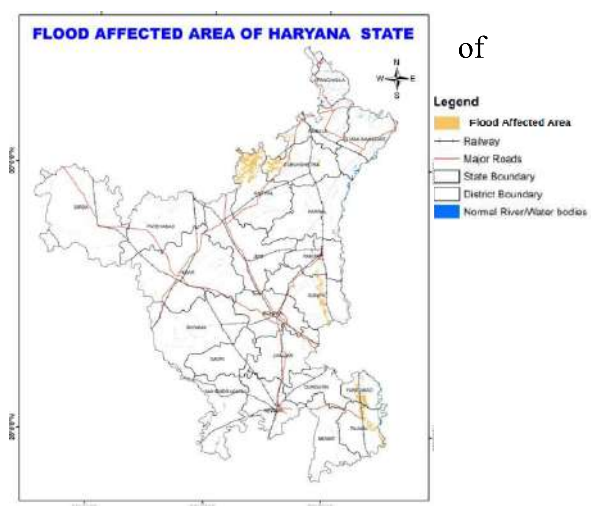
	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 2nd -11th July 2005 due to rise in water levels in Vishwamitri and Narmada rivers	11
2	2006	Floods occurred during 2nd -24th August 2006 due to heavy rains	7
3	2007	Floods occurred during 2nd week of July , 2nd week of Ag 2007 due to heavy rains	6
4	2008	Floods were reported in Gujarat in 3rd week September 2008 due to heavy rains	6
5	2009	Floods were reported in Gujarat in the last week of July 2009 due to heavy rains during 24-27th, Sep 2009 and also due to high tide scenario.	2
6	2013	Floods were reported in Gujarat in the last week of September 2013 due to sudden rise in the water levels of the Vishwamitri river	1
7	2017	Floods were reported due to heavy rains during 25-26th Jul 2017	4
8	2018	Floods were reported due to heavy rains during 1st week of August 2019 with many rivers in Central and South Gujarat flowing near danger mark.	6
9	2020	Heavy rains lashed Gujarat during 4th week of August 2020. According to reports inundation due to heavy rains was reported in Ahmedabad, Gandhinagar, Patan, and Sarkhej districts in Gujarat	4
10	2021	Heavy rains lashed Gujarat during 17-22nd May 21 under the influence of Cyclone Tauktae. It was an Extremely Severe Cyclonic storm and became the strongest tropical cyclone	9

several other states in India, Gujarat has its major rivers, Sabarmati, Narmada, Tapi, and Mahi, which cause floods almost every year due to heavy rain during the monsoon seasons.

Major flood events in Gujarat are recorded during the years 2005, 2006, 2007, 2020, and 2021. The total area flooded in the state is estimated at about 517,770 ha. However, Ahmedabad is the most affected district, accounting for an area of 233,388 ha, followed by Patan and Surendranagar. Flooding implies big damage to infrastructure, property, and agriculture; hence disaster management and flood mitigation are important.

6. Haryana

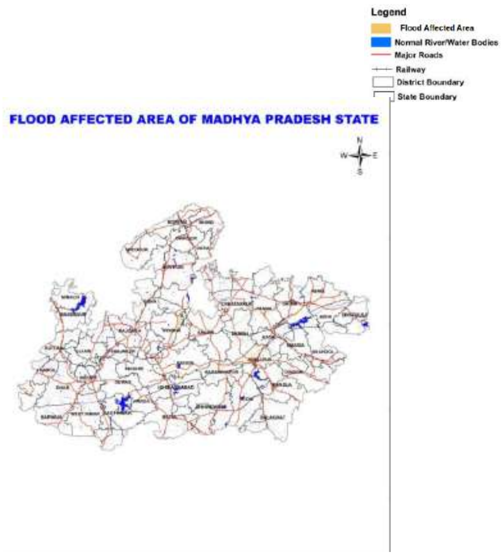
Haryana is in northern India with a minimal risk of major flooding through the state lacks large rivers. The topography of the state is quite low, creating some kind of depression basin especially around the Delhi-Rohtak-Hisar-Sirsa axis, thereby augmenting the possibility of more flooding during heavy rainfall conditions. The adjacent rivers mainly in Yamuna, Ghaggar, and Markanda influence the pattern of flooding in Haryana.



	Year	Description of the flood event	Districts affected
1	2004	Floods hit Haryana due to continuous rains during the 6th -09th August 2004.	4
2	2010	Floods hit Haryana due to continuous rains du ring 9-10th Jul, 4-9th Aug , 12-26th Sep 2010	12
3	2018	Floods were reported in the state of Haryana due to heavy torrential rains during last week of July, 2018 .	2
4	2019	Floods were reported in the state of Haryana due to incessant rains during third week of August, 2019.	5

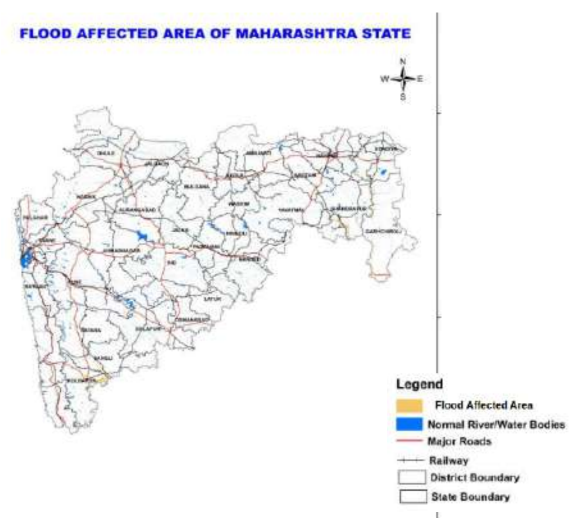
The causes of flooding include both natural and human-induced elements, such as improper drainage and barriers that inhibit the free flow of water. Huge floods have been witnessed in the past in 1977, 1980, 1988, 1995, 2004, and 2010. The total flood-inundated area for the entire state of Haryana is about 67,852 hectares, causing enormous damage to the states' essential agricultural areas and considerable losses in crops and cattle.

7. Madhya Pradesh



Madhya Pradesh is one of the most frequently flooded riverine areas and it is located in the central part of India. Depressions are moving very slowly, heavy unending rains, and that is the general cause of flooding in the region. It encompasses 3.6 % of the flood-prone regions of India. Significant floods have occurred between 2005 and 2022. Jabalpur, Vidisha, and Raisen districts were worst affected. The total area flooded in the state is approximately 2,10,809 hectares, and Jabalpur has accounted for the maximum flood-affected area of 35,696 hectares. Flooding in the state is mostly due to increased water levels of the important rivers Narmada, Betwa, and Chambal.

8. Maharashtra

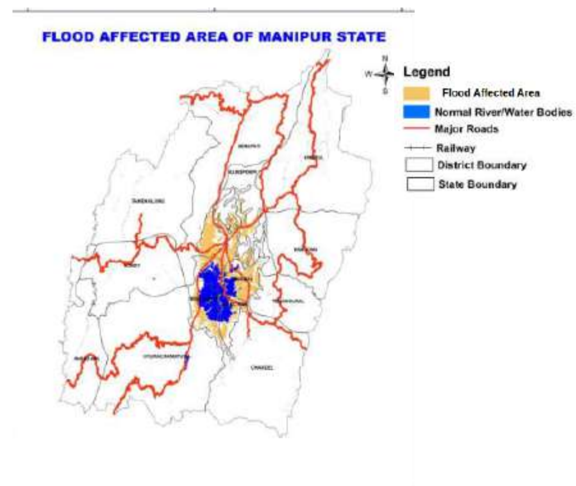


Flooding is quite common in the western Indian state of Maharashtra, primarily because of the very large river flows and annual monsoons. There are four big rivers that flow through this region: Godavari, Krishna, Bhima, and Tapi as well as 720 km of the state coastline on the Arabian Sea. So, both riverine and coastal floods occur in this area. Major flood events in recent times are: The 2005 Mumbai floods, floods of Wainganga and Wardha rivers in the year 2013, and every year urban flooding at Mumbai, Krishna and Godavari rivers

	Year	Description of the flood event	Districts affected
1	2005	Floods occurred during 29th Jul -5th August and 17th Sep 2005 due to heavy rains	5
2	2006	Many low-lying areas in parts of Maharashtra's Vidarbha region were inundated due to rains during 10-13th Aug 2006	4
3	2013	Floods were reported in Maharashtra state during last week of July, 2013	9
4	2016	Floods were reported in first week of August in the state of Maharashtra due to heavy torrential rains during 1st week of 2016	4
5	2019	Floods were reported in first week of August in the state of Maharashtra due to heavy torrential rains during 6-15th Aug 2018	6
6	2020	Heavy incessant rains lashed Maharashtra during the third week of August, 2020.	3
7	2022	Heavy incessant rains were reported in various parts of Maharashtra in July & August 2022.	8

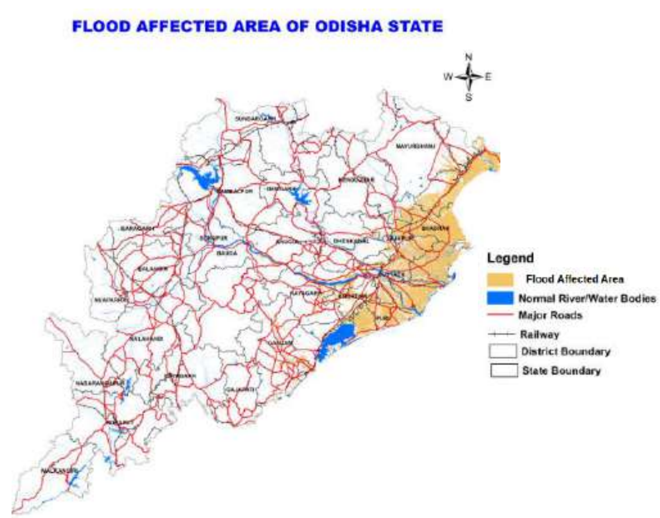
causing tremendous flooding in 2019 and 2020 after heavy rainfalls. Total flood-affected area in Maharashtra is approximately 2,33,590 ha. Major affected area is Chandrapur with 54,009 ha. Other affected areas are Kolhapur with 46,304 ha, Gadchiroli with 38,847 ha, and Bhandara with 16,915 ha.

9. Manipur



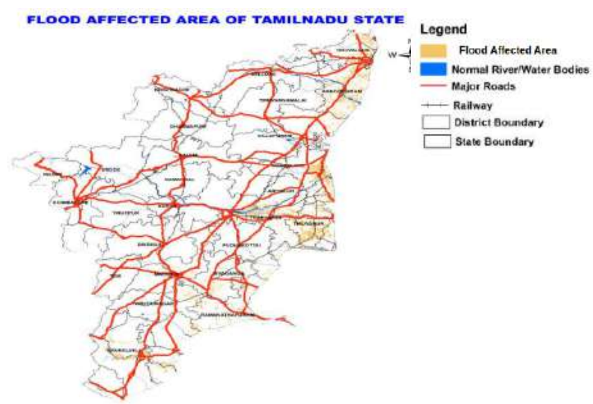
Floods generally take place in Imphal Valley and other low lands of Manipur. It is also flanked by a sequence of undulating hills along the central valley, making the state glaring for topographic diversity. The prominent rivers of Manipur, amongst them are Barak, Imphal, Iril, Thoubal, and Chindwin have been sources of irrigation, hydroelectric power, as well as drinking water. However, the rivers both in the hill and the valley create perennial floods all the monsoon months. The longest river in the state is the Barak River, which merges with the Meghna in Bangladesh. When its tributaries, such as the Imphal River, and most notably the Iril and Thoubal, overflow the central plains, this amplifies the risk of floods and influences agriculture, infrastructure, and living conditions in the state. Other contributing factors include waterlogging in other areas as part of the flooding condition of the Loktak Lake-the biggest freshwater lake in the region.

10. Odisha



The state of Odisha experiences heavy flooding throughout the year, with frequent intense floods during the monsoon season mainly due to intensive precipitation focused over a period of three months that causes flash floods as well as poor water discharge. There are three main rivers that cause floods: Mahanadi, Brahmani and Baitarani rivers that are braided inside a common delta and aggravated by high tides and siltation. Cyclones like Phailin also cause floods in the state. The State has experienced many ravaging floods and cyclones in the past several decades, affecting almost every district and boasting extensive crop, infrastructure, and human losses, with flood-affected areas crossing 14.24 lakh hectares.

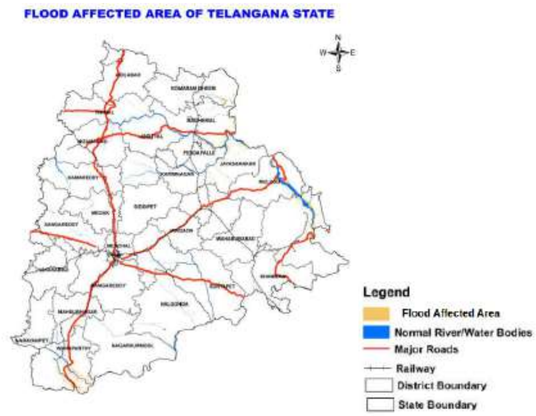
11. Tamil Nadu



Tamil Nadu in south India particularly faces the problem. Its geographical status and monsoon patterns have placed the state in an exposed position against the problem. Most of the major rivers run through the state-the Kaveri, Bhavani, and Vaigai-all increasing the risk of flooding during monsoons. The 2015 flood in Tamil Nadu was a major disaster due to northeast monsoons that brought heavy rains upon the city of Chennai. The cyclone Nivar, that hit the state in 2020 also gave an aggravating blow to the vulnerability as these lashed torrential rains and resulted in devastating damage across the state. In the state, repeated flood events have been seen in 2007, 2008, 2009, and 2010, frequently connected to low-pressure systems and cyclonic activities in Bay of Bengal. Cumulative flood-affected area in Tamil Nadu stands at 5,52,010 hectares.

S.No	Year	Description of the flood event	Districts affected
1	2007	Floods were reported in Tamilnadu due to heavy rains, resulted from a low pressure in Bay of Bengal in the third week of December, 2007.	4
2	2008	Heavy rains lashed different parts of Tamilnadu due to the influence of a depression in Bay of Bengal and the cyclonic storm.	1
3	2009	Heavy monsoon rains lashed Tamilnadu during 2nd Week of November 2009.	1
4	2010	Floods occurred due to heavy rains	10
5	2012	Flood-like situation prevailed in majority of the coastal districts in Tamilnadu by first week of November 2012.	3
6	2020	Tamilnadu Floods& Cyclones (Cyclone NIVAR and BUREVI)	11

12. Telangana

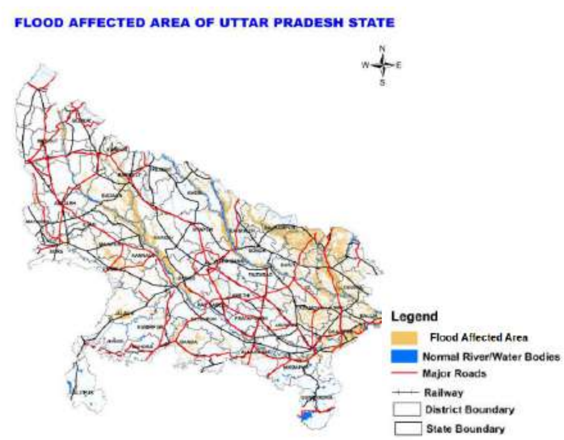


Telangana State is situated on the Deccan Plateau and has been flood-prone for decades, primarily because of excess monsoons and major rivers flowing from outside, Godavari and Krishna. Several floods devastated the state of Telangana, including recent ones, such as the Hyderabad floods in 2020 and Godavari floods in 2022. The Hyderabad Flood was due to the heavy rain after a deep depression passed over parts of the city. Several districts are currently being affected by floods in the Godavari river- Bhadradri Kothagudem, Mulugu, and Mancherial. As estimated 1,02,318 hectares of area is affected by flood in Telangana and Bhadradri Kothagudem, Mulugu and Mancherial are the worst-affected districts.

	Year	Description of the flood event	Districts affected
1	2006	Floods occurred during 5th -8th July, 5th – 18th Aug 2006 due to rise in water in Godavari River.	1
2	2010	Floods were reported due to heavy rains during 7-10th July 2010	3
3	2012	During fourth week of August 2012, heavy rains lashed Telangana. Flood alerts were issued for Godavari and Sabari rivers.	1
4	2013	Floods occurred due to rise in water level in Godavari during 20-26th Jul, 2-6th, oct 2013	2
5	2020	Floods were reported in Parts of Telangana state during the third week of August, 2020 under the influence of heavy incessant rains. River Godavari and its tributaries were reported to be flowing in severe flood situation	7
6	2022	Heavy rains were reported in Telangana during 2nd week of July 2022. Godavari river and its tributaries were flowing above the danger level at many places in Telangana State, and the villages adjacent to the Godavari river were inundated by floods. Satellite data was analyzed from 14 – 27th July 2022	6

Continuous floods occur mainly due to the Godavari and its tributaries which swell considerably during monsoons.

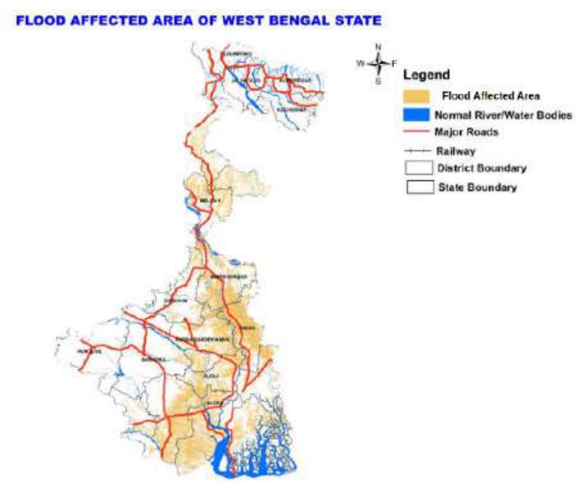
13. Uttar Pradesh



Uttar Pradesh is a part of the Indo-Gangetic plain and, due to the enormous river system there, the area always experiences periodic floods. Flooding in rivers Ganga, Yamuna, Ghaghra, Gomti, and Rapti rightly explain flood incidents, particularly in the eastern region of the state. This vast flat plain area tends to cause overflow and congestion in drainage owing to heavier rainfall during June to September, and the urban and rural premises within this region also contribute to the cause. Flood-prone districts account for

24% of the total flood-affected area and 23% of total flood damages in India. Important districts are Siddharth Nagar, Gorakhpur, and Maharajganj subjected to very regular flood events due to high river levels. During this period, important floods occurred during the years 2003, 2005, 2007, 2008, 2010, and 2020 where massive losses occurred for the infrastructure of croplands and in loss of lives.

14. West Bengal



West Bengal is very prone to floods, particularly in the Sundarbans and districts of Murshidabad and Howrah. The complicated river system the region has-hanging valleys like Hooghly and Damodar-most times cause floods across the locality during monsoons. West Bengal is susceptible to floods due to its diversified geography and major rivers such as Ganges, Hooghly, and Damodar. Some of the very widespread flood occurrences are those of the years 2003, 2004, 2019, and 2020 since a total area of 1,969,750 hectares came under its effect. Main Causes are **Excessive Monsoon Rainfall**, **Geographic Configuration**.

Impacts Of Floods in India [Source]

- **Loss of Life:**
    - Floods cause deaths because of drowning, injuries, infections, or electrocution. According to **the National Disaster Management Authority(NDMA),** floods are one of the most frequent and deadly natural disasters in India.
    - Every year on average 1,600 lives are lost due to floods.
    - Only half past 2023, **at least 60 deaths have been confirmed** due to floods across North India, though the actual toll may be higher.
- **Damage to Property:**

- Floods damage or destroy houses, buildings, roads, bridges, railways, power lines, communication networks, and other infrastructure.
- Floods can also damage or wash away crops, livestock, vehicles, and other assets.
- According to the NDMA, floods affect about **75 lakh hectares** of land and inflict damage worth **Rs 1,805 crore to crops,** houses and public utilities every year in India.
- In 2023, floods caused extensive damage to several landmarks in Delhi, such as the **Red Fort and the Supreme Court.**

- **Displacement of People:**
  - According to the **Internal Displacement Monitoring Centre**, floods displaced about **5.4 million people** in India in 2020.
  - In 2023, floods displaced **thousands of people in North India,** especially in Himachal Pradesh and Punjab.
  - Foods force people to leave their homes and seek shelter in safer places. This disrupts their normal lives and livelihoods.

Environmental Degradation:

- Floods can have negative impacts on the environment by eroding the soil, altering the natural habitats of **flora and fauna, polluting the water sources, and increasing the risk of landslides and epidemics.**
- Floods can also affect the ecological balance of rivers and wetlands by changing their hydrology and biodiversity.
- For example, floods **can threaten the survival of endangered** species such as the **Gangetic dolphin** and the **gharial** in the Yamuna River.

- **Economic Losses**:
  - Floods can affect the economic growth and development of India by reducing the **agricultural output, disrupting the industrial**

production, affecting the trade and commerce, and increasing the expenditure on relief and rehabilitation.

- Floods **can also affect the tourism sector** by damaging the cultural heritage and natural attractions. According to a study by the World Bank, floods cost India about **$14 billion** annually in direct losses.

Mitigation and Preparedness [Source]

Structural Measures

- **The InterLinking of Rivers programme (ILR) programme:**
  - It is aimed at linking different **surplus rivers** of the country with deficient rivers so that the excess water from surplus regions could be diverted to deficient regions.
  - **For instance: Ken-Betwa linking project** is the flagship project of the national government and is crucial for the **water security and socio-economic developmen**t of **Bundelkhand region.**
- **Reservoirs:**
  - **Storage reservoirs** are artificial structures designed to store excess water during high-flow periods and release it during low-flow periods.
  - They moderate flood peaks by reducing water volume and velocity downstream; conserves water for irrigation, power generation, and supply.
  - **Example**: **Bhakra Nangal Dam** on the **Sutlej River** has a storage capacity of about 9621 Million Cubic Meter (MCM), aiding in flood control, power generation, and irrigation.
- **Managing Coastal Flood:**
  - The 2004 Tsunami made people realize that mangroves can serve as a reliable safety hedge against **coastal calamities l**ike storm surge and coastal flooding.

- **MISHTI Initiative** for mangroves plantation was launched in the Union Budget 2023-24.

- **Embankments:**
  - **Embankments** are raised structures that confine water flow within channels or along riverbanks.
  - They protect adjacent areas from flooding; increase river carrying capacity; divert excess water; provide access roads and recreational areas.
- **Diversions:**
  - **Diversions** are structures that redirect water flow from one channel to another and they reduce flooding by transferring excess water to less vulnerable areas or reservoirs; providing irrigation or drinking water to other regions.
  - **Example: Indira Gandhi Canal project** diverts water from **Sutlej and Beas rivers t**o the **Thar desert** in Rajasthan for irrigation and drinking.

Non-structural Measures:

- **Flood Forecasting and Early Warning:** Systems that provide early estimates of approaching floods using meteorological and hydrological data.
  - They **facilitate timely evacuation of people and assets;** assists in reservoir management and flood relief coordination.
  - **Example**: **Central Water Commission (CWC)** operates a network of forecasting stations that issue daily flood alerts.
- **Flood Plain Zoning:** It is regulatory measures that control land use in flood-prone areas based on vulnerability and promotes conservation of natural flood buffers like wetlands and forests.
  - **Example: National Disaster Management Authority (NDMA)** guidelines classify flood-prone land into four zones: prohibited, restricted, regulated, and free.

- **Flood Insurance**: It is in the form of financial compensation for flood-related losses to individuals or groups who pay a premium which may reduce government relief burdens; encourages risk reduction measures; creates a database for flood risk assessment.
    - **Example**: **Pradhan Mantri Fasal Bima Yojana (PMFBY)** provides crop insurance for losses due to floods and other calamities.
- **Flood Awareness:** Flood **awareness** and **education** initiatives to raise awareness preparedness and response capabilities; fosters a culture of safety and resilience among communities.
    - **Example: NDMA** conducts awareness campaigns and training programs focused on flood management in India.

1.1.6. Cyclones

Introduction to Cyclones

A cyclone is a highly intense, low-pressure system that forms over warm ocean waters. They are characterized by strong winds, heavy rainfall, and a storm surge. The majority of cyclones affect India mainly in the form of a tropical cyclone, forming over the Indian Ocean region.

Causes of Cyclones:[source]

Major factors include:

- A fall in the atmospheric pressure over the sea surface
- Effect of the wind
- Influence of the sea bed
- A funneling effect
- The angle and speed at which the storm approaches the coast
- The tides

How Cyclones are formed:[source]

The development cycle of tropical cyclones may be divided into three stages:

Formation and Initial Development Stage:
The formation and initial development of a cyclonic storm depends upon various conditions. These are:

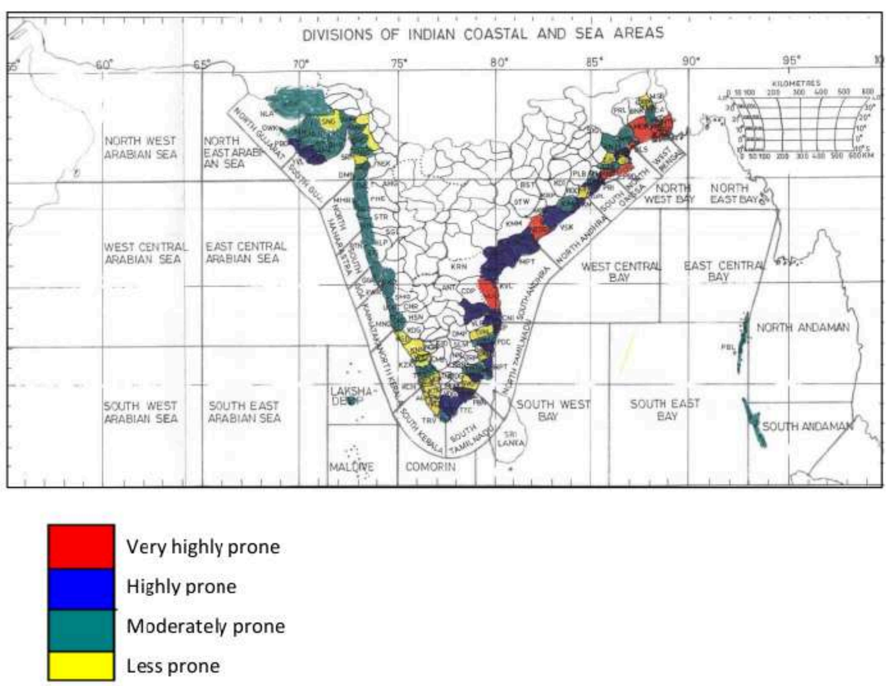
- A warm sea (a temperature in excess of 26 degrees Celsius to a depth of 60 m) with abundant and turbulent transfer of water vapor to the overlying atmosphere by evaporation.
- Atmospheric instability encourages formation of massive vertical cumulus clouds due to convection with condensation of rising air above the ocean surface.

Mature Tropical Cyclones:
When a tropical storm intensifies, the air rises in vigorous thunderstorms and tends to spread out horizontally at the tropopause level. Once air spreads out, a positive perturbation pressure at high levels is produced, which accelerates the downward motion of air due to convection. With the inducement of subsidence, air warms up by compression and a warm 'Eye' is generated. Generally, the 'Eye' of the storms has three basic shapes: *(i)* circular; *(ii)* concentric; and *(iii)* elliptical. The main physical feature of a mature tropical cyclone in the Indian Ocean is a concentric pattern of highly turbulent giant cumulus thundercloud bands.

Modification and Decay:
A tropical cyclone begins to weaken in terms of its central low pressure, internal warmth and extremely high speeds, as soon as its source of warm moist air begins to ebb, or is abruptly cut off. This happens after its landfall or when it passes over cold waters. The weakening of a cyclone does not mean that the danger to life and property is over.

Frequency and Distribution

On average, five to six cyclonic disturbances occur per year in the North Indian Ocean, encompassing the Bay of Bengal and Arabian Sea. The Bay of Bengal along India's eastern coast is the most dominant area forming most of the cyclones. More cyclones occur along the east coast than on the west coast, which is the Arabian Sea.The east coast, lying over the Bay of Bengal, is highly exposed to cyclones; Odisha, West Bengal, Andhra Pradesh, and Tamil Nadu fall in this category. It has some less intense but still categorized as a severe cyclone along the west coast, which lies over the Arabian Sea, states like Gujarat and Maharashtra come in this category.



[fig-1]

The India Meteorological Department (IMD) has played a critical role in tracking and predicting cyclones since the late 19th century. IMD's data, coupled with satellite observations (INSAT), radar, and Doppler weather technology, has improved the prediction of cyclone landfalls and their severity[1]. According to reports from the National Disaster Management Authority, the number of cyclones that have entered the Indian shores in the recent past has significantly increased, mainly due to climate warming and increased sea-surface temperatures[2].

Most recent studies indicate that the impacts of global warming, including warming seas and altered patterns of weather, supercharge cyclones, as observed in these examples: Phailin (2013), Hudhud (2014), and Amphan (2020), which caused widespread destruction and were categorized as a super cyclonic storm, one of the most powerful storms in the Bay of Bengal over the last decade[3]. A series of studies sought to draw attention to the fact that, in the future, storm surges combined with sea level rise would pose the biggest threat to densely populated coastal regions of India.

Classification of cyclones by IMD based on wind speed:[source]

- Low pressure(L): Less than 31 km/h
- Depression (D):31-49 km/h
- Deep Depression(DD): 50-61 km/h
- Cyclonic Storm (CS): 62-88 km/h
- Severe Cyclonic Storm (SCS): 89-118 km/h
- Very Severe Cyclonic Storm (VSCS): 119-221 km/h
- Super Cyclonic Storm (Sup. CS): 222+ km/h

Most Vulnerable States and Districts :[source]

Important states where cyclones are likely to strike include Odisha ,Andhra Pradesh ,Tamil Nadu and West Bengal also on the eastern coast, and Gujarat on the western coast. The report by IMD has pinpointed some districts that have been labeled the most susceptible to cyclones. Among them are Balasore, Jagatsinghpur, and Kendrapara of Odisha; Nellore and East Godavari in Andhra Pradesh; South 24 Parganas and Medinipur in West Bengal.

These areas are classified as high-risk on factors such as the frequency of incidence in cyclones, historical impacts that occurred, and geographical features that make them prone to both storm surges and strong winds.

Economic and Social Impacts:[source]

- **Loss of Human Life and Property**: Thousands are affected every year due to the extreme nature of cyclones in recent times. Infrastructure like buildings, houses, roads, and communication lines get destroyed and have to be rebuilt and recovered with a loss of millions of rupees.
- **Agricultural Sector and Livelihoods**: Agricultural activity mainly happens along the coastal districts in Odisha and Andhra Pradesh. All these activities are lost during a cyclone. Crop losses mean there will be shortages of food items, and agricultural incomes will be lost for farmers. For instance, the cyclones even disturb fishing communities near the coasts because the destructive storms destroy boats, nets, and other related infrastructures that form the basics for their source of living.

Preparedness and Mitigation Efforts:[source]

- **Early Warning Systems:** The IMD along with National Disaster Management Authority have used Doppler radar and satellite imaging to detect cyclones and provide advance warning. This enhanced cyclone forecast has allowed the authorities to issue evacuation warnings in time and thus saved lives.
- **Evacuation and Cyclone Shelters:** Setting up cyclone shelters in the vulnerable areas on India's east coast would provide safe shelter during storms. For instance, evacuations and cyclone shelters were effective in the case of Cyclone Amphan, drastically reducing the number of fatalities compared to the massive 1999 Orissa Super Cyclone, which had left thousands dead.
- **Infrastructure Resilience:** Apart from a better coastal infrastructure - storm-resistant housing, embankments, and elevated roads-vast reductions

in the effects of cyclones can be seen in affected regions. It is evident that the Government is assigning more and more importance to building infrastructure resilient to climate change, which may be further developed resilient to cyclones so as to speed up the recovery.

1.1.7. Earthquakes

Introduction to Earthquakes

An earthquake is the sudden shaking of the ground caused by a rapid release of stored elastic energy in the Earth's crust. This energy accumulates over time along faults as strain and is released as seismic waves when the strain exceeds the rock's breaking point. These seismic waves ripple outward from the point of origin (the epicenter) like water waves, traveling through the Earth's surface. The speed and intensity of these waves depend on the geological composition of the region.

The only part of the released energy that we directly experience is the wave energy, which causes the ground shaking felt by people and recorded by seismic instruments worldwide. Earthquakes are primarily caused by tectonic movements, volcanic activity, and, increasingly, human activities.

Table 1. Top ten Indian earthquakes

Date	*Earthquake*	*Magnitude*	*Deaths in India*
16 Jun 1819	Kuchchh	8	1,500
12 Jun 1897	Shillong Plateau	8.7	1,500
04 Apr 1905	Kangra	8	19,000
15 Jan 1934	Nepal-Bihar	8.3	11,000
26 Jun 1941	Andaman	8.1	Thousands
15 Aug 1950	Assam	8.6	1,530
21 Aug 1988	Nepal-Bihar	6.6	1,004
30 Sep 1993	Killari	6.2	7,928
26 Jan 2001	Bhuj	~~7.7~~	13,805
26 Dec 2004	Sumatra-Andaman	9.2	10,749
08 Oct 2005	Kashmir	7.4	1,308

Causes of Earthquakes

1. **Tectonic Movements**: According to the theory of plate tectonics, the Earth's lithosphere (consisting of the crust and upper mantle) is divided into several plates that move continuously. The interaction between these plates, primarily at their boundaries, leads to earthquakes. These interactions include:
    - **Divergent Boundaries**: Plates move apart.
    - **Convergent Boundaries**: Plates collide or move toward each other.
    - **Transform Boundaries**: Plates slide past each other.

    The Indian plate, moving northeast at about 5 cm/year, collides with the Eurasian plate, forming the Himalayan mountain range and the Tibetan plateau. This tectonic activity is responsible for significant seismic events in the region, including the devastating Himalayan earthquakes.

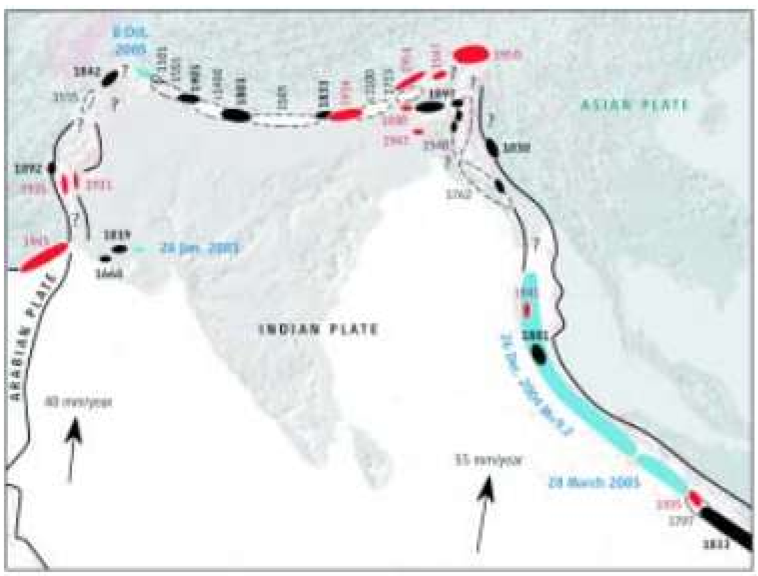


Fig. 2 Great and major earthquakes in the Indian subcontinent (Bilham, 2006). Question marks show the region where either the earthquakes have not occurred in past 200 years or there are no data to support or reject the occurrence of earthquakes.

2. **Volcanic Activity**: Earthquakes can also accompany volcanic eruptions when magma rises through cracks in the Earth's crust, causing stress and

fracturing. These earthquakes, often smaller in magnitude, can still cause significant damage in volcanic regions.

3. **Human-Induced Earthquakes**: In recent years, human activities such as mining, reservoir-induced seismicity (due to dam construction), and oil extraction have triggered minor earthquakes. These activities disturb the balance of forces in the Earth's crust, leading to seismic events.

Types of Seismic Waves

- **Primary Waves (P-waves)**: The fastest seismic waves, compressing and expanding the ground in the direction of wave propagation.
- **Secondary Waves (S-waves)**: These slower waves move the ground perpendicular to the direction of wave propagation, causing more pronounced shaking.
- **Surface Waves**: Traveling along the Earth's surface, these waves cause the most destruction due to their large amplitude and prolonged shaking.

Magnitude and Intensity

- **Magnitude**: Measured using the Richter scale, magnitude quantifies the energy released by an earthquake. While small earthquakes below magnitude 3.0 are often imperceptible, those above magnitude 7.0 can cause widespread damage.
- **Intensity**: The Modified Mercalli Intensity (MMI) scale measures the observed effects of an earthquake, including the destruction of buildings and the subjective experiences of people.

Earthquake Hazard Zones in India

India's seismic activity is largely influenced by its proximity to the collision zone between the Indian and Eurasian tectonic plates. This has led to frequent and severe earthquakes, particularly in the northern and northeastern parts of the country. The key regions of seismic activity include:

1. **Himalayan Region**: The convergence of the Indian and Eurasian plates leads to underthrusting, which causes strain to accumulate over time. This strain is released during infrequent, but devastating, earthquakes. Historical events include the 1897 Shillong Plateau earthquake and several large-magnitude Himalayan earthquakes over the last century.

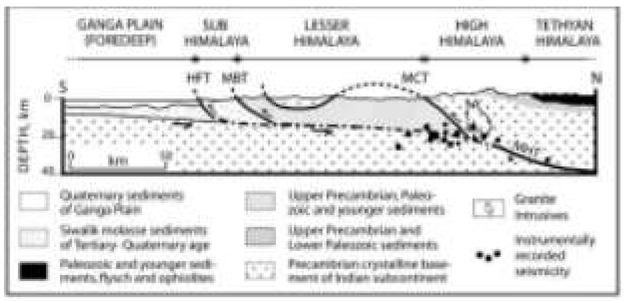


Fig. 3 Generalized north-south section across the Himalaya for the central portion of the Himalayan arc (Seeber and Armbruster, 1981). Figure after Kumar et al. (2006).

2. **Indo-Gangetic Plains**: Although far from the plate boundaries, this region experiences seismic activity due to fault lines running through the plains.
3. **Western India (Gujarat)**: The 2001 Bhuj earthquake (magnitude 7.7) was one of the deadliest in recent history, causing extensive damage and loss of life. This region remains vulnerable to intraplate earthquakes.
4. **Andaman Region**: The 2004 Sumatra-Andaman earthquake (magnitude 9.1) triggered a massive tsunami that devastated coastal regions across the Indian Ocean, including India. This event highlighted the importance of preparedness for underwater earthquakes and tsunamis.

Impacts of Earthquakes

1. **Structural Damage**: Buildings, bridges, and infrastructure not built to withstand seismic forces can collapse during an earthquake. The extent of damage depends on construction quality and the proximity to the epicenter.

2. **Tsunamis**: Underwater earthquakes can generate tsunamis, leading to widespread coastal devastation. The 2004 Indian Ocean tsunami is an example of how seismic events can have catastrophic secondary effects.
3. **Soil Liquefaction**: In water-saturated soils, the intense shaking caused by an earthquake can cause the ground to behave like a liquid. This phenomenon can lead to the sinking or collapse of buildings and infrastructure.
4. **Loss of Life**: Earthquakes are often accompanied by significant loss of life due to building collapses, landslides, and secondary disasters such as fires. Preparedness and the time of day an earthquake strikes greatly affect casualty numbers.

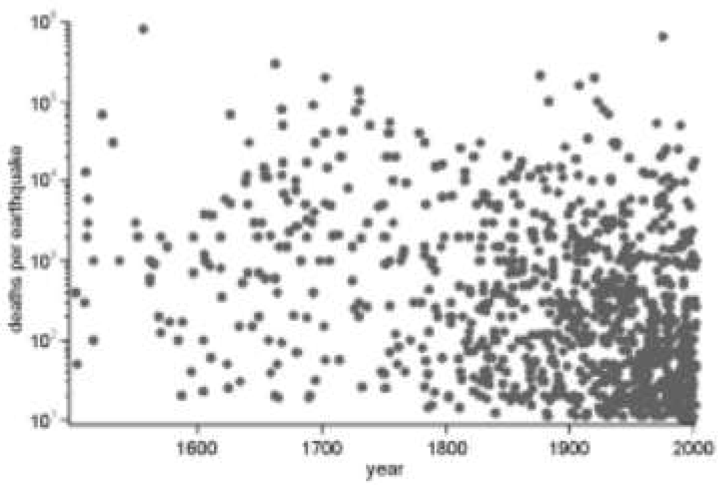


Fig. 1 Global earthquake fatalities since sixteenth century (Bilham, 2004).

Case Studies of Major Indian Earthquakes

1897 Shillong Plateau Earthquake:

- **Magnitude and Location**: Occurred on June 12, 1897, with a magnitude of **8.0** on the Richter scale. The epicenter was located at 25.7°N and 91.1°E, in the Shillong Plateau, northeastern India. It was one of the most significant recorded earthquakes in the area.

- **Impact**: This earthquake caused severe damage due to **liquefaction** of the ground, resulting in destruction across the region. The main shock occurred at **5:15 PM** and was recorded globally. The event triggered widespread aftershocks, which added to the devastation. Liquefaction caused sinking of buildings, cracking of the earth, and other geological disturbances. Its effects reached the plains of the **Brahmaputra River**.
- **Documentation and Analysis**: The event was documented in Europe, and no exact number of casualties is available. However, the scale of destruction was immense. Its intensity caused land deformation and large-scale property damage, leaving a lasting impact on the Shillong Plateau region. The aftershocks and the earthquake's legacy are comparable to other large seismic events in the region.
- **Geological Evidence**: The region most affected was **Shillong Plateau** and its northern extension, running west-east for about **300 km**. The earthquake provided crucial geological evidence for the presence of a **shallow-dipping detachment fault**. Geological studies later confirmed that the earthquake was related to tectonic forces beneath the Shillong Plateau, with a rupture extending more than **200-400 km**

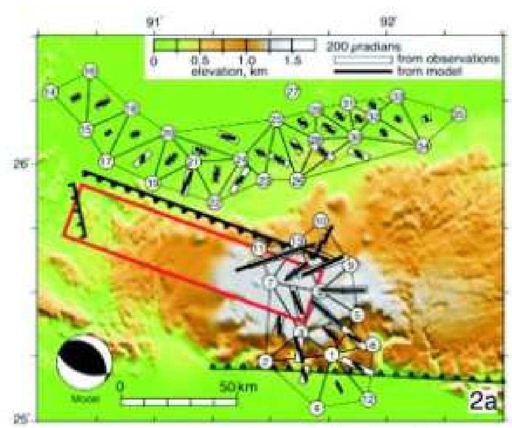


Fig. 4 Trigonometrical stations remeasured on and north of the Shillong Plateau following the 1897 earthquake. White rectangles are calculated from the triangulation observations, and black bars show the strains calculated for the best-fitting planar dislocation. Red rectangle indicates subsurface location of this SW dipping dislocation; thick black line with teeth shows the surface intersection of the continuation of this plane to the land surface (slip terminated 9 km below the surface). Short black line at western edge of fault plane indicates location of Chedrang fault. Line with open teeth to south of the Plateau shows location of the Dauki fault (Bilham and England, 2001).

1997 Jabalpur Earthquake

- **Region**: Central India
- **Magnitude**: 6.0 (Surface-wave magnitude)
- **Location & Impact**: This intraplate earthquake occurred near the Narmada-Son Lineament in the central part of India on May 22, 1997. It was significant due to the widespread coverage of the fault rupture and aftershocks, impacting the nearby urban areas, including Jabalpur city. This earthquake involved reverse faulting associated with basement faults. The earthquake was felt across a large region, and it caused major damage to infrastructure and loss of lives, with a death toll of 39.
- **Seismic Features**: The region is part of the Narmada-Son rift zone, which is known for tectonic activity and is an area of concern for seismic hazards.
- **Notes**: The earthquake's significance lies in its occurrence in a relatively stable region of Central India, and the damage it caused brought attention to the seismic risk of intraplate fault lines in India.

2001 Bhuj Earthquake

The Gujarat region, particularly the Kutch area, experienced the devastating Bhuj earthquake in 2001, which measured 7.7 on the Richter scale.

Date and Significance: Occurred on **June 16, 1819**, this earthquake in the **Rann of Kachchh** (also known as the Allah Bund earthquake) is noted as one of the largest **intraplate earthquakes** globally. It produced significant surface deformations and uplift across a large area.

Geological Impact:

- The earthquake caused a **major uplift**, extending over an area **80-90 km long** and **6 km wide**, with a vertical displacement of about **3-6 meters** along the fault. The most notable uplift occurred along the **Allah Bund**, which created a natural dam across the river and transformed the topography of the region.

- The event also resulted in the formation of a scarp (steep bank or slope) known as the **Allah Bund fault**. This faulting led to widespread flooding in surrounding regions as rivers like the Kori River were dammed.

Magnitude: The inferred magnitude from surface deformation and fault analysis is estimated to be **Mw 7.7**, with the rupture likely extending up to **50 km** along the fault. The rupture dipped at an angle of **45°** to the north, and the slip along the fault was **3-8 meters**.

Further Studies and Implications:

- Bilham (1999) and subsequent researchers (Oldham, 1926; Rajendran and Rajendran, 2001) have used remote sensing and topographical analysis to update the understanding of the earthquake. This includes integrating data from the **2001 Bhuj earthquake**, which occurred in a similar region and used modern methodologies to better understand fault movements.
- It is suggested that the total length of the **Allah Bund scarp** may have extended an additional **100 km** further east, beyond what was initially observed (Oldham, 1926). These findings have helped to model the fault dynamics of intraplate earthquakes in the region.

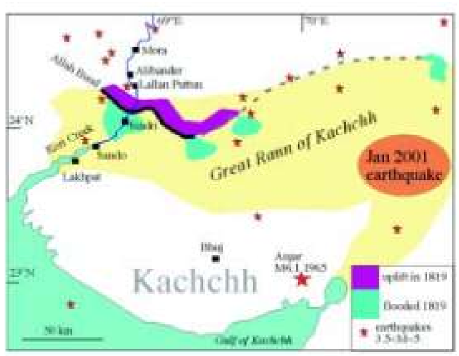


Fig. 7 Uplift during the 1819 Kachchh earthquake dammed the Kori River north of a zone of uplift termed the Allah Bund, and submerged the region to its south surrounding the fort at Sindri. On the basis of morphological changes recorded by Survey of India maps Oldham (1926) suggests that faulting may have extended a further 100 km to the east (dashed). (Bilham, 1999)

2004 Sumatra-Andaman Earthquake

- **Region**: Andaman Sea (Western Indian Ocean)
- **Magnitude**: 9.1 (Moment magnitude)
- **Location & Impact**: This massive undersea earthquake occurred on December 26, 2004, and triggered a series of devastating tsunamis across the Indian Ocean, affecting multiple countries, including India. The epicenter was located off the western coast of northern Sumatra, and the earthquake caused the seafloor to displace over a large area. The resulting tsunamis caused widespread destruction along the eastern coast of India, particularly in Tamil Nadu, and severely affected the Andaman and Nicobar Islands.
- **Seismic Features**: This earthquake was caused by the subduction of the Indian plate beneath the Burma plate and is one of the largest recorded earthquakes globally. The associated tsunamis resulted in over 230,000 deaths across multiple countries.
- **Notes**: The Sumatra-Andaman earthquake is significant not only for its magnitude but also for the scale of the tsunamis and the lessons it provided on tsunami preparedness in the Indian Ocean region.

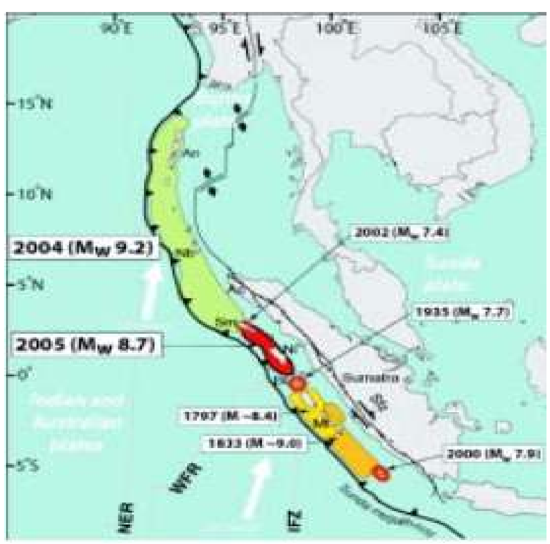


Fig. 8 The India Sunda subduction zone and rupture of the 2004 Sumatra Andaman earthquake (Briggs et al., 2006).

Mitigation and Preparedness

1. **Building Codes and Standards**: Implementing seismic-resistant construction designs is crucial in mitigating the damage caused by earthquakes. Structures should be built to withstand lateral forces generated by seismic waves.
2. **Earthquake Early Warning Systems**: These systems can provide critical seconds or minutes of warning before an earthquake strikes, allowing people to evacuate buildings and seek shelter.
3. **Public Awareness and Preparedness**: Educating the public about earthquake safety measures—such as "Drop, Cover, and Hold On"—is essential for reducing casualties. Regular drills and public awareness campaigns can save lives during seismic events.
4. **Post-Earthquake Recovery**: The recovery process includes rebuilding infrastructure, providing medical care, and offering psychological support to survivors. Effective disaster management plans are vital for swift recovery and long-term resilience.

1.1.8. Landslides

A landslide is a fast-moving event where rock, debris, or soil slides downslope due to gravity.These events are a significant natural hazard globally and play a key role in shaping landscapes, especially in mountainous regions. Landslide occurrence depends upon different parameters such as geological and geomorphological processes, changes in vegetation cover, landuse and hydrogeologic conditions. Landslides are triggered by many factors including heavy precipitation, earthquakes and human activities (Safae et al. 2010; Alkevli and Ercanoglu 2011). In addition to loss of lives, landslides destroy residential and industrial area and negatively affect water quality in rivers and streams (Schuster, 1996).

Landslide Classification:

Types of Movement

- **Falls**: These involve the rapid descent of rocks and boulders that detach from steep slopes or cliffs, typically along fractures, joints, or bedding planes.
- **Topple**: This refers to the forward rotation of debris or rock masses away from a slope. Failure usually occurs near the base of the rock block.
- **Slides**: A slide is the downward movement of material along a defined slip surface.
    - **Rotational Slide**: In this type, the movement occurs in a rotational manner around an axis that runs parallel to the ground surface and across the slide.
    - **Translational Slide**: In this case, the landslide mass moves along a flat, planar surface, sometimes with rotation or backward tilting.
- **Lateral Spreads**: This refers to lateral movement, typically occurring on gentle slopes or flat terrain. It is often caused by liquefaction due to earthquakes.

Types of Flows

- **Debris Flow**: A rapid mass movement where a mix of loose soil, rock, organic material, and water flows downhill. It is commonly triggered by heavy rainfall or rapid snowmelt.
- **Earth Flow**: A viscous flow of fine-grained material, saturated with water, moving downslope.
- **Mudflow**: A fast-moving fluid mass consisting of both fine and coarse-grained materials, usually flowing along drainage channels.
- **Creep**: A slow, steady, downward movement of materials caused by gravity, affecting a large area over time.

Types of Materials

- **Rock**: Refers to hard or firm solid masses.
- **Debris**: Material where 20% to 80% of the particles are larger than 2 mm, with the rest smaller than 2 mm.

- **Earth**: Material in which 80% or more of the particles are smaller than 2 mm.
- **Soil**: A mixture of solid particles, generally comprising minerals and rocks.
- **Mud**: Material in which 80% or more of the particles are smaller than 0.06 mm.

Table 1. The classification of landslides.

Abbreviated Classification of Slope Movements				
Type of movement		TYPE OF MATERIAL		
		Bed Rock	Engineering Soils	
			Predominantly Course	Predominantly Fine
Fall		Rock Fall	Debris Fall	Earth Fall
Topple		Rock Topple	Debris Topple	Earth Topple
Slide	Rotational (Slump)		Rotational Debris Slide	Rotational Earth Slide
	Translational	Translational Rock Slide	Translational Debris Slide	TranslationalEarth Slide
Lateral Spread		Rock Spread	Debris Spread	Earth Spread
Flow		Rock Flow (Deep creep)	Debris Flow (Soil Creep)	Earth Flow (Soil Creep)
Complex	Combination of two or more principal types of movement			

Source: Landslide Atlas of India

Landslides are one of the most destructive natural disasters, especially in mountainous regions, where they take hundreds of lives each year and cause widespread damage. They disrupt transportation, block communication networks, and destroy property, leaving affected communities struggling to recover. Some regions, like the western coasts of North and South America, Central America, the Alpine areas of Europe (including Italy, France, Switzerland, and Austria), and parts of Asia such as the Himalayas in India and Nepal, are particularly vulnerable. This vulnerability is often due to rapid development and human activities needed to support growing populations.

In 2006, landslides were ranked as the third deadliest natural disaster globally, according to the United Nations International Strategy for Disaster Reduction (UN/ISDR) and the Centre for Research on the Epidemiology of Disasters (CRED). That year, approximately 4 million people were affected by landslides. Countries like Colombia, Tajikistan, India, and Nepal face the highest risks, with fatality rates exceeding one person per 100 square kilometers annually (Nadim et al., 2006).

Landslides are one of the most frequent geological hazards in hilly regions worldwide, often triggered by natural factors such as rainfall and compounded by geological and anthropogenic causes. Rainfall-induced landslides occur due to the combined influence of water on topography, geology, soil, and vegetation, leading to significant environmental and human impacts. These include increased sediment discharge from soil erosion and a tragic loss of lives annually.

In India, landslides pose a severe threat due to its diverse physiographic and climatic conditions. Approximately 0.42 million square kilometers, or 12.6% of the country's total land area (excluding snow-covered regions), is prone to landslides. The vulnerable regions are distributed as follows:

- 0.18 million square kilometers in the North East Himalayas, including Darjeeling and Sikkim.
- 0.14 million square kilometers in the North West Himalayas (Uttarakhand, Himachal Pradesh, and Jammu & Kashmir).
- 0.09 million square kilometers in the Western Ghats and Konkan hills (Tamil Nadu, Kerala, Karnataka, Goa, and Maharashtra).
- 0.01 million square kilometers in the Eastern Ghats, particularly the Araku area in Andhra Pradesh (**Source: Geological Survey of India**).

The monsoon season exacerbates landslide occurrences in these regions. Both the Himalayas and Western Ghats are particularly susceptible due to their steep topography and high rainfall levels. Additionally, India's rapid population growth in mountainous regions has intensified the risk, with the country hosting 17% of the global population.

India is among the top four countries most vulnerable to landslides globally, contributing approximately 16% of rainfall-induced landslides worldwide (Source: ISRO's Landslide Atlas of India). Tragically, the country accounts for around 8% of global landslide-related fatalities, with 13.17% of its land area prone to landslides, and 4.75% classified as 'extremely high risk.'

Kerala is particularly notable for its vulnerability, with over 14% of its land categorized as 'extremely high susceptibility' (Source: ILSM by IIT Madras). This increasing susceptibility calls for heightened awareness and mitigation strategies to reduce the devastating impact of landslides across the nation.

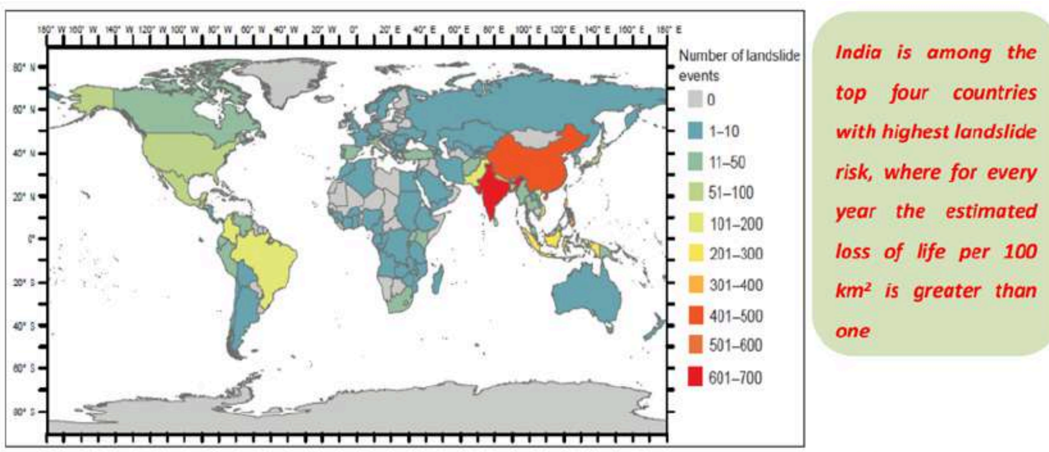
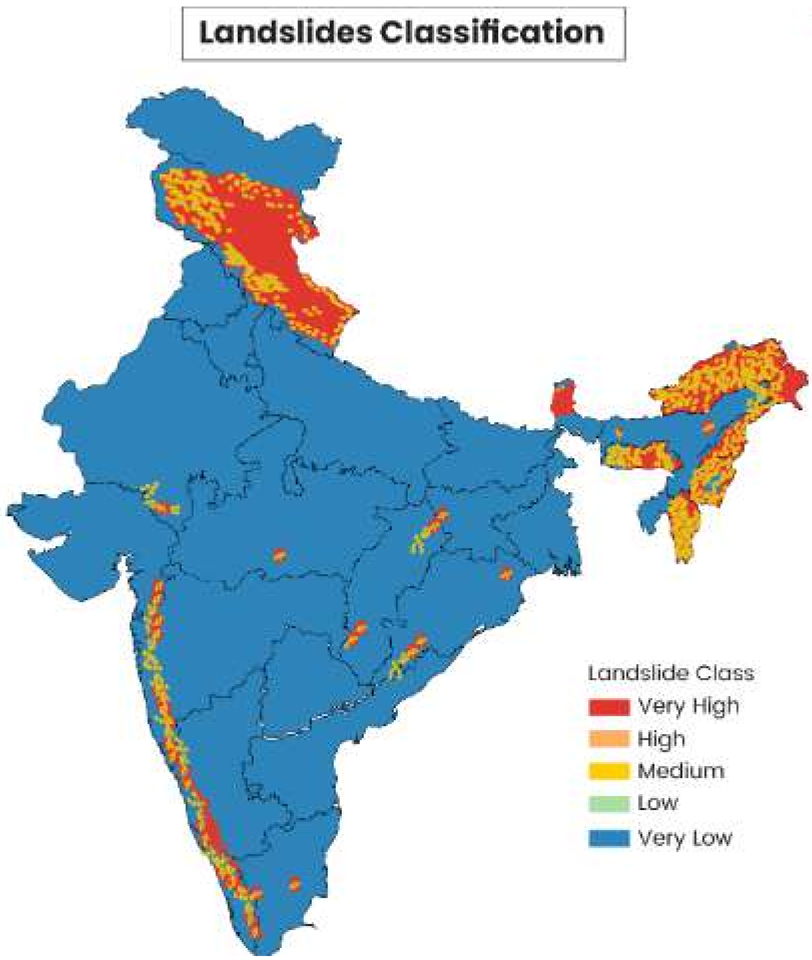


Figure 1. Country-wise non-seismically triggered fatal landslides from 2004 to 2016 (Source: Froude and Petley, 2018).

[figure_source]



Causes of Landslides in India

Natural Causes

1. **Heavy Rainfall**
   Intense or prolonged rainfall triggers landslides in steep regions as water acts as a lubricant, loosening soil and rocks.
   Example: The 2013 Uttarakhand cloudburst caused widespread landslides in the region.[source]

2. **Earthquakes**
   Sudden ground movements due to earthquakes exert stress on the earth's crust, causing materials to slide downhill.
   Example: The tectonically active Himalayas are highly susceptible to earthquakes, leading to frequent landslides.[source]

3. **River Dynamics**
   Rivers with high flow rates, especially in their youthful stages, erode mountain slopes, destabilizing the land.
   Example: Increased flow in the Chaliyar River caused sediment erosion, leading to the Wayanad landslide disaster.[source]

4. **Snow Melting**
   Rapid melting of snow due to rising temperatures destabilizes slopes and increases landslide risks.
   Example: Melting glaciers in the Himalayas often lead to slope failures and debris flows.[source]

5. **Volcanic Activity**
   In mountainous areas, volcanic eruptions can destabilize slopes, resulting in landslides.

Anthropogenic (Human-Induced) Causes

1. **Infrastructure Development**
   The construction of roads, railways, dams, and other infrastructure in mountainous areas disturbs natural slopes, increasing landslide risks.
   Example: The construction of the Konkan Railway in the Western Ghats is linked to frequent landslides in the region.[source]

2. **Mining and Quarrying**
   Extraction of minerals and stones disrupts surface structures and weakens soil cohesion, making slopes vulnerable to landslides.

Example: Mining of iron ore, bauxite, and other minerals in the Western Ghats has increased landslide occurrences.[source]

3. **Deforestation**
   Large-scale removal of vegetation weakens root strength, reducing soil stability and increasing susceptibility to landslides.
   Example: Plantation agriculture in the Western Ghats has replaced native trees, raising disaster risks.[source]

4. **Unsustainable Tourism**
   Increased tourist influx in fragile ecosystems like the Himalayas and Western Ghats leads to over construction, destabilizing slopes.
   Example: Tourism-related infrastructure in these regions contributes significantly to landslide occurrences.

5. **Climate Change**
   Human-induced climate change has intensified extreme weather events, including heavy rainfall and glacial melting, thereby exacerbating landslide risks.
   Example: The warming of the Arabian Sea has increased rainfall in the Western Ghats, amplifying landslide events.[source]

6. **Shifting Cultivation**
   Clearing forests for temporary farming disrupts soil structure, leaving slopes vulnerable to erosion and landslides.

7. **Overgrazing**
   Overgrazing by livestock removes vegetation cover, exposing soil to erosion and increasing landslide risks.

8. **Unregulated Urbanization**
   Unplanned urban growth in hilly areas without proper geological assessments destabilizes slopes.

Example: The eastern slope of Nainital (Uttarakhand) is sinking due to the heavy load of unregulated hotels and residential buildings.[source]

Impacts of Landslides: [study]

1. **Loss of Lives:** Landslides cause tragic loss of human and animal lives, as seen in Wayanad, where over 250 deaths were reported.

2. **Economic Losses** - Reconstruction, rehabilitation, and relief efforts following landslides lead to significant economic strain.

3. **Infrastructural Damage and Restricted Movement** - Landslides damage buildings and roads, blocking transportation routes and hindering movement.

4. **Jeopardized Water Availability** - Debris from landslides can block rivers, forming dams and limiting water access for nearby communities.

5. Displacement and Migration - Landslides force people to evacuate, causing social disruption and psychological stress.

Catastrophic landslides have historically caused immense devastation in the Himalayas, leading to significant loss of life, blocking river valleys, and destroying vital infrastructure like roads and buildings. One of the most tragic examples is the **1998 Malpa landslide** in Uttarakhand, which claimed 221 lives. Similarly, the **2013 Uttarakhand disaster**, triggered by extreme rainfall, resulted in widespread floods and landslides, causing large-scale human casualties and destruction.

In India, the **Western Ghats** rank as the second most landslide-prone region after the Himalayas. This area has always been a matter of concern due to its steep slopes and thick soil cover, which make it highly susceptible to landslides. Notable examples include the **Amboori landslide** in Kerala and the **Marappalam landslide** in the Nilgiris of Tamil Nadu. The devastating impact of these events underscores the region's vulnerability.In **2018**, incessant rainfall triggered widespread landslides across Kerala, Karnataka, and Tamil Nadu, resulting in over

500 deaths. This disaster highlighted the deadly consequences of landslides compounded by heavy monsoons.

A comprehensive database compiled from news reports and disaster management statistics reveals that landslides and associated events, like earthquakes and floods, caused **10,305 deaths in India between 1998 and 2018**. Many of these disasters are intertwined, making it difficult to attribute casualties solely to landslides. However, this figure reflects the profound human and environmental toll of landslides in India, demanding stronger mitigation and disaster response efforts.

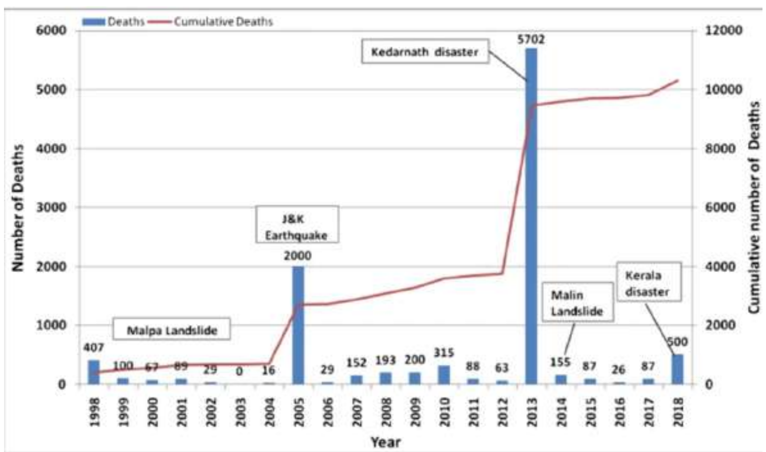


Fig. Deaths due to landslides in India during the 1998–2018 period

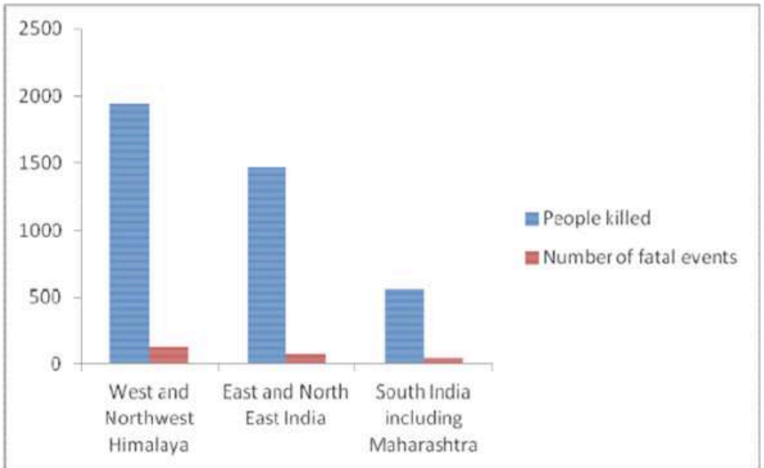


Figure 2: Geographical Distribution of fatal landslide events and number of persons killed during the years between 2011 and 1800 in different parts of India

[figure_source]

MAJOR LANDSLIDE-PRONE REGIONS IN INDIA:

In India the occurrence of landslides is an annual and recurring event in the various hill and mountain ranges. The Himalayas and the Western Ghats are the two regions in India most vulnerable to landslides. The Himalayan mountain range consists of geologically young, tectonically unstable formations, making it prone to intense seismic activity. In contrast, the Western Ghats and Nilgiri Hills are relatively stable but have elevated plateau margins affected by recent tectonic movements. These distinct geological settings result in different types of landslides in each region, reflecting their unique structural characteristics.The risk is particularly high during the monsoon season from June to September, due pore water pressure development.

Himalayas:

The Himalayas, often referred to as the "abode of snow," are the youngest and one of the most geologically active mountain ranges in the world. Stretching across several countries, including India, Nepal, Bhutan, and China, this vast mountain chain is characterized by rugged terrain, steep slopes, and deep valleys, making it both ecologically unique and highly prone to natural calamities. Due to their continuous geological uplift, the Himalayas are subjected to constant erosion, which, combined with seismic activity and dynamic forces from rivers cutting through rock, creates a landscape that is highly vulnerable to a range of natural disasters, particularly landslides.

The Himalayas regions belong to moderate to very high global hotspot landslide hazard zonation with a high Mortality rate for expected annual mortality risk of landslides worldwide (Nadim et al. 2006; Yang et al. 2015). Landslides, debris flows, soil erosion, and other mass-wasting processes are prominent features of the Himalayan region. These erosional activities have contributed to the formation of the Himalayan Foreland basins, characterized by the Sub- and Lesser Himalayan zones and the Indo-Gangetic Plain (Singh and Singh, 2020).

The high incidence of landslides in the Himalayas is attributed to the region's vulnerable rock formations, steep slopes, and the buildup of strain from the northward movement of the Indian Plate beneath the Asian Plate (Singh, 2019, and references therein). This ongoing plate movement and its collision with the Eurasian Plate result in frequent earthquakes and neotectonic activities. Weak and unstable rocks are more prone to landslides than stronger, more competent rocks. Similarly, steeper slopes have a higher likelihood of landsliding compared to gentler gradients. Once the balance in the rugged mountainous terrain is disturbed, the frequency of landslides increases significantly.

During both summer and winter monsoons, landslides and related disasters heavily impact human life in the Himalayan region. Many settlements are located in ancient landslide zones due to the presence of fertile soils. Rainfall elevates pore-water pressure in slope materials, often triggering landslides. Other triggers include earthquakes, increased load on slopes, changes in slope gradient, mining, hill cutting, construction, and various human activities.

Causes of Landslides in Himalayan Region [source]

1. Rock Characteristics and Effects

The inherent properties of rocks significantly influence landslide occurrences. Key factors include chemical composition, mineral content, and textural attributes, which determine a rock's overall strength. Secondary discontinuities, such as faults, joints, and bedding planes, further contribute to slope instability. The interaction between these discontinuities and slope geometry frequently leads to rock failure. Additionally, weathered surface materials exacerbate the potential for instability, making certain regions more prone to landslides.

2. Anthropogenic Influences

Human activities have significantly intensified landslide risks by altering natural conditions. Major anthropogenic impacts include:

- **Topographic Modifications**: Construction, mining, and road-cutting activities disturb natural slopes.
- **Water Circulation Disruption**: Changes in surface and subsurface water flow destabilize slopes.
- **Land Use Changes**: Deforestation, urbanization, and removal of slope support reduce stability.

  Such interventions aggravate pre-existing vulnerabilities, accelerating the frequency and severity of landslides.

3. Tectonic Boundaries and Their Effects

The Himalayan region is characterized by prominent tectonic boundaries, including the South Tibetan Detachment System (STDS), Main Central Thrust (MCT), Main Boundary Thrust (MBT), and Himalayan Frontal Thrust (HFT). These boundaries play a critical role in accommodating stress within the orogeny, resulting in earthquakes and related slope failures. The proximity of a location to these tectonic features often determines the extent of landslide susceptibility.

4. Earthquakes and Associated Hazards

Earthquakes are a significant trigger for landslides, particularly in seismically active regions such as the Himalayas. Key impacts include:

- **Ground Shaking**: This leads to liquefaction of soil and destabilization of rocks, increasing the likelihood of slope failure.
- **Co-Seismic Landslides**: These contribute to 20–25% of total earthquake-related losses and are particularly devastating in mountainous regions.
- **Stress Accumulation**: Fault movements weaken slope materials, resulting in rockfalls and topple events.
  Historical seismic events, such as the Assam (1897), Kangra (1905), and Nepal (2015) earthquakes, have demonstrated the extensive impact of earthquake-induced landslides.

5. Paleo-Landslides and Their Influence

Prehistoric landslides, or paleo-landslides, are common in the Himalayan region. These areas often host human settlements due to the presence of fertile soils, making them vulnerable to renewed landslide activity. Paleo-landslides are typically associated with geomorphic features such as river nick points, which indicate past rejuvenation. Deposits from ancient lakes and paleoseismic structures further corroborate landslide activity linked to historical seismic events.

South Western Ghats: [source]

The South Western Ghats, an ancient mountain range older than the Himalayas, stretch approximately 1,500 km along the western coast of India. This chain, spanning from Tamil Nadu to Maharashtra through Kerala, Karnataka, and Goa, serves as a natural barrier between the Arabian Sea and the peninsular region. The range begins near the Tapi River in the north (21°16'N) and extends southwards to

Kanyakumari (8°19'N). The southern segment, known as the Southern Block, includes prominent mountain ranges such as the Nilgiris, Anamalais, Cardamom Hills, and Agasthyamalai.

The Ghats play a crucial role in intercepting moisture-laden winds from the Arabian Sea, resulting in heavy rainfall, particularly in the southern regions. While the northern parts of the Ghats experience rainfall for about four months, the southern regions witness extended downpours lasting eight to nine months, receiving over 2,000 mm of rain annually. This varied climate has led to distinct vegetation patterns, with tropical wet evergreen forests dominating the western slopes and moist and dry deciduous forests found on the eastern slopes.

The Western Ghats, traditionally considered one of the most stable regions in India, has become increasingly susceptible to landslides due to various environmental and human-induced factors. After the Himalayas, the Western Ghats is the second most landslide-prone area in India. Despite its historical stability, the region has seen a significant increase in landslide occurrences in recent decades, raising concerns for both the safety of its residents and the surrounding ecosystem.

The primary factors contributing to the growing vulnerability of the Western Ghats to landslides include uncontrolled environmental degradation, particularly the destruction of forests and valleys, along with steep slopes and thick soil cover. These physical characteristics make the region inherently prone to landslides, especially during periods of heavy rainfall. Moreover, human activities such as urbanization, tourism, and unplanned development have exacerbated the issue, leading to a deterioration of the natural balance.

As human activity increases, particularly in the form of tourism and pilgrimage, the region has experienced heightened ecological disturbances. The Western Ghats Ecology Expert Panel has identified that approximately 37% of the South Western Ghats falls within fragile ecozones, making the region more sensitive to environmental changes. These disturbances, combined with the region's susceptibility to heavy rainfall, have contributed to the frequency and severity of landslides, which pose significant risks to human life, property, and the environment.

Landslide Management in India [source]

1. **NDMA Guidelines (2009)**
   - Established comprehensive guidelines for landslide hazard management and mitigation.
2. **Landslide Hazard Zone (LHZ) Task Force**
   - Set up after the Malpa disaster to conduct geotechnical surveys, land-use zoning, and regulatory activities.
3. **Institutional Roles**
   - Geological Survey of India (GSI): Focal agency for LHZ-related activities, monitoring, and mitigation.
   - Department of Science and Technology (DST) and Ministry of Environment, Forests, and Climate Change (MoEFCC): Responsible for broader landslide management initiatives.
4. **Landslide Hazard Atlas (2004)**
   - Published by BMTPC and Anna University, featuring small-scale maps of landslide-prone areas.
5. **National Landslide Sensitivity Mapping (NLSM)**
   - Initiated by GSI in 2014-2015 to map landslide-prone areas at a macro scale (1:50,000) across 0.42 million square kilometers.

Landslide Mitigation Measures [source]

1. **Reforestation and Afforestation:** Planting native tree species enhances soil stability, reduces water runoff, and improves ecosystem health.

2. **Sustainable Land Use Management:** Enforcing strict regulations on land use in hilly regions to prevent deforestation, unplanned construction, and unsustainable farming practices.
3. **Early Warning Systems:** Establishing advanced early warning systems using rainfall data, soil moisture sensors, and meteorological parameters to issue timely alerts.
4. **Engineering Solutions:** Building retaining walls, terraces, and drainage systems to stabilize slopes and mitigate soil erosion.
5. **Disaster Preparedness and Response:** Conducting regular drills, preparing evacuation plans, and training local communities in disaster response strategies.
6. **Community Involvement:** Engaging local communities in mitigation efforts through awareness campaigns, skill training, and providing alternative livelihood opportunities.
7. **Research and Monitoring:** Carrying out scientific studies to analyze landslide patterns and vulnerabilities while implementing advanced monitoring techniques.
8. **Resilient Infrastructure:** Designing landslide-resistant roads, bridges, and infrastructure, prioritizing vulnerable-free locations, and integrating effective drainage systems.

1.2 Objectives of the study:

- **Analyze Rainfall and Temperature Trends Across Indian States:** Study historical and recent data on rainfall and temperature across Indian states to uncover long-term trends, seasonal variations, and regional patterns. Highlight changes in monsoon intensity, annual average temperatures, and their impact on different geographical regions.

- **Examine Correlation Between Rainfall and Temperature:** Evaluate the relationship between rainfall and temperature changes using statistical analyses. Identify whether warming trends influence precipitation patterns, such as increased variability or shifts in monsoon timings.
- **Explore Environmental Disasters in India**: Focus on major natural disasters, including floods, cyclones, earthquakes, and landslides. Investigate their frequency, severity, and impact on human lives, property, and infrastructure across India's diverse regions.
- **Gain Disaster-Specific Insights Through Data and Visualization:** Utilize data-driven visualizations to analyze the causes, trends, and regional impacts of each disaster type. Highlight how India's unique geography and climatic conditions contribute to disaster vulnerabilities and recurring patterns.

1.3 Study Area:

India’s unique geography and climatic diversity make it a vital region for studying climate change and its impacts. From the snow-capped Himalayas to the tropical coasts, India experiences a wide range of weather patterns, including monsoons, heatwaves, and cyclones. This diversity allows for an in-depth analysis of how localized climate changes affect ecosystems, agriculture, and livelihoods.

India is also one of the most vulnerable countries to climate change. Reliance on monsoon rains for agriculture, rising sea levels threatening coastal regions, and the increasing intensity of heat waves make the country a global hotspot for climate risks. Reports, such as the Global Climate Risk Index, consistently rank India among the most affected nations by extreme weather events, with disasters like floods, droughts, and landslides becoming more frequent and severe.

With over 1.4 billion people, India has a dense population living in highly climate-sensitive zones. Rapid urbanization and industrial growth have heightened the country’s exposure to environmental hazards, making it crucial to understand the socio-economic impacts of climate change here. Additionally, India's efforts to meet global climate goals, such as net-zero emissions by 2070, highlight its significant role in shaping international climate policies.

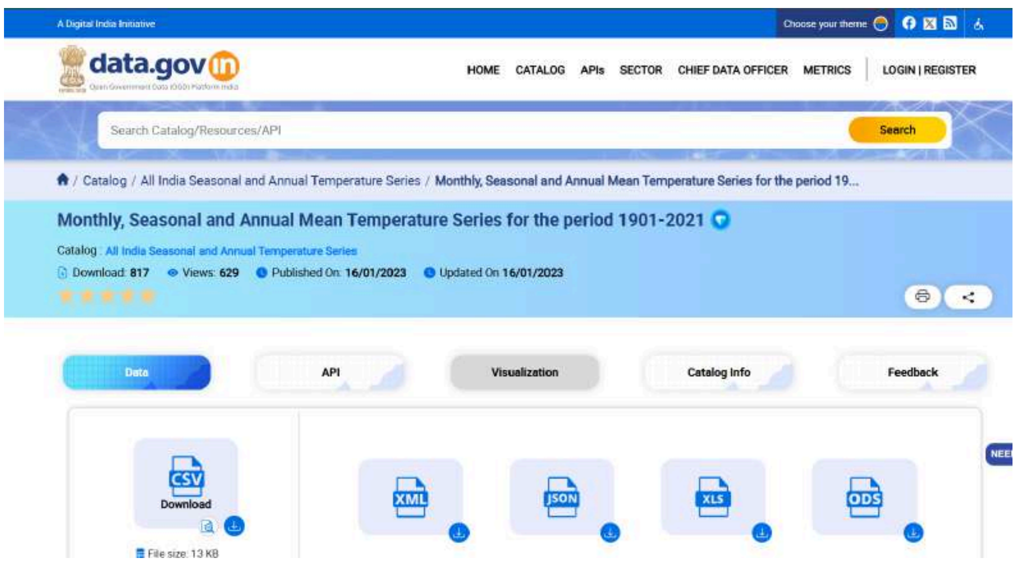
Studying India not only sheds light on how climate change and disasters evolve in diverse environments but also provides lessons for other developing nations facing similar challenges.

2. Materials and Methods:

2.1 Materials:

Temperature:

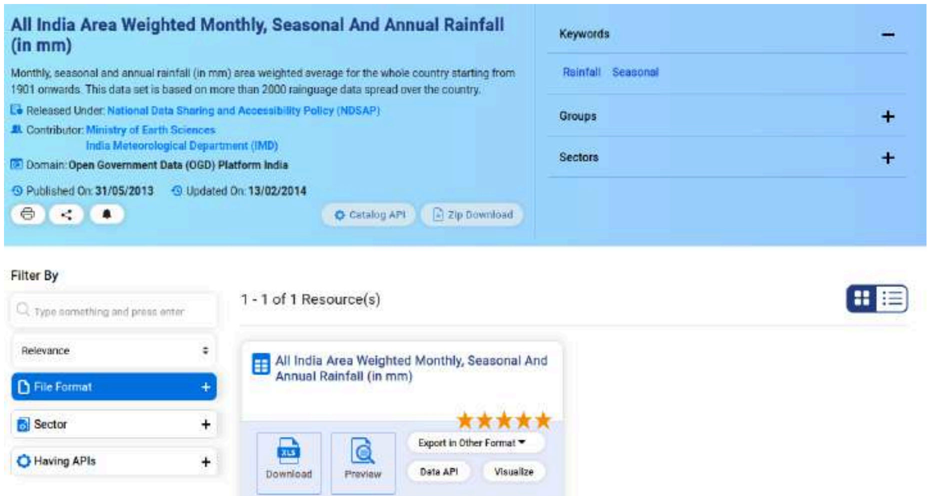
The dataset is taken from data.gov.in



data.gov.in is India's official Open Government Data platform, offering free access to datasets across various sectors.The Monthly, Seasonal, and Annual Mean Temperature Series (1901–2021) dataset provides long-term temperature trends for India, The Monthly, Seasonal, and Annual Mean Temperature Series (1901–2021) dataset provides long-term temperature trends for India.

Rainfall:

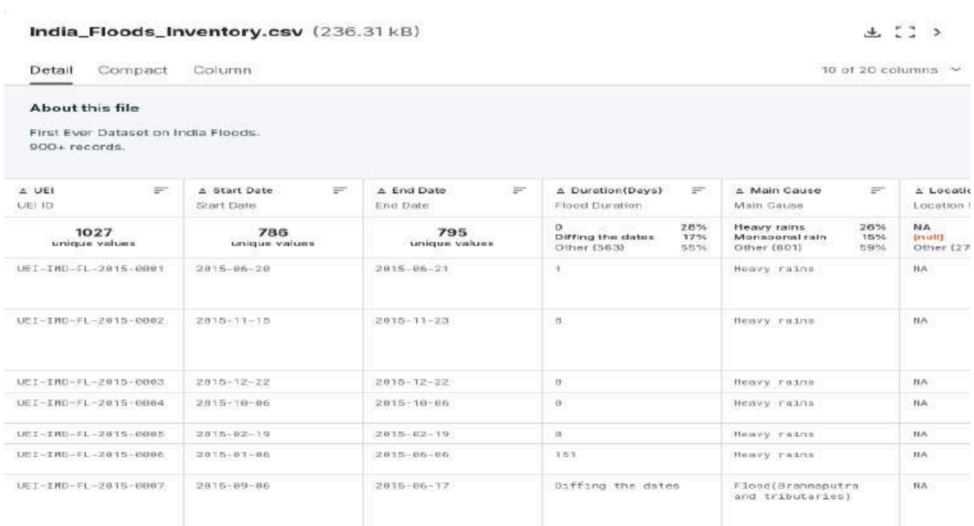
The dataset is taken from data.gov.in



data.gov.in is India's official Open Government Data platform, offering free access to datasets across various sectors.Monthly, seasonal and annual rainfall (in mm) area weighted average for the whole country starting from 1901 onwards. This data set is based on more than 2000 rain gauge data spread over the country.

Floods:

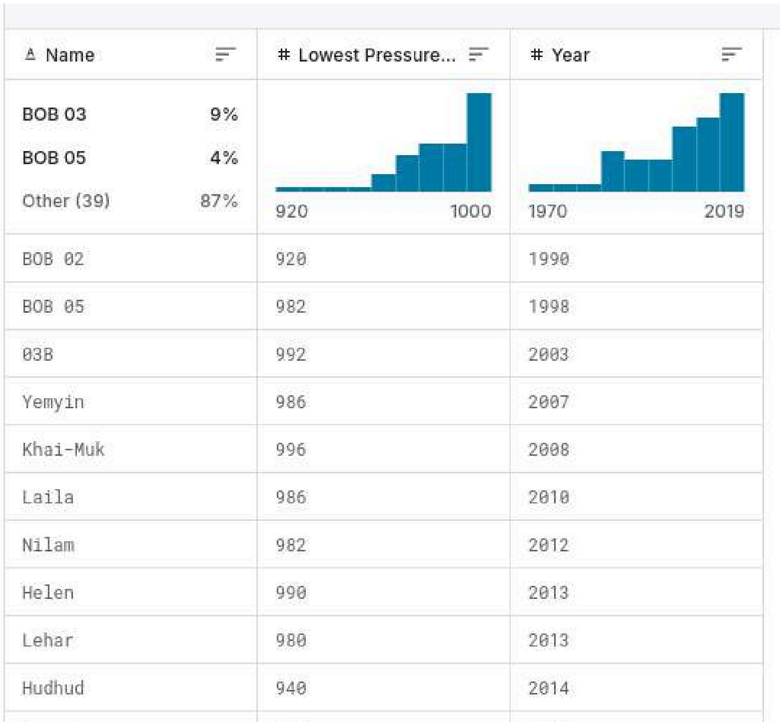
Flood Dataset from [Kaggle]



This is a list of notable recorded floods that have occurred in India. Floods are the most common natural disaster in India. The heaviest southwest the BRAHMAPUTRA and other rivers to distend their banks, often flooding surrounding areas. Climate change has played an important role in causing large-scale floods across central India.

Cyclones:

The dataset used in this study was obtained from [Kaggle.]



Name	Lowest Pressure...	Year
BOB 03 9% BOB 05 4% Other (39) 87%	920 1000	1970 2019
BOB 02	920	1990
BOB 05	982	1998
03B	992	2003
Yemyin	986	2007
Khai-Muk	996	2008
Laila	986	2010
Nilam	982	2012
Helen	990	2013
Lehar	980	2013
Hudhud	940	2014

This is a list of notable recorded cyclones that have occurred in India.

The basic data of this study were extracted from IMD's electronic atlas of cyclonic disturbances from 1891 to 2008. The available records in the dataset encompass the pathways of cyclones, intensity, wind speeds, storm surges, and rainfall data associated with these events. Real time-developments of cyclones were studied by using satellite data coming from INSAT and imagery from Doppler weather radars. Data regarding storm surges, wind speed, and precipitation have been taken from Vulnerability Atlas of India, by Building Material Technology Promotion Council, Ministry of Urban Affairs [4].

Included were secondary data on coastal population density and vulnerability of infrastructure, as well as disaster management plans sourced from the state disaster management authorities, especially from Odisha and Andhra Pradesh. Historical records on cyclone damage-lives lost, property loss, and the consequent agricultural productivity loss-were reviewed for the evaluation of economic and social loss caused by cyclones in these areas. In addition, research from websites such as ResearchGate presented data on land-falling cyclones from 1891 to 2018 and cyclonic disturbances in the North Indian Ocean from 1891 to 2015. Intensification of storms in the 21st century was obtained from the recent studies published as an IPCC's Sixth Assessment Report.

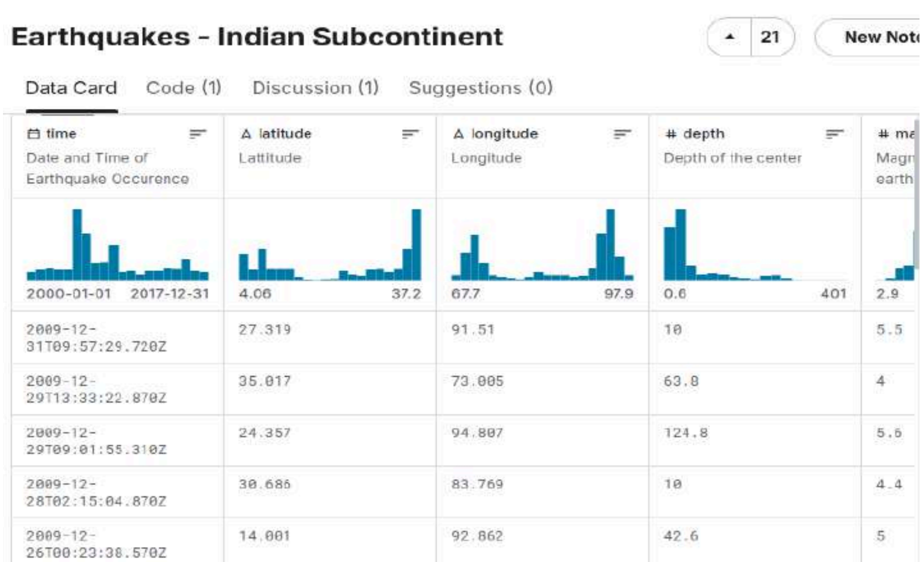
Earthquakes:

The dataset used in this study was obtained from Kaggle.

Focuses on the Indian subcontinent's earthquake data. This dataset provides a comprehensive overview of seismic activities, including details such as earthquake magnitude, depth, location (latitude and longitude), and time of occurrence. We have extracted the data of periods 2000-2017.

The data includes essential information for analyzing temporal patterns, geographical distribution, and seismic intensity across the Indian subcontinent. It enables the identification of high-risk zones and trends in seismic activities. The dataset is valuable for understanding earthquake dynamics in regions impacted by the tectonic interactions of the Indian and Eurasian plates.

The dataset we used for Earthquake is :


Earthquakes - Indian Subcontinent

21 New Not

Data Card Code (1) Discussion (1) Suggestions (0)

time	latitude	longitude	depth	ma
Date and Time of Earthquake Occurence	Lattitude	Longitude	Depth of the center	Magn earth
2000-01-01 – 2017-12-31	4.06 – 37.2	67.7 – 97.9	0.6 – 401	2.9
2009-12-31T09:57:29.720Z	27.319	91.51	10	5.5
2009-12-29T13:33:22.870Z	35.017	73.005	63.8	4
2009-12-29T09:01:55.310Z	24.357	94.807	124.8	5.6
2009-12-28T02:15:04.870Z	30.686	83.769	10	4.4
2009-12-26T00:23:38.570Z	14.001	92.862	42.6	5

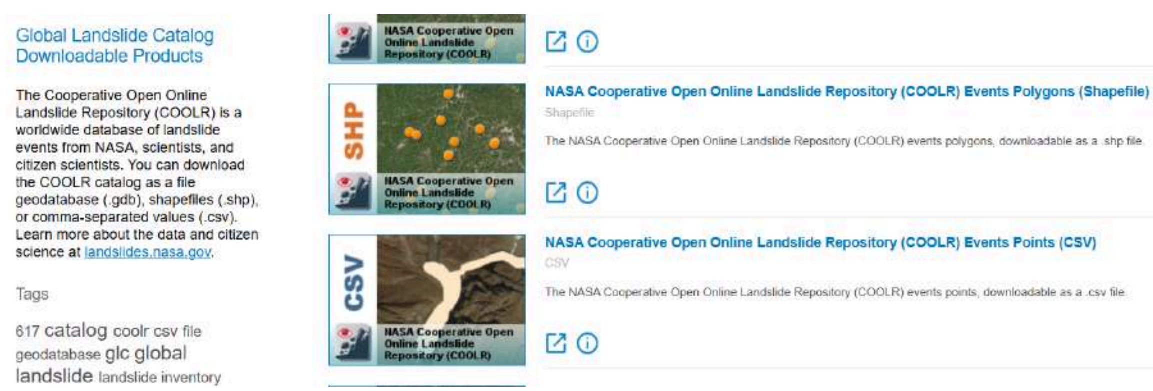
Landslides:

The dataset used in this study is sourced from [NASA's National Climate Computing System (NCCS) ArcGIS Map and App Gallery]().

It provides access to downloadable Global Landslide Catalog (GLC) products through the Cooperative Open Online Landslide Repository (COOLR). COOLR is a comprehensive global database of landslide events contributed by NASA, scientists, and citizen scientists. Users can access and download the catalog in various formats, such as .gdb, .shp, or .csv. We have isolated landslide data specific to India for the period 1990 - 2022

The data includes essential information for analyzing spatial patterns, temporal trends, and landslide triggers across the country. It enables the identification of high-risk regions and trends in landslide occurrences. The dataset is valuable for understanding landslide dynamics in areas affected by monsoon rainfall and human activities.

The dataset used for landslides is **NASA Cooperative Open Online Landslide Repository (COOLR) Events Points (CSV) file**



2.2 Methods:

2.2.1 Pearson Correlation

The Pearson correlation coefficient (PCC) is a statistical tool that measures the strength and direction of the linear relationship between two variables.In this analysis,PCC was applied to assess the extent of linear dependence between annual averages of temperature and rainfall across different regions.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

r = correlation coefficient

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

The dataset contained insufficient data (e.g., NaN values) for certain states, it limited the ability to compute the Pearson Correlation Coefficient (PCC) for those regions. PCC calculations require complete paired data points for both temperature and rainfall. Missing or incomplete data can skew results or make computation infeasible

State	Temp Vs Rainfall annual correlation
Arunachal pradesh	0.0004018935539
Bihar	-0.02108179279
Chhattisgarh	-0.04520718493
Himachal pradesh	-0.01412936641
Jharkhand	-0.03493531923
Kerala	-0.09494171132
Lakshadweep	-0.05549356303
Orissa	-0.03601484391
Punjab	-0.01902971495
Tamil nadu	-0.02865232161
Uttarakhand	-0.0103010434

- **Positive Correlation(Close to +1):**
  A strong positive PCC indicates that as annual temperatures increase, annual rainfall also tends to increase, and vice versa. However, in this study, most positive correlations are near zero, reflecting a weak or negligible relationship between temperature and rainfall.

- **Negative Correlation (Close to -1):**
  A strong negative PCC, such as Kerala's -0.994, implies a robust inverse relationship, where higher temperatures are associated with markedly lower rainfall. This highlights a significant climatic pattern in Kerala, emphasizing the impact of temperature on rainfall variability in the region

- **Near Zero Values (Close to 0):**
  PCC values close to zero, such as Arunachal Pradesh's 0.0004, suggest an almost nonexistent relationship. In such cases, changes in annual temperatures do not reliably predict corresponding changes in rainfall, indicating other factors likely influence rainfall variability in these regions

3. Results and Discussion:

3.1 Temperature

3.1.1 Dataset Visualization

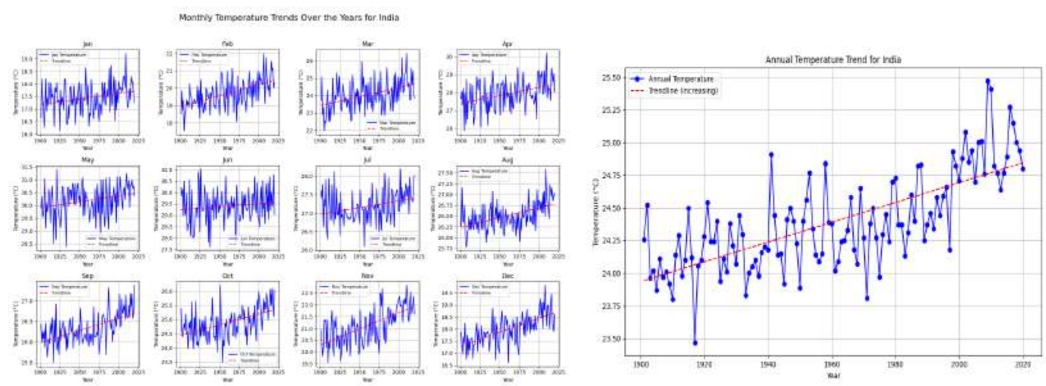
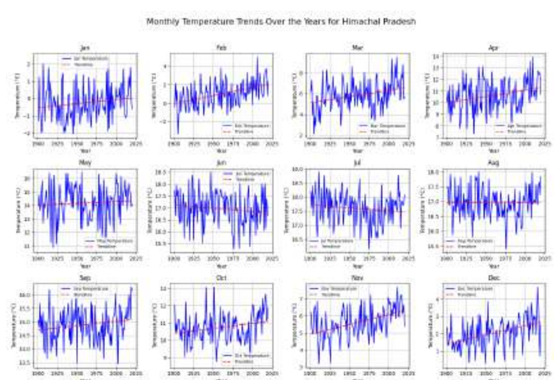
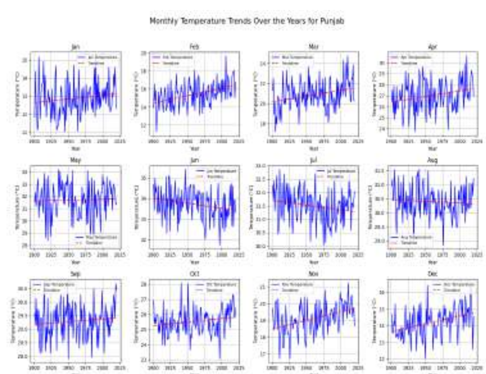


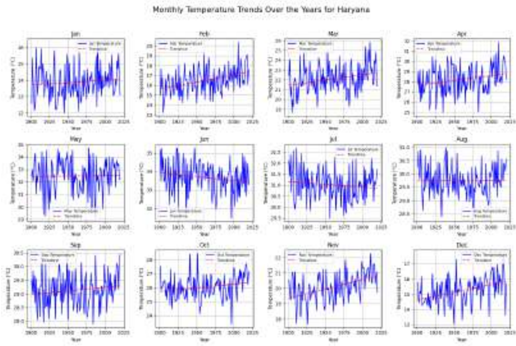
Fig 3.1.1 Monthly and Annual average temperatures in India over years along with the trend line

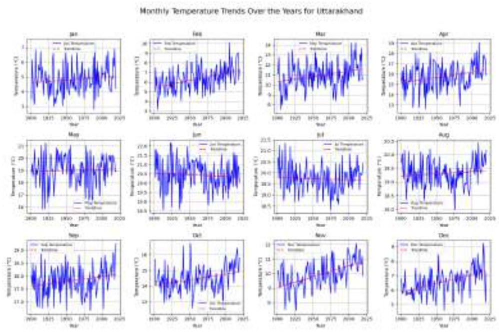
3.1.2 Monthly Data Analysis

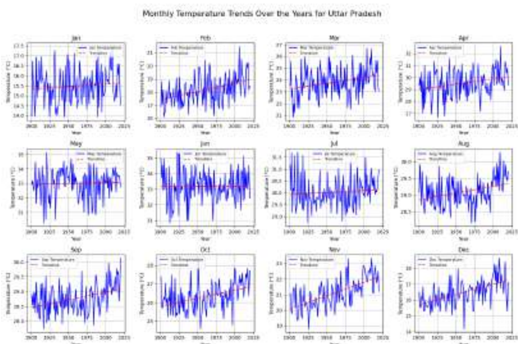
Northern States: Himachal Pradesh, Punjab, Haryana, Uttarakhand, Uttar Pradesh, Chandigarh, Delhi

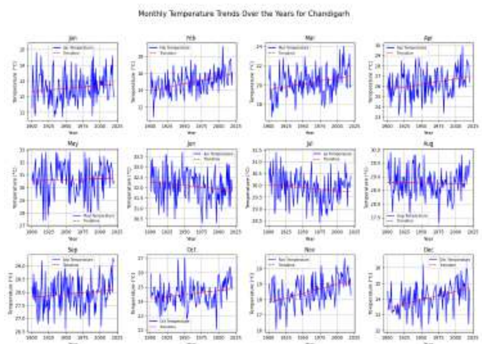


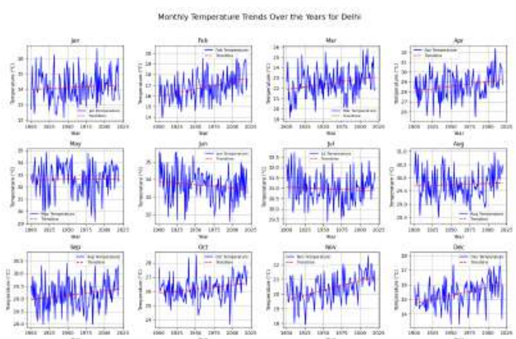






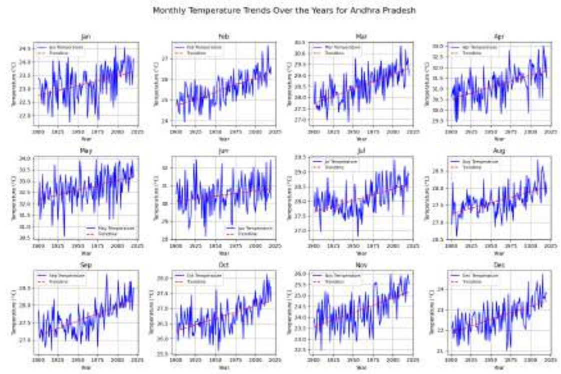


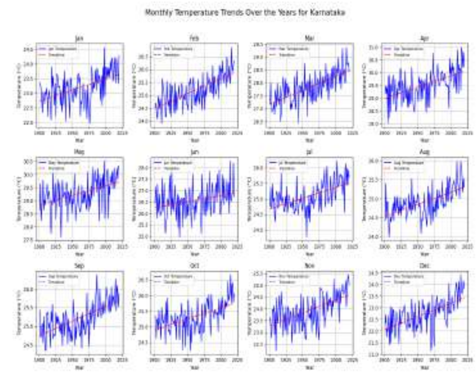


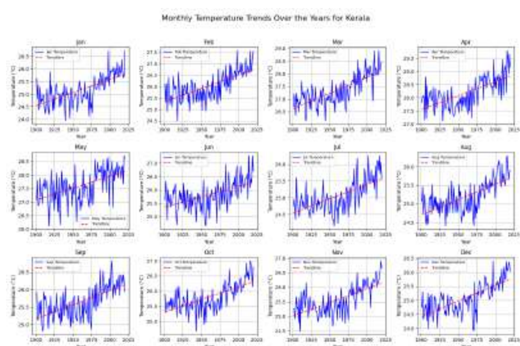


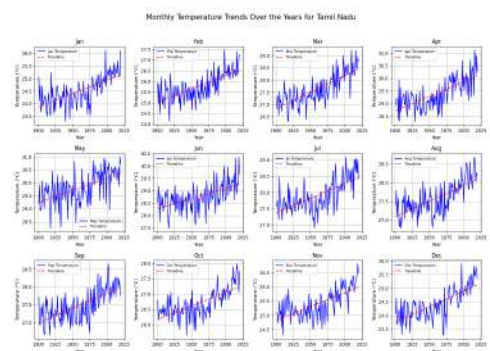
Observations: The northern plains experience extreme seasonal variations, with scorching summers and cold winters. However, a warming trend has been observed over recent decades, especially during summer months. Mountainous regions like Himachal Pradesh, and Uttarakhand remain cooler due to altitude and snow cover, with noticeable winter cooling trends.

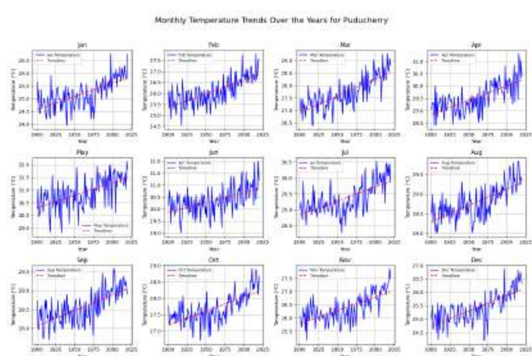
Southern States: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Puducherry, Lakshadweep

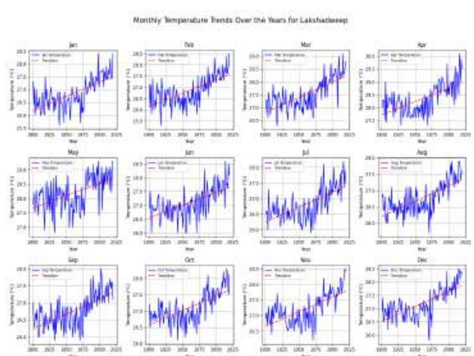






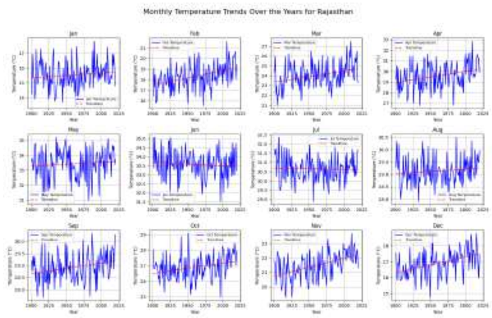


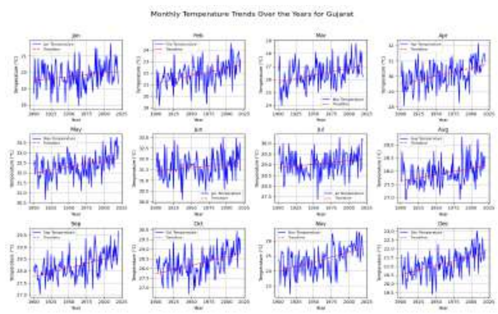


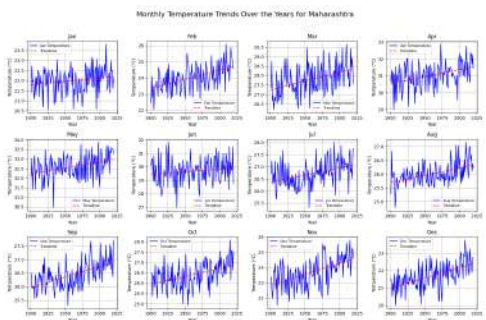


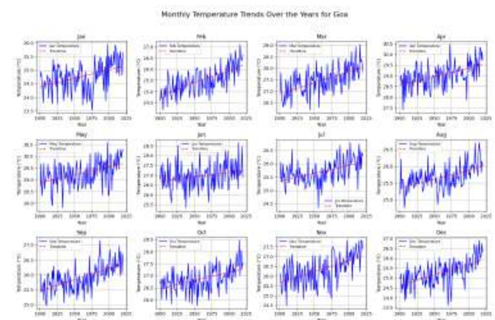
Observations: Southern states, with a tropical climate, experience relatively stable temperatures throughout the year. However, there is a gradual warming trend, particularly during post-monsoon and winter seasons. Coastal areas like Kerala and Tamil Nadu experience moderating effects of the ocean, keeping temperature anomalies less pronounced.

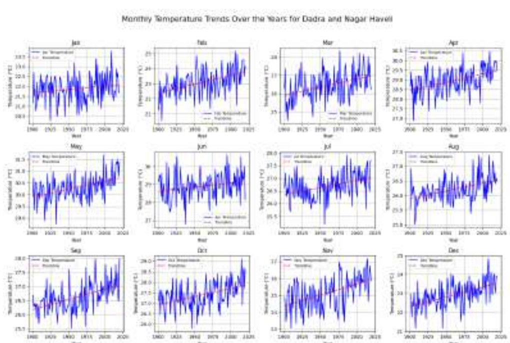
Western States: Rajasthan, Gujarat, Maharashtra, Goa, Dadra & Nagar Haveli and Daman & Diu

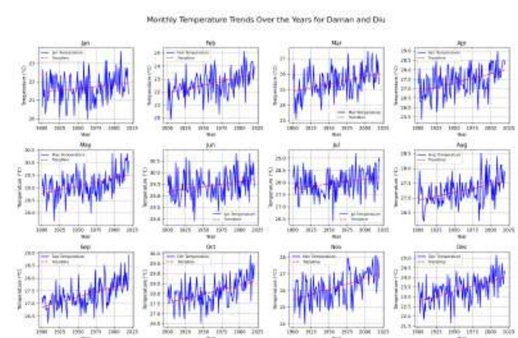








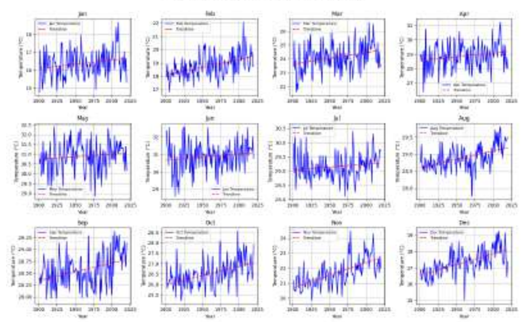




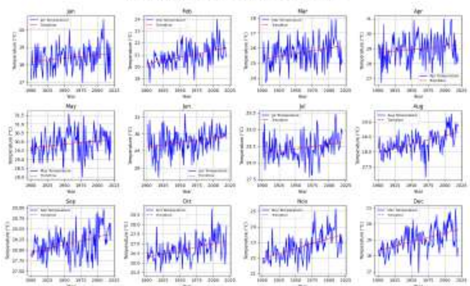
Observations: States like Rajasthan and Gujarat show rising temperature trends, with intensified heatwaves during summer. Desert regions in Rajasthan show significant diurnal temperature variations. Coastal areas like Maharashtra and Goa experience warmer temperatures due to urban heat island effects and proximity to the sea.

Eastern States: Bihar, West Bengal, Jharkhand, Odisha, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura

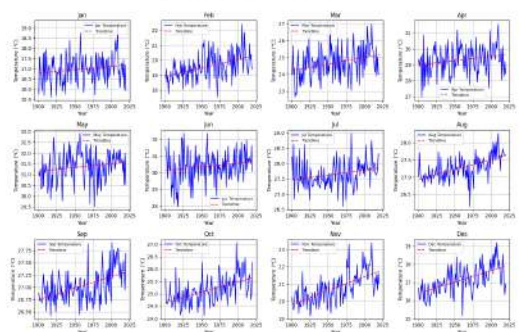
Monthly Temperature Trends Over the Years for Bihar



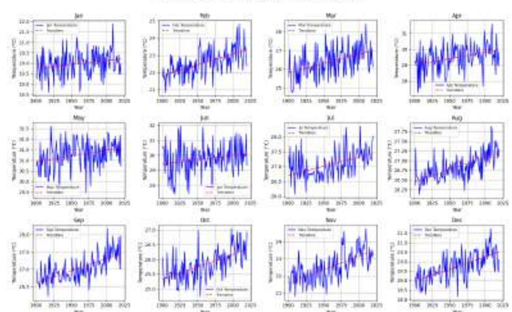
Monthly Temperature Trends Over the Years for West Bengal



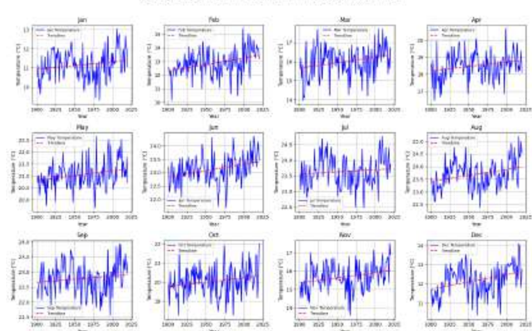
Monthly Temperature Trends Over the Years for Jharkhand



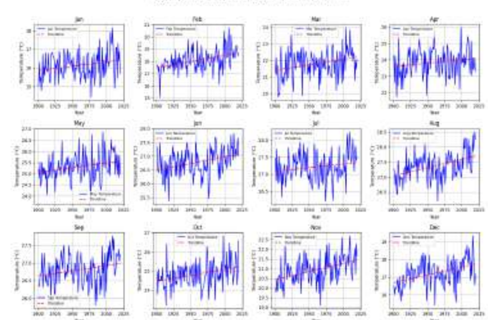
Monthly Temperature Trends Over the Years for Orissa



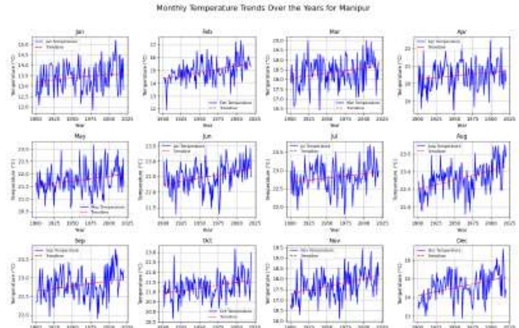
Monthly Temperature Trends Over the Years for Arunachal Pradesh



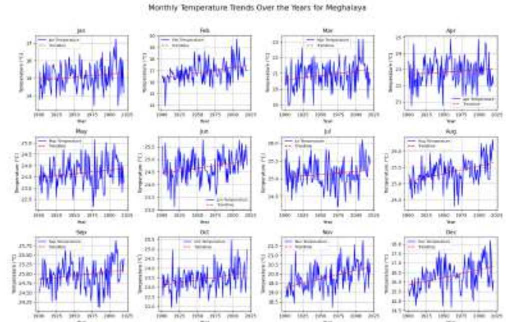
Monthly Temperature Trends Over the Years for Assam

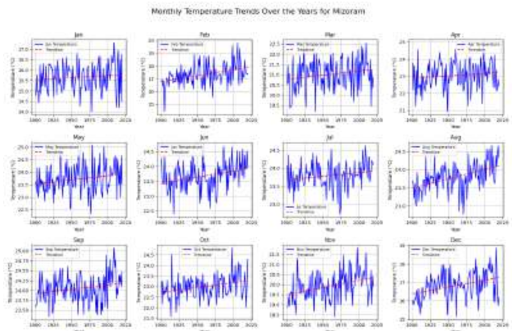


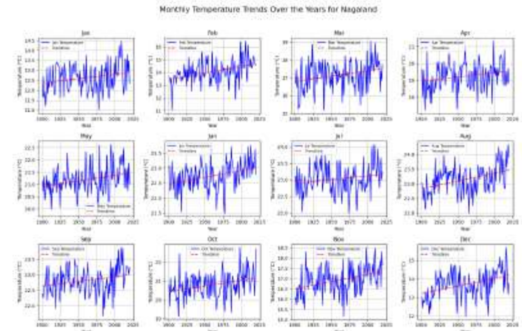
Monthly Temperature Trends Over the Years for Manipur

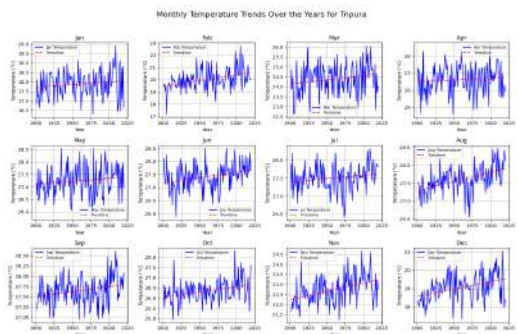


Monthly Temperature Trends Over the Years for Meghalaya





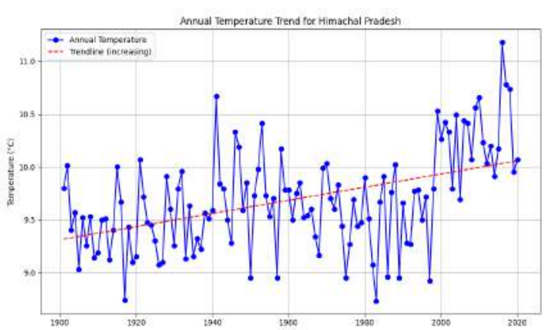


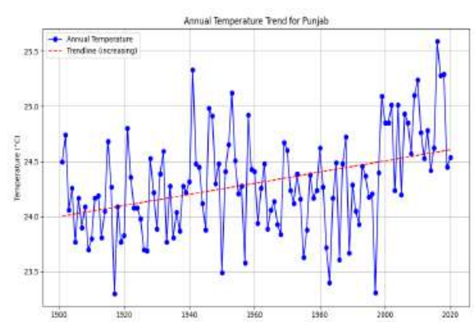


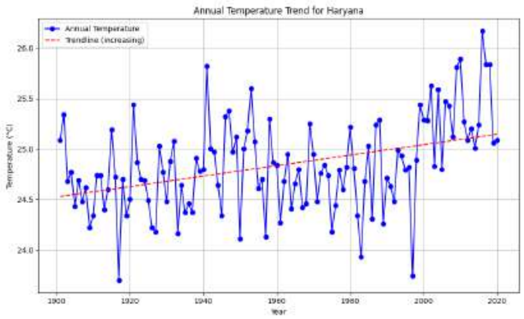
Observations: Eastern states experience humid subtropical climates, with warmer winters compared to the north. The region shows a warming trend during pre-monsoon periods. States like West Bengal and Odisha also face temperature spikes during cyclonic disturbances.

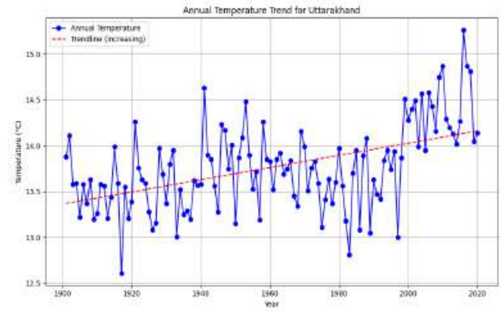
3.1.3 Annual Data Analysis

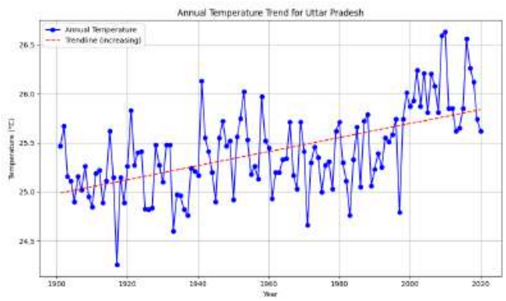
Northern States: Himachal Pradesh, Punjab, Haryana, Uttarakhand, Uttar Pradesh, Chandigarh, Delhi

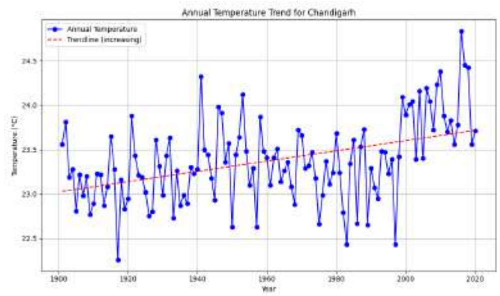


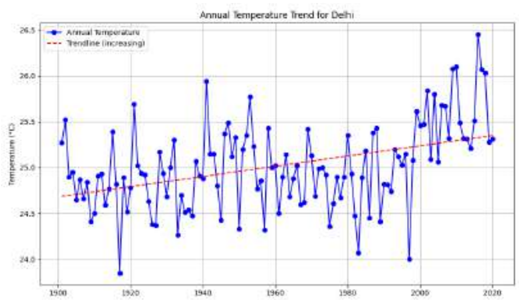






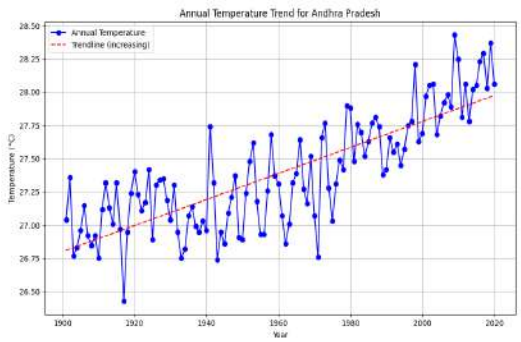


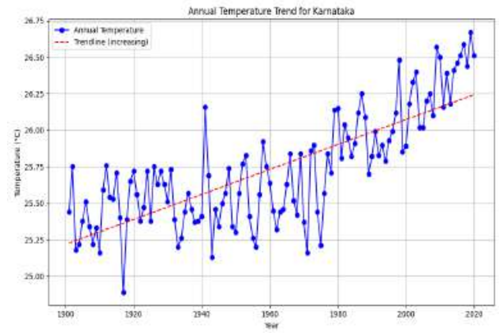


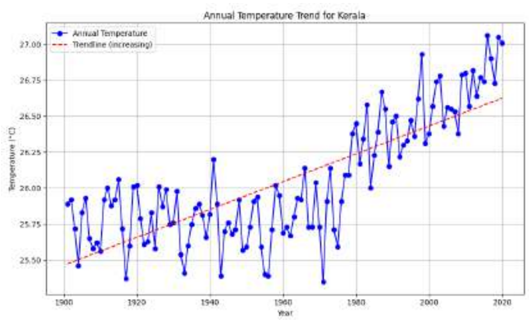


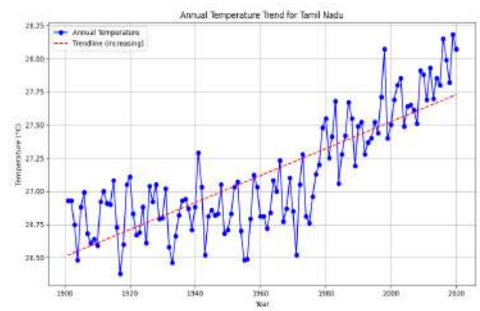
Observations: Northern plains show a marked warming trend in annual average temperatures, particularly during the summer months. The mountainous regions (e.g., Himachal Pradesh and Uttarakhand) exhibit milder warming trends annually due to altitude effects, but increased glacier melting highlights the impact of rising temperatures in higher altitudes.

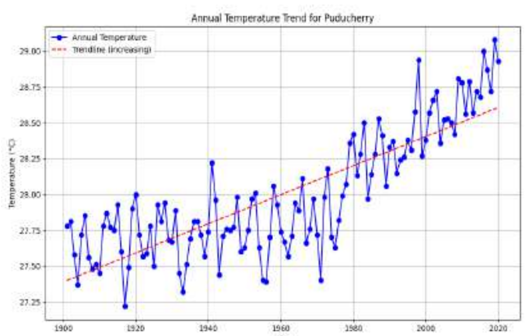
Southern States: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Puducherry, Lakshadweep

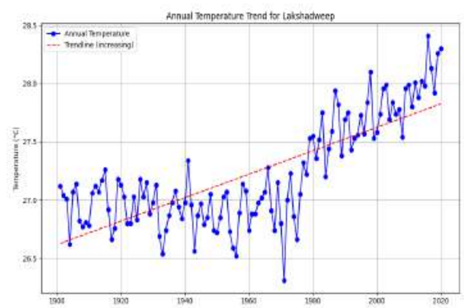






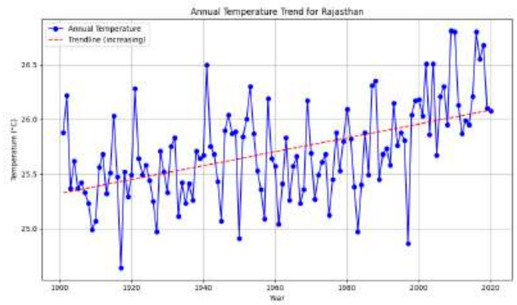


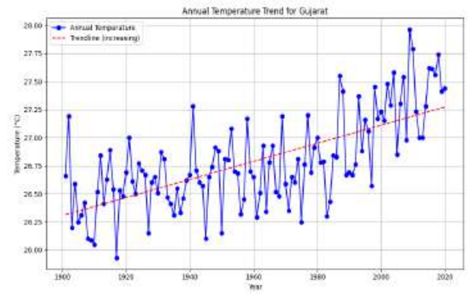


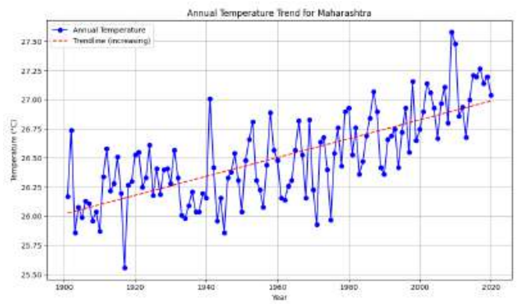


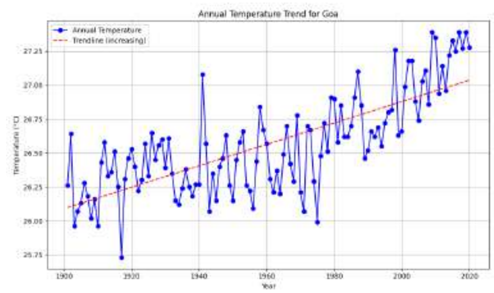
Observations: Southern India consistently shows annual warming trends. Coastal states like Kerala and Tamil Nadu experience moderated warming due to the influence of the oceans. However, inland areas such as Andhra Pradesh and Karnataka see sharper increases in annual average temperatures, especially post-monsoon.

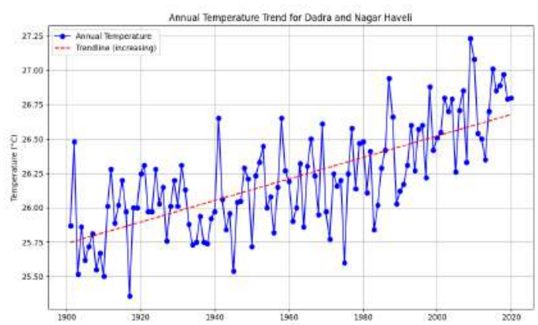
Western States: Rajasthan, Gujarat, Maharashtra, Goa, Dadra & Nagar Haveli and Daman & Diu

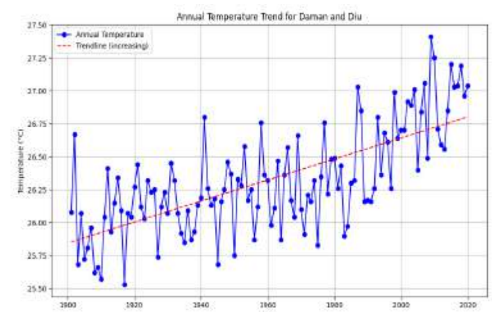






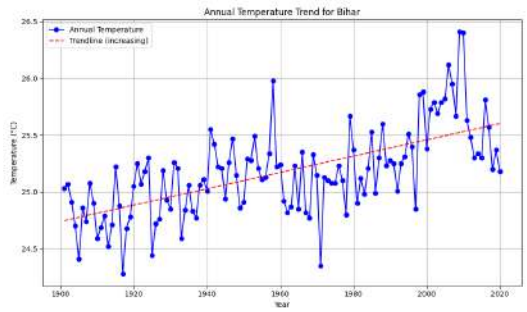


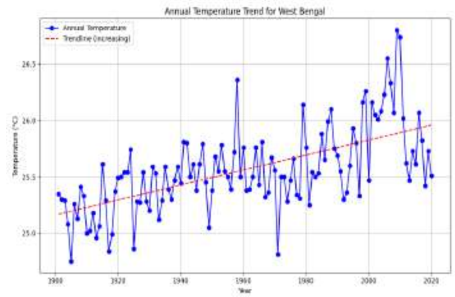


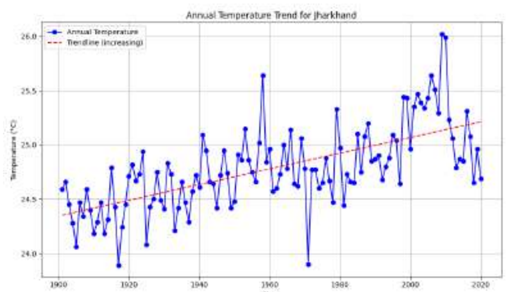


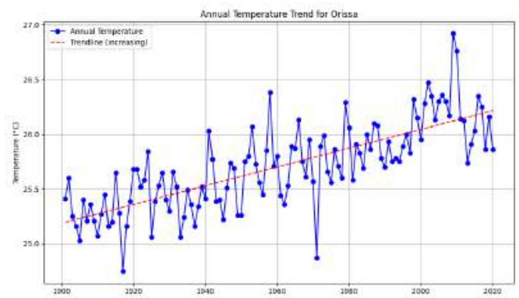
Observations: Western India, including Rajasthan, Gujarat, and Maharashtra, experiences some of the sharpest annual warming rates. The Thar Desert has seen intensified warming throughout the year, contributing to significant annual temperature increases. Coastal regions like Gujarat's coastline exhibit smaller variations due to oceanic moderation but still reflect an upward trend.

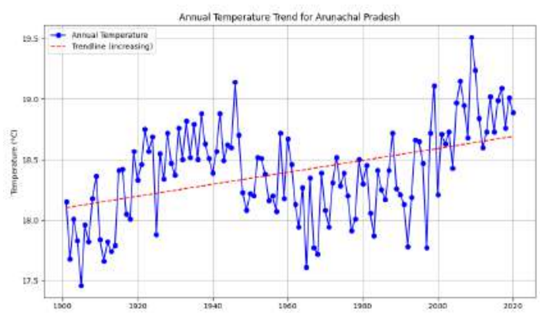
Eastern States: Bihar, West Bengal, Jharkhand, Odisha, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura

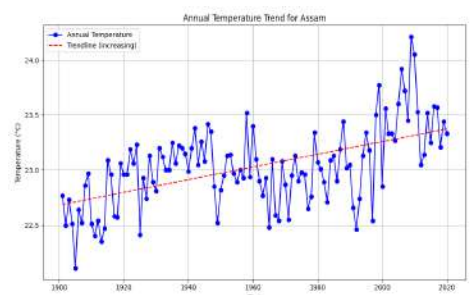


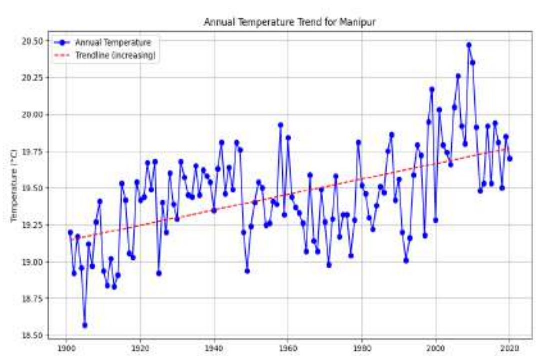


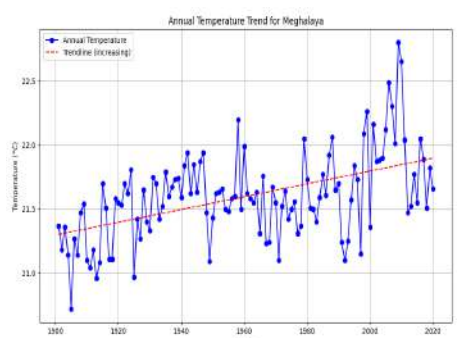


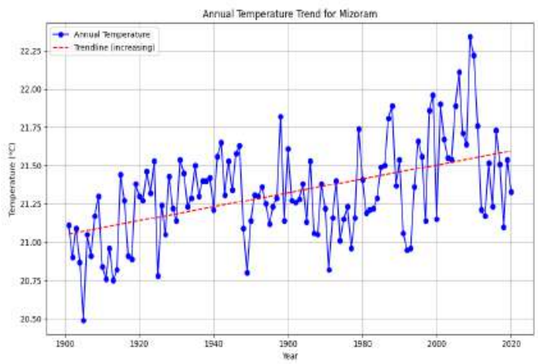


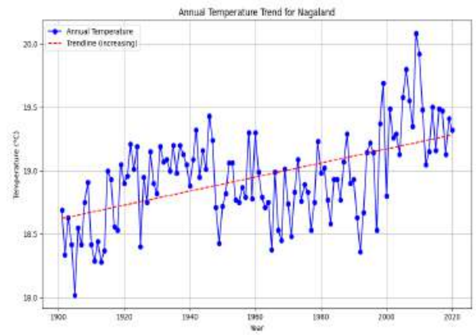


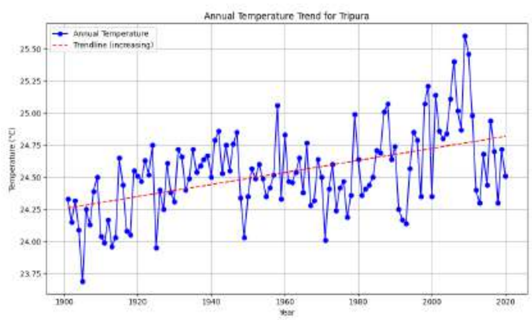








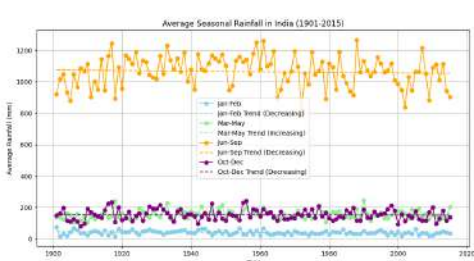




Observations: Eastern states, including Bihar, West Bengal, Odisha, and Jharkhand, exhibit strong warming trends annually, with higher pre-monsoon and summer temperatures driving the rise. Northeastern states also show warming trends, although the dense forest cover and hilly topography mitigate the temperature increase to some extent. Urbanization and deforestation in the eastern and northeastern states amplify warming effects in these regions.

3.2 Precipitation

3.2.1 Dataset Visualization



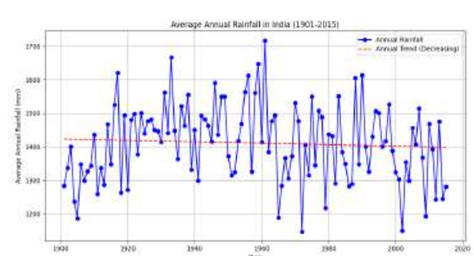
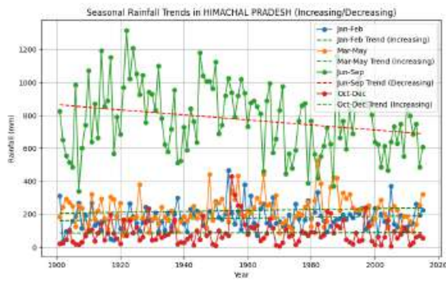
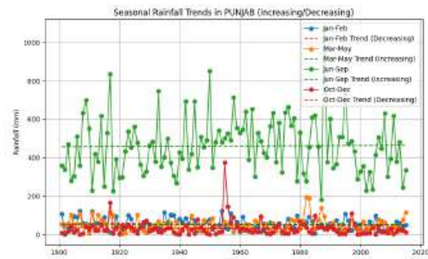


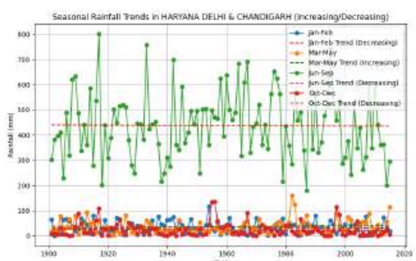
Fig 3.2.1 Monthly and Annual average precipitation in India over years along with the trend line

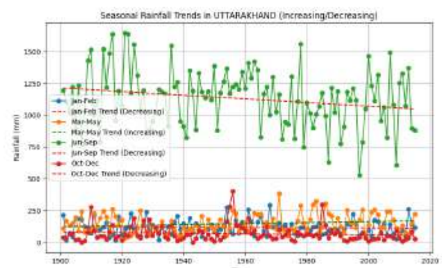
3.2.2 Monthly Data Analysis

Northern States: Himachal Pradesh, Punjab, Haryana, Uttarakhand, Uttar Pradesh, Chandigarh, Delhi



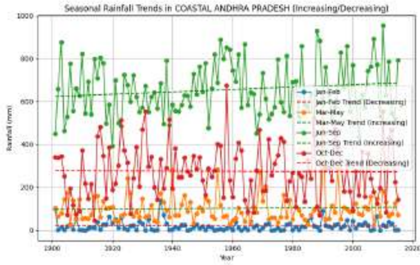


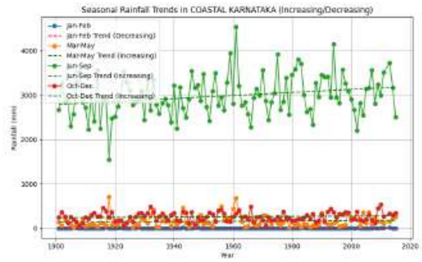


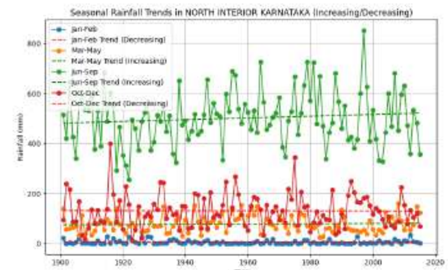


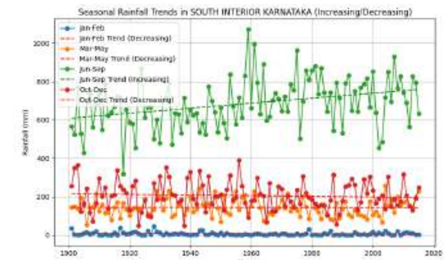
Observations: These states typically experience a dry period in the first half of the year (Jan-May), followed by intense monsoon rains (Jun-Sep), and moderate to low post-monsoon rainfall (Oct- Dec). Abnormality in Jammu and Kashmir is because of Snow winter, and melting of this snow in summers(after winters)

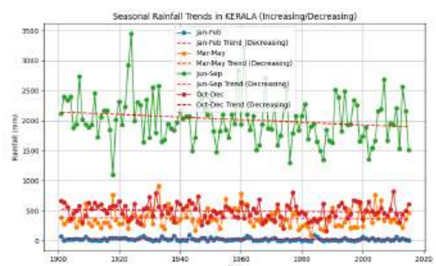
Southern States: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu,Lakshadweep

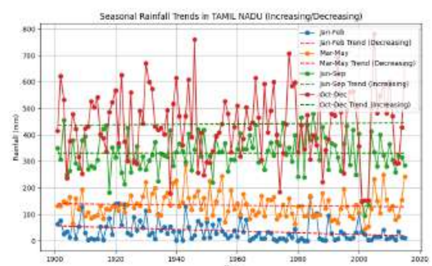


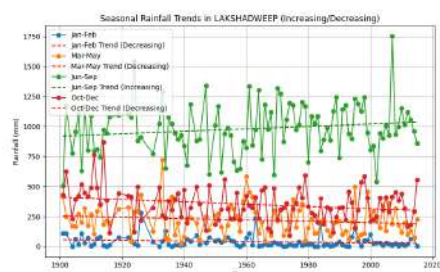






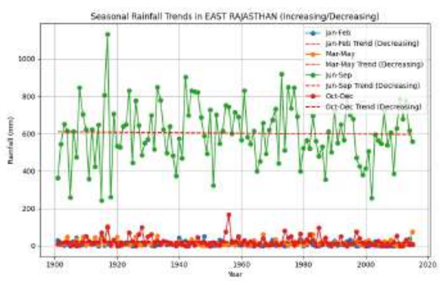


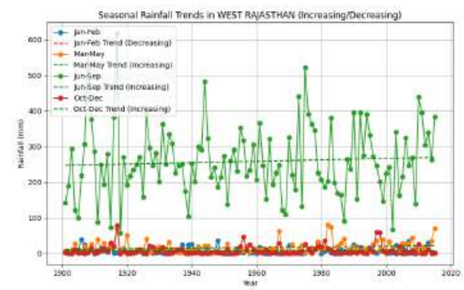


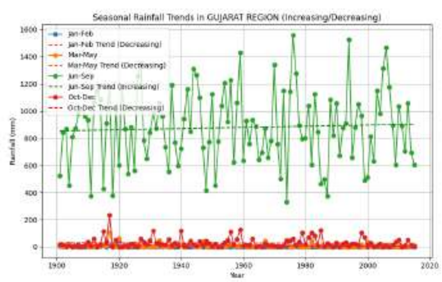


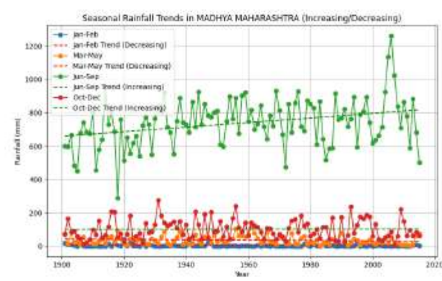
Observations: The southern regions tend to show a dry January-May period, with substantial rainfall in the monsoon (Jun-Sep) and some significant post-monsoon rainfall (Oct-Dec). Coastal regions likeKerala receive the highest rainfall during monsoons. Abnormality for AP: Coastal AndhraPradesh, being on the coastline, is frequently affected by cyclonic systems that form in the Bay of Bengal,The Presence of hills near the coast can lead to enhanced orographic rainfall, where moisture-laden winds from the ocean are forced upwards by the terrain, causing increased precipitation.

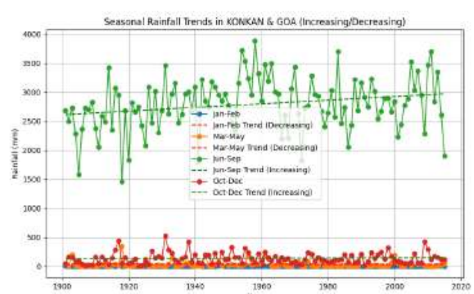
Western States: Rajasthan, Gujarat, Maharashtra, Goa





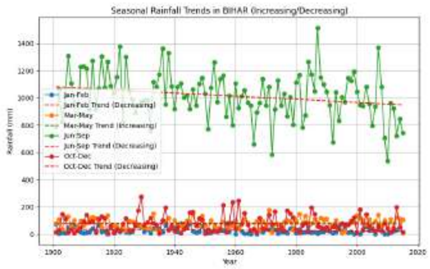


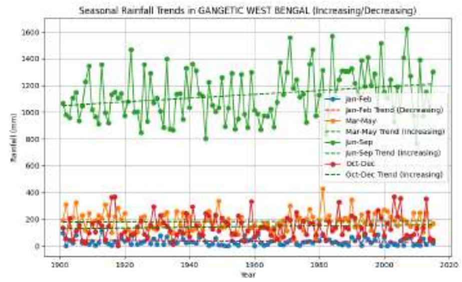


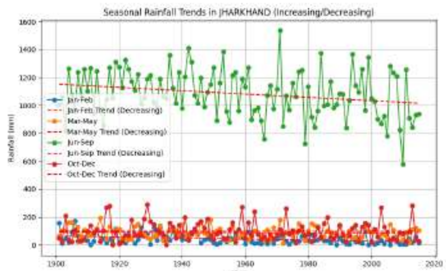


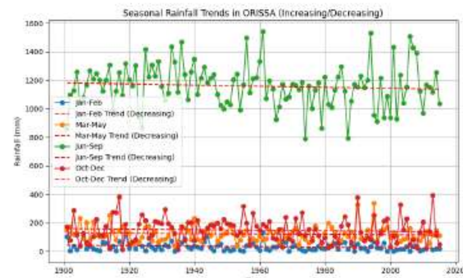
Observations: The western region is characterized by low rainfall in the first half of the year, followed by significant monsoon rainfall in Jun-Sep, especially in coastal areas like Goa and parts of Maharashtra.

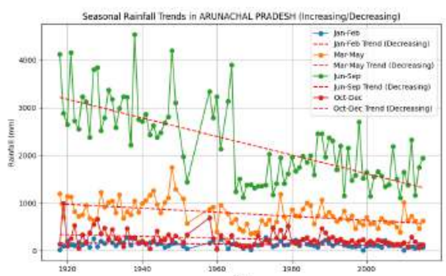
Eastern States: Bihar, West Bengal, Jharkhand, Odisha, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura

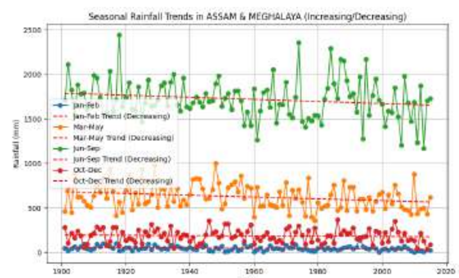


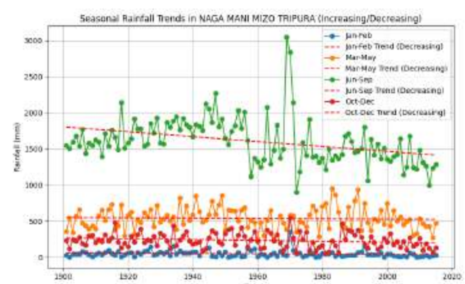








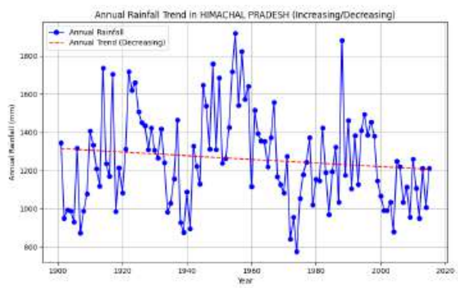


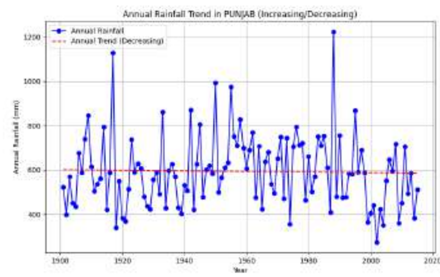


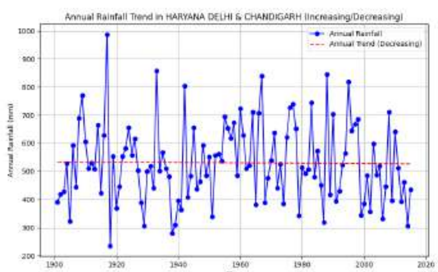
Observations: Eastern regions exhibit high rainfall during the monsoon (Jun-Sep) and moderate post-monsoon rains (Oct-Dec), with minimal rainfall in the first part of the year (Jan-May). Assam and Meghalaya, located in the northeastern part of India, experience some of the heaviest rainfall in India, especially in Meghalaya, which is home to Mawsynram, one of the wettest places on Earth. Also experience intense early monsoon rains (starting as early as March-April), especially in the hilly areas

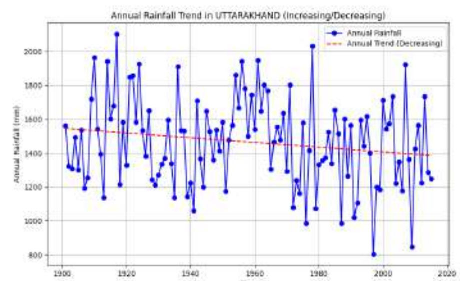
3.2.3 Annual Data Analysis

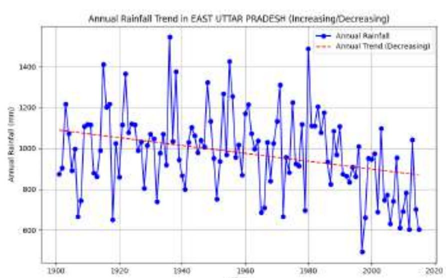
Northern States: Himachal Pradesh, Punjab, Haryana, Uttarakhand, Uttar Pradesh, Chandigarh, Delhi

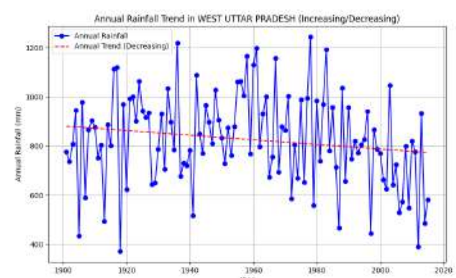






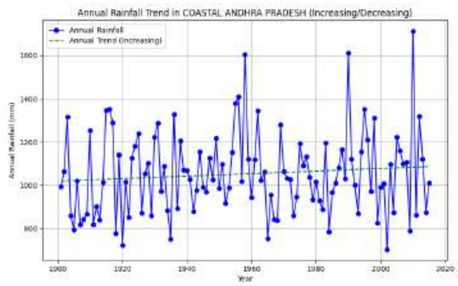


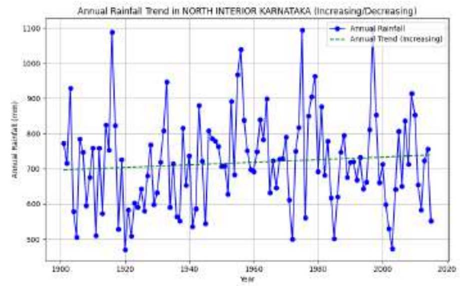


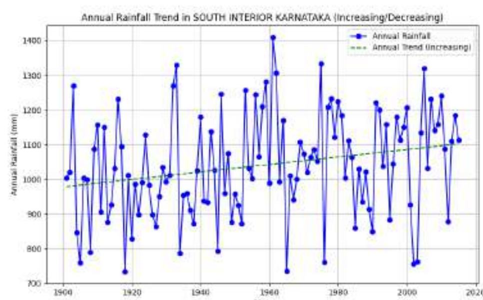


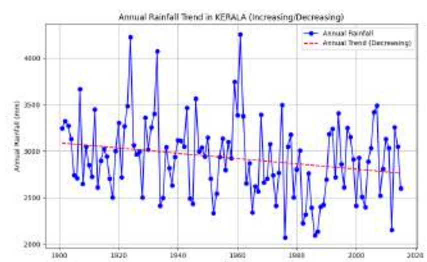
Observations: Variability in Rainfall: There is a significant fluctuation in annual rainfall levels across the years, indicating variability in the monsoon patterns. High Peaks and Lows: Some states display distinct peaks and troughs, reflecting periods of heavy monsoon and drought-like conditions. Consistent Rainfall Patterns: A few states show relatively stable patterns, though inter-annual variations are still present.

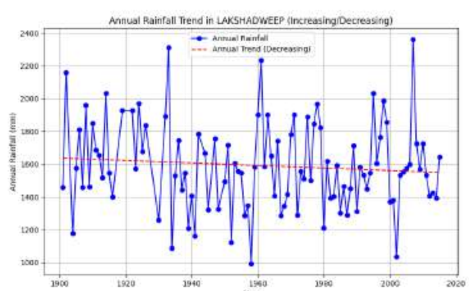
Southern States: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu,Lakshadweep

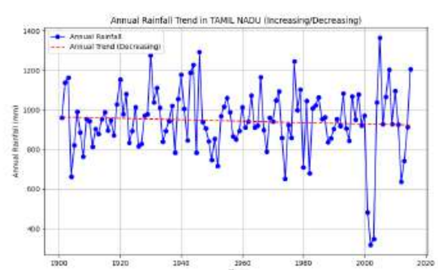






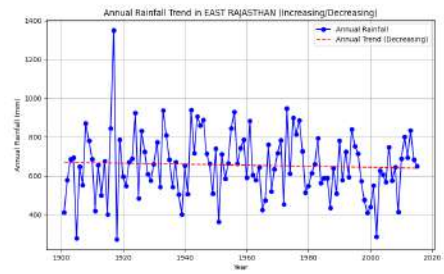


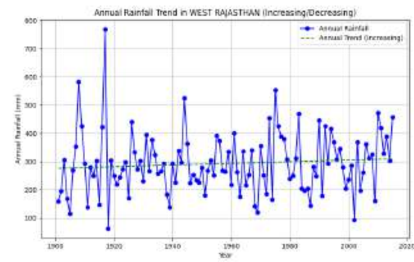


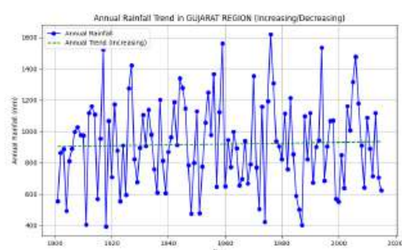


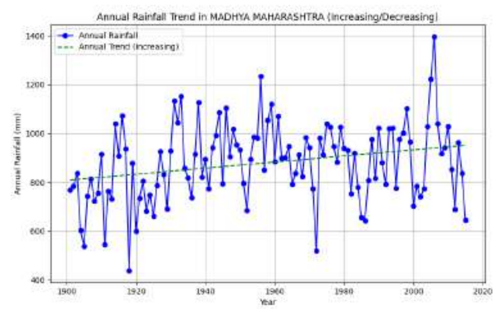
Observations: Higher Consistency: Southern states generally show more consistent rainfall patterns, with fewer extreme fluctuations compared to Northern states. Moderate to High Rainfall: Most of these states receive substantial rainfall, especially Kerala, which shows consistently higher rainfall levels. Seasonal Variability: The variations align with monsoon seasons, as the charts likely reflect annual trends influenced by the monsoon cycles.

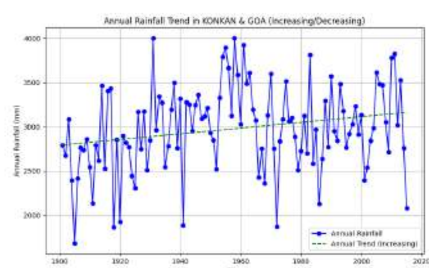
Western States: Rajasthan, Gujarat, Maharashtra, Goa





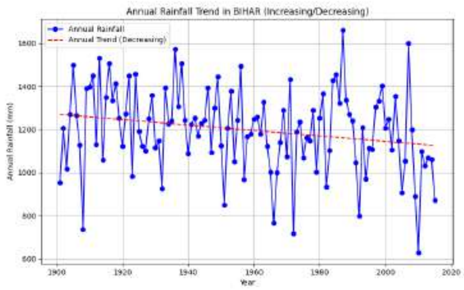


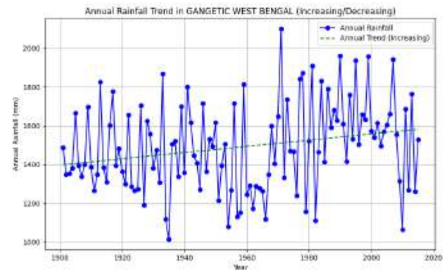


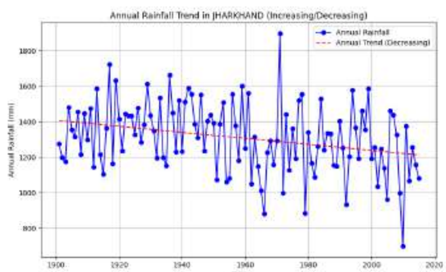


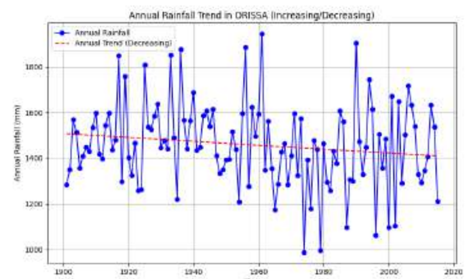
Observations: Lower Rainfall in Certain States: Rajasthan and Gujarat show relatively lower rainfall levels compared to Maharashtra and Goa, consistent with their semi-arid climate. High Peaks in Coastal Areas: Goa, and parts of Maharashtra have higher peaks, reflecting monsoon influence along the western coast. Yearly Fluctuations: There is visible variability in rainfall across the years, indicating changing monsoon patterns in Western India.

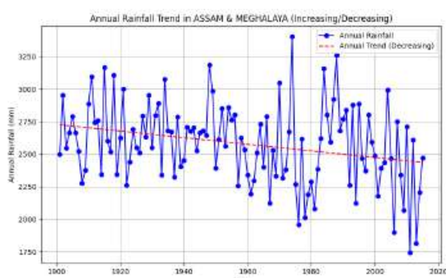
Eastern States: Bihar, West Bengal, Jharkhand, Odisha, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura

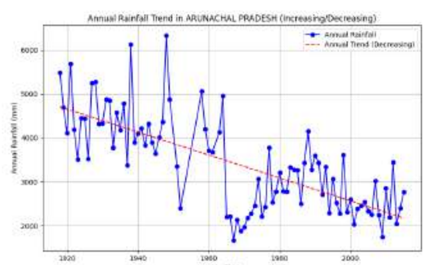


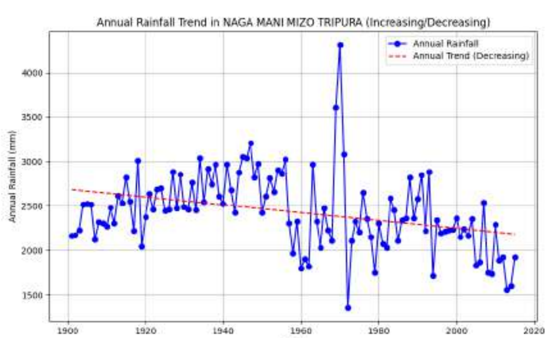








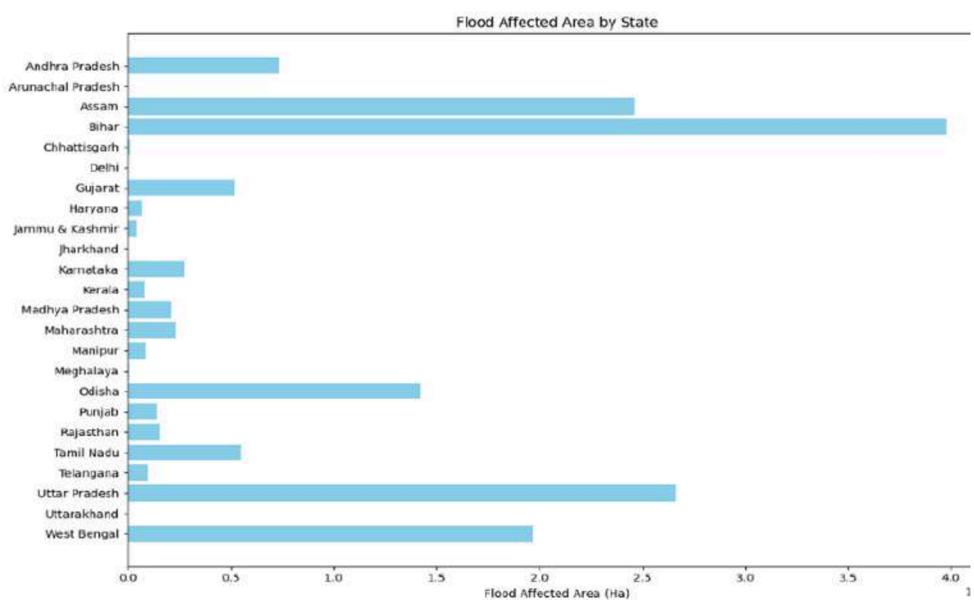




Observations: High Rainfall Regions: States like Arunachal Pradesh, Assam, and Meghalaya exhibit consistently high annual rainfall, likely influenced by their proximity to the Eastern Himalayas and the Bay of Bengal monsoon currents.Variability Across States: There is noticeable inter-annual variability in rainfall, with some states experiencing significant fluctuations, indicating varying monsoon intensity across years.Seasonal Peaks: The charts show periodic peaks that align with monsoon season, particularly for states closer to the coast or mountainous regions, which receive substantial rainfall during the monsoon months.Lower and Stable Rainfall in Some States: States like Bihar and Jharkhand display relatively lower and more stable rainfall patterns compared to northeastern states, reflecting differences in regional climate.

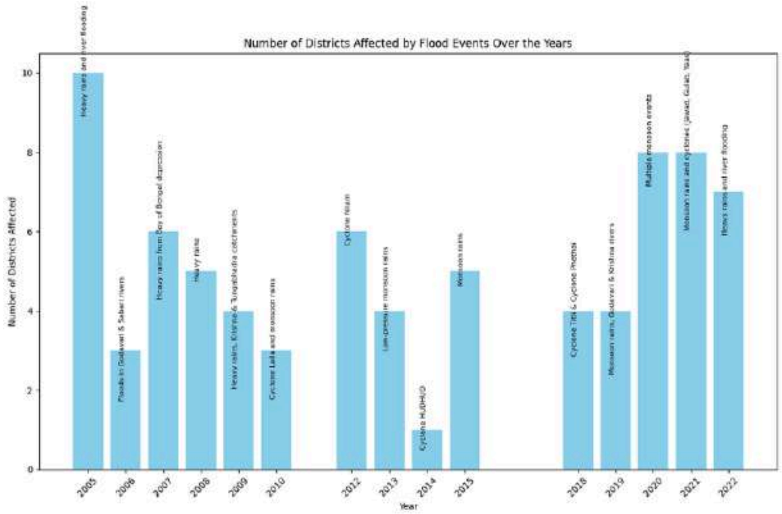
3.3 Floods

3.3.1 Dataset Visualization



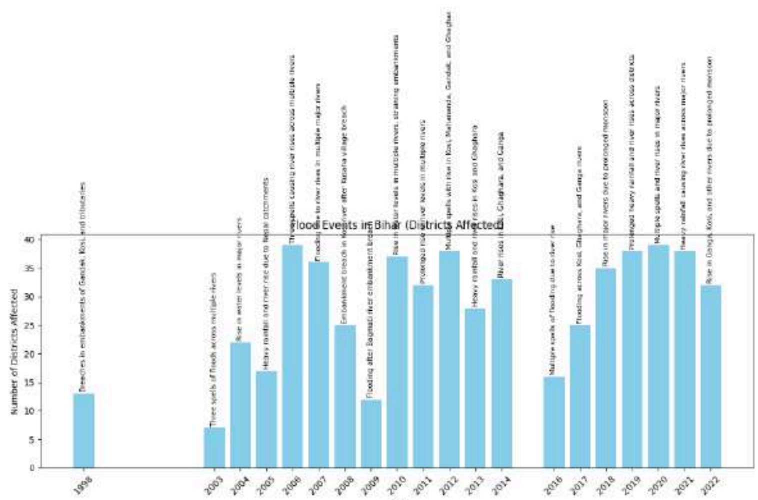
Flood impacts in Indian states vary greatly due to geography and climate. States like Bihar and Uttar Pradesh, located along major rivers such as the Ganges, are highly vulnerable to floods

1. **Andhra Pradesh**



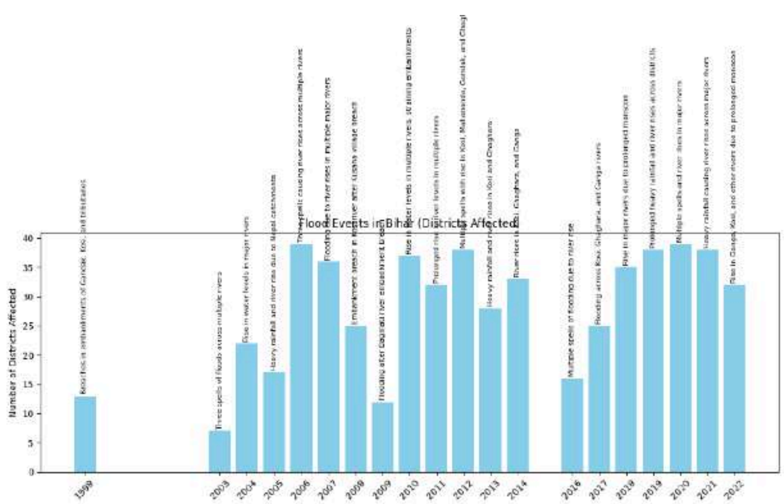
Floods are mostly due to heavy rains and cyclones from Bay of Bengal

2. **Assam**



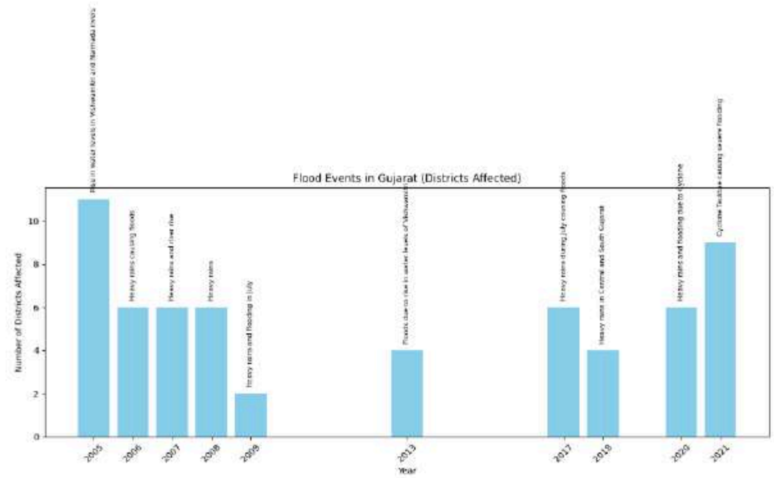
Floods are mostly due to heavy rains and cyclones from Bay of Bengal

3. **Bihar**



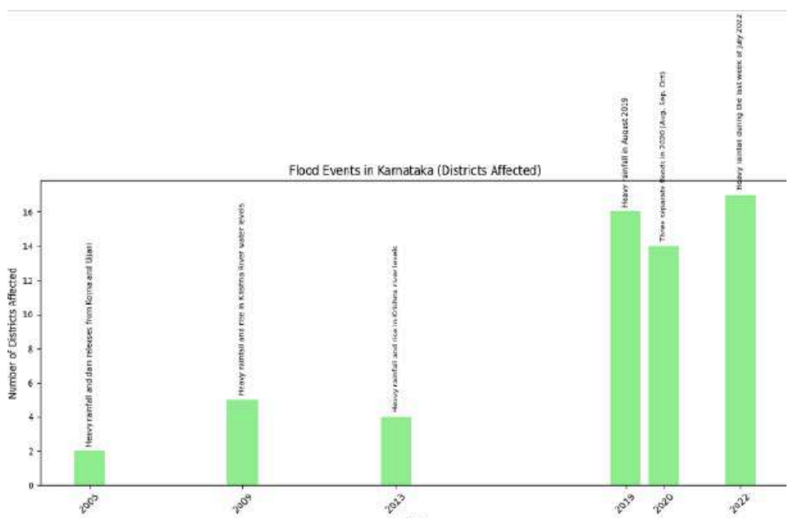
Bihar is affected mostly due to Flash floods

4. **Gujarat**



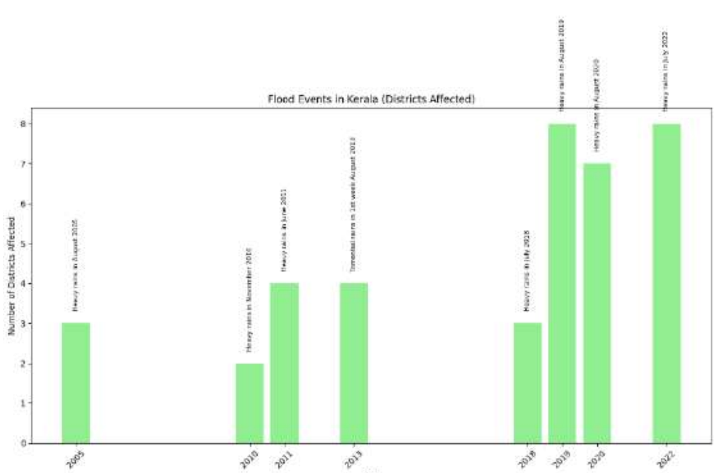
Mostly due to Heavy rains.

5. **Karnataka**



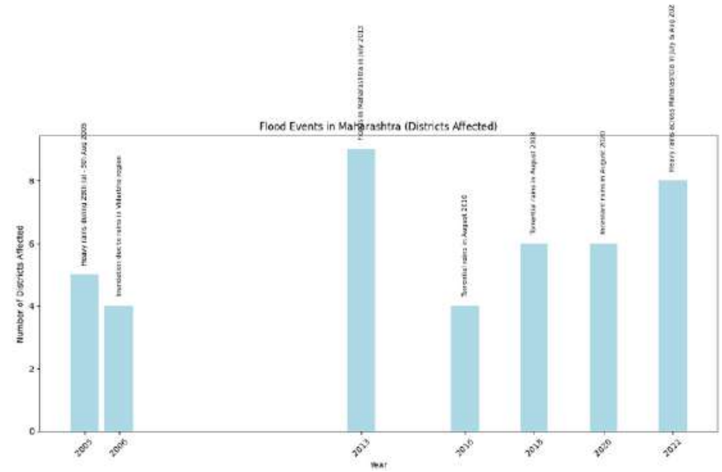
Floods in Karnataka are caused mainly by the heavy monsoon rains, which then affect the coastal and northern regions.

6. **Kerala**



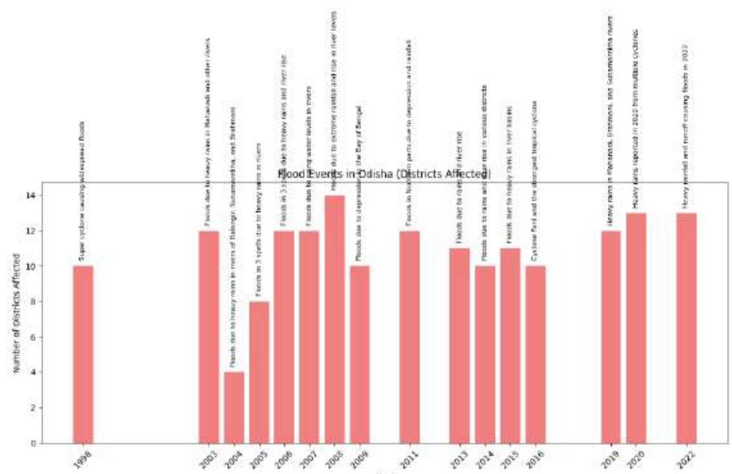
Caused due to River stretches, rainfall level exceeding over the years-> rivers overflow->floods.

7. Maharashtra



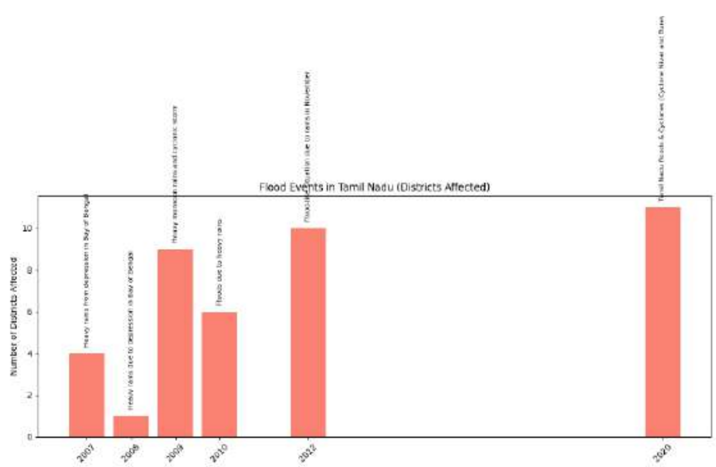
Flooding occurs due to overflow of rivers

8. Odisha



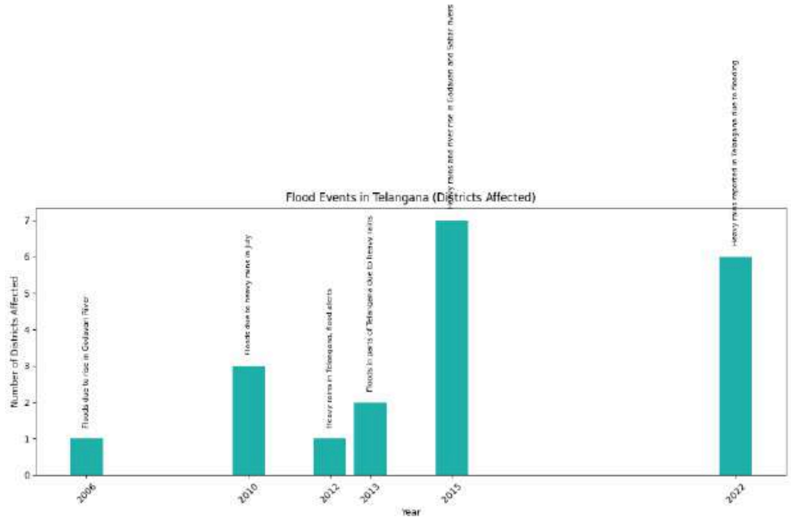
Overflow of rivers, rains cause flooding. Cyclones like Phailin also cause floods in the state.

9. Tamil Nadu



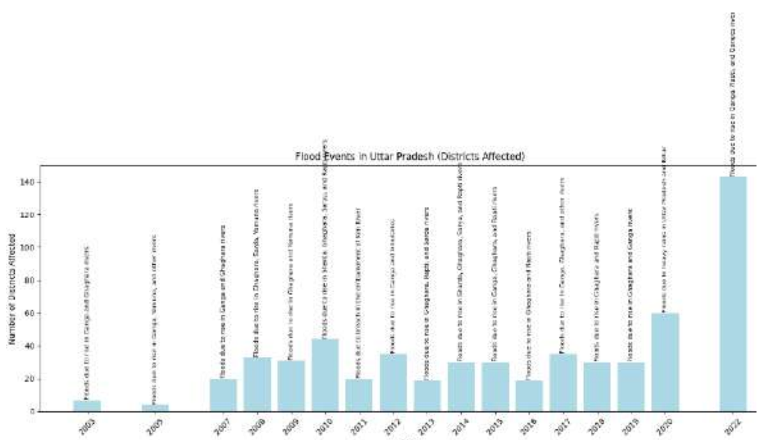
Floods occur due to northeast monsoons that brought heavy rains upon the city of Chennai.

10. Telangana



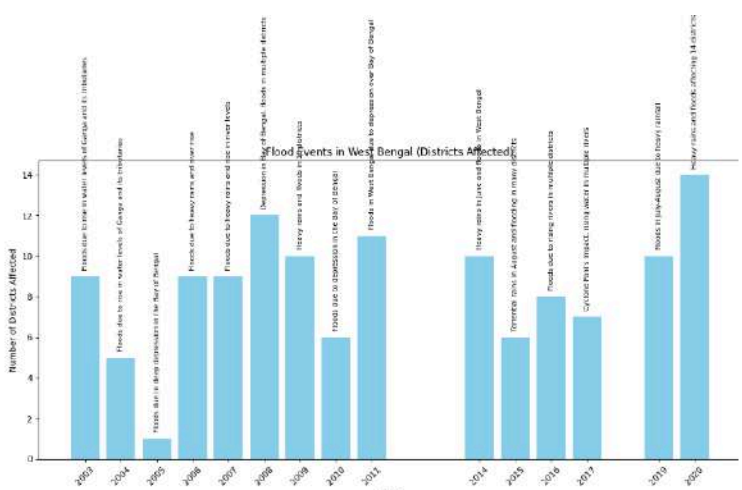
Floods Occur due to heavy rains

11. Uttar Pradesh



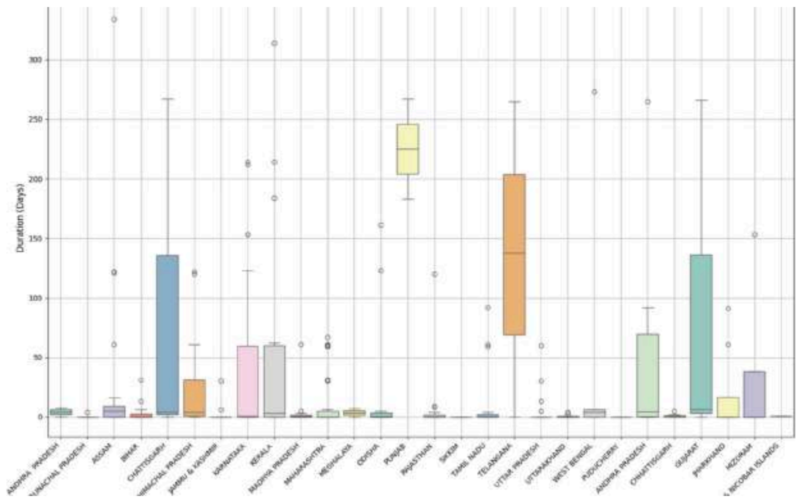
Flooding in rivers Ganga, Yamuna, Ghaghra, Gomti, and Rapti rightly explain flood incidents, particularly in the eastern region of the state.

12. West Bengal

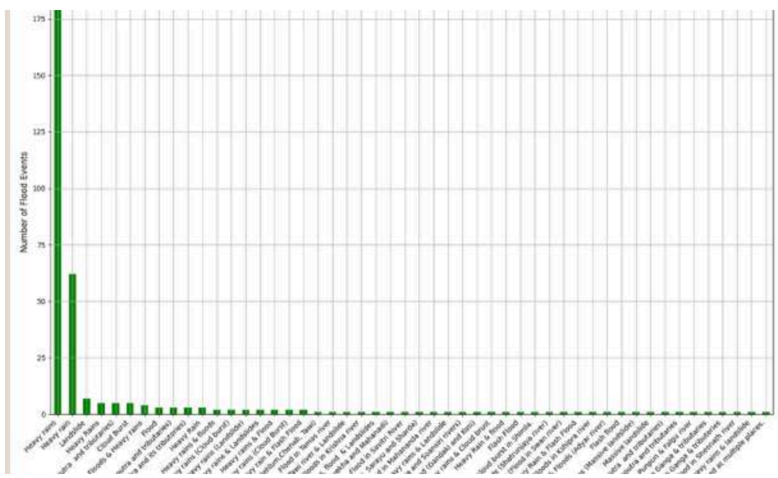


West Bengal has floods due to overflowing of rivers.

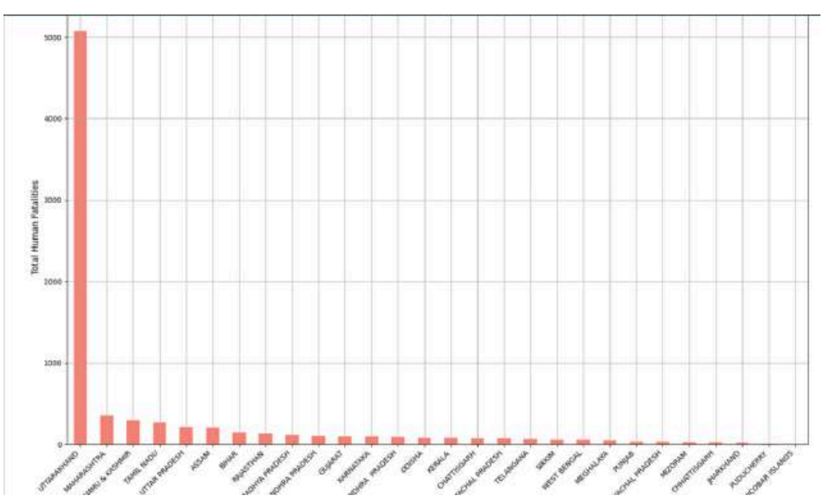
3.3.2 Observations - Overall Indian States



Duration Of Floods Across States.



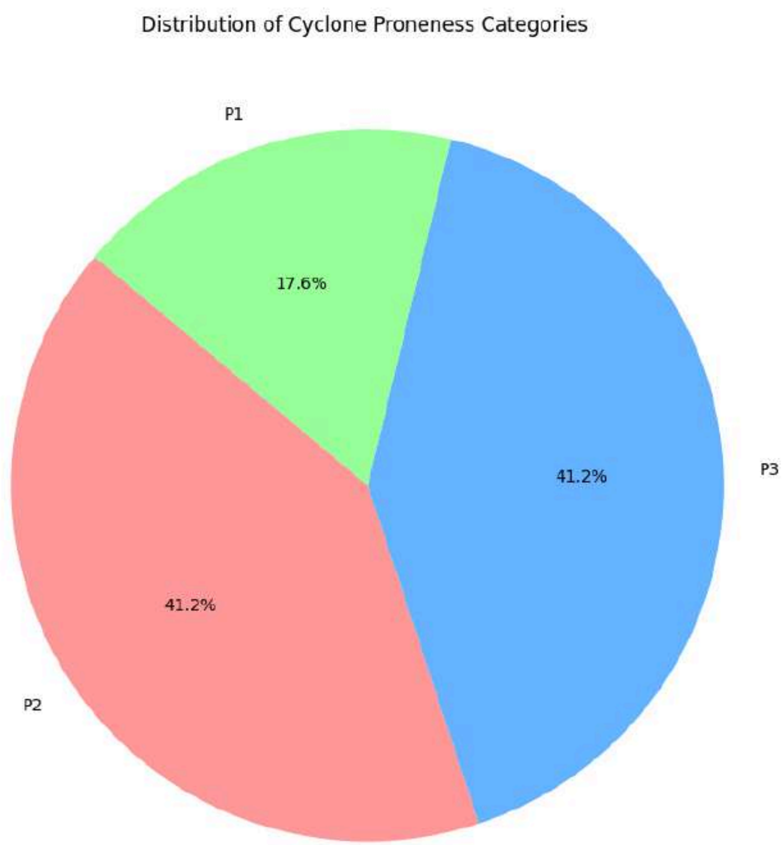
Number Of Flood associated with each cause of Floods, Most Of the floods are associated with heavy rainfalls.



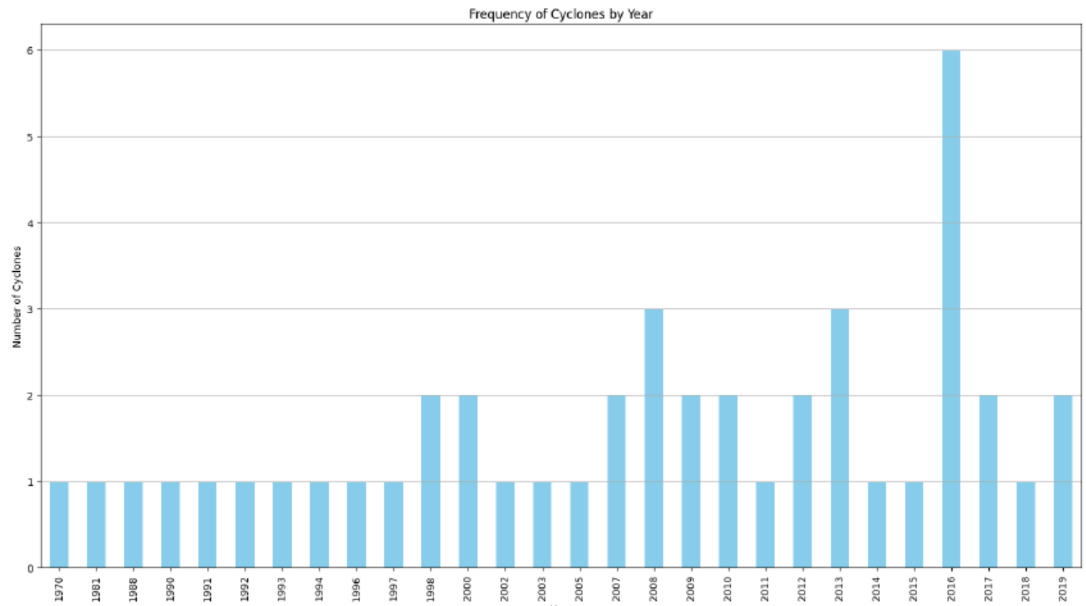
Human Fatality due to Floods across States in India States like Goa, Kerala, and Gujarat experience fewer fatalities. It majorly depends on Infrastructure.

3.4 Cyclones

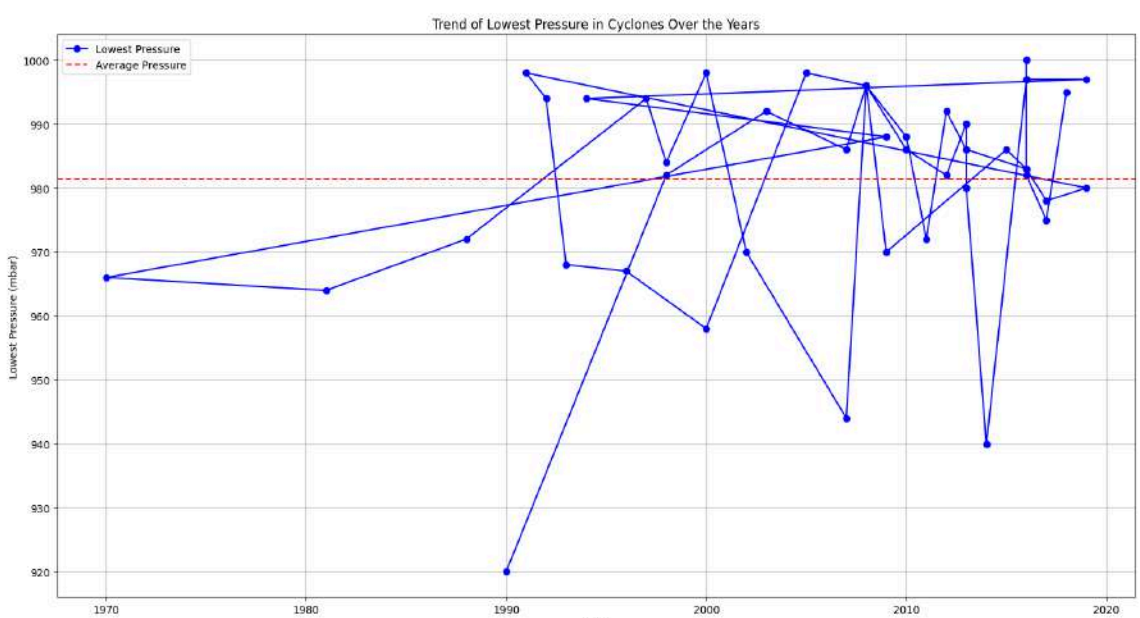
3.4.1 Dataset Visualization



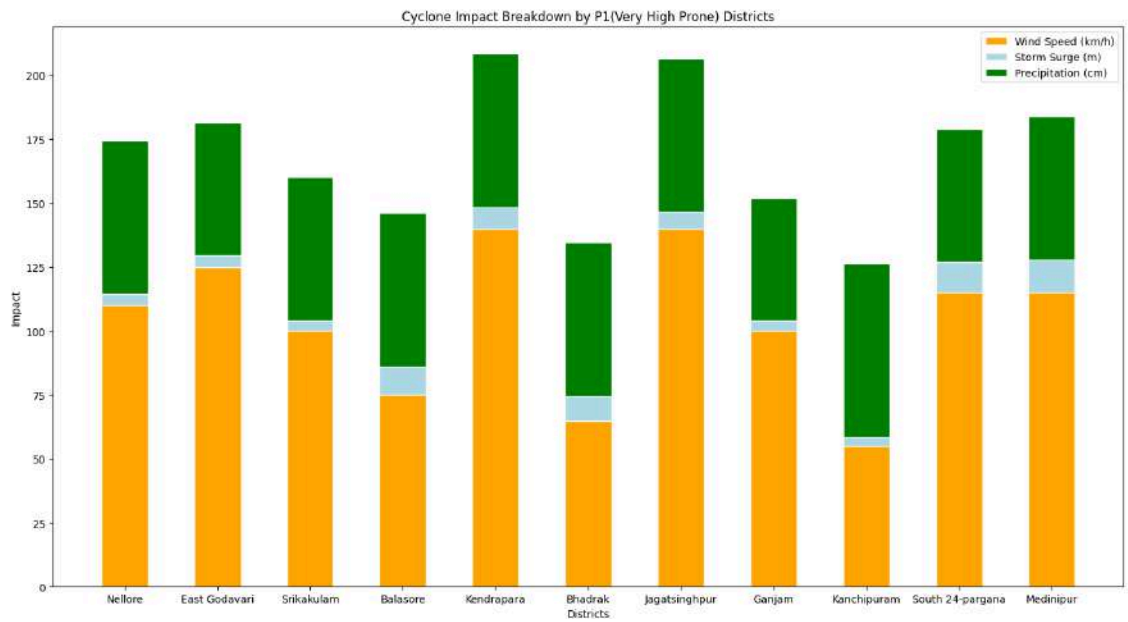
The above pie chart denotes the distribution of cyclone proneness in India as we can see Very high proneness(P1) is 17.6% while moderate(P2) and low proneness(P3) have the same proportion that is 41.2%.



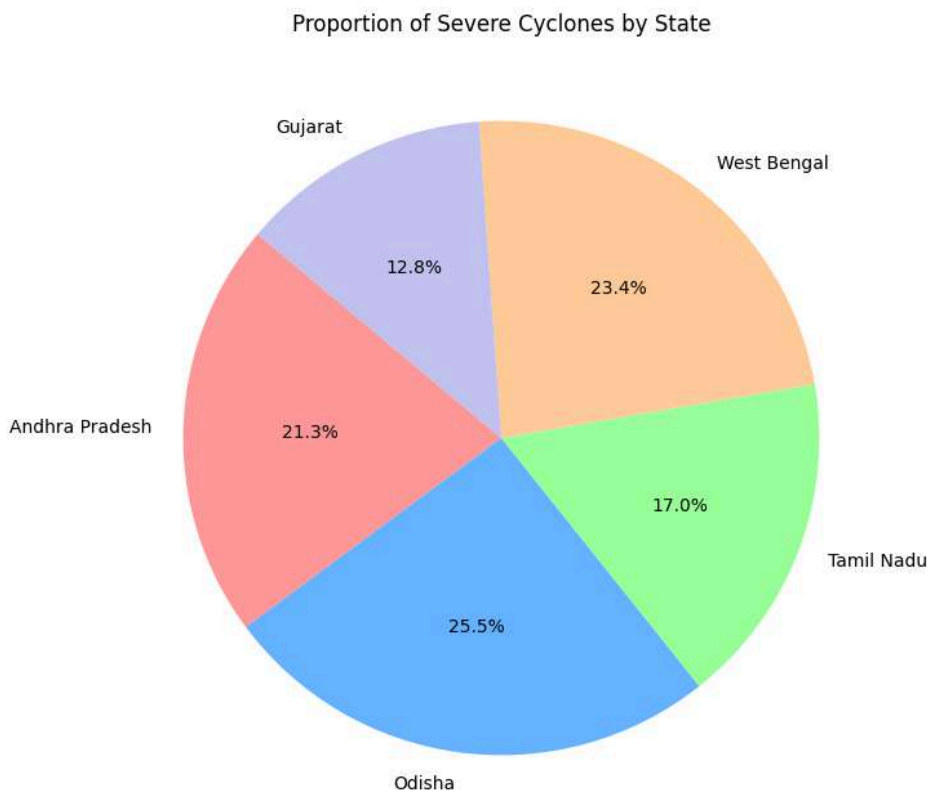
The graph illustrates the yearly frequency of cyclones from 1970 to 2019. A large portion of years between 1970 and 2005 reflects a low, stable frequency of only 1 or 2 cyclones. However, after 2005, cyclone activity started to rise. Notably so in the years 2008 and 2016 when the observed frequency peaks at that time. From the graph, the year 2016 stands out with the highest frequency with recorded 6 cyclones. It could be a new trend in climatic patterns or better detection abilities lately.



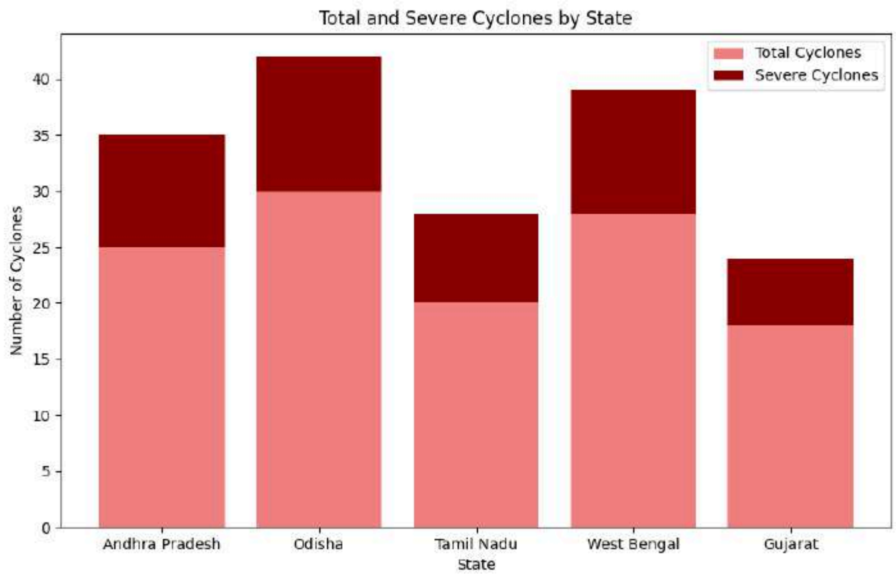
The graph illustrates the trend of the lowest recorded pressure in cyclones from 1970 to 2020. The blue line represents the changing pressure values that had quick drops as the cyclone intensified. Such quick drops happened towards the late 1980s, early 1990s, and in the years of the 2010 period, implying high-intensity cyclone activities during those years. Although there is no distinct trend of increasing or decreasing pressure, most values remain above 950 mbar, with occasional extreme lows. The red dashed line represents the average pressure level, highlighting the variability and intensity of certain cyclones over the years.



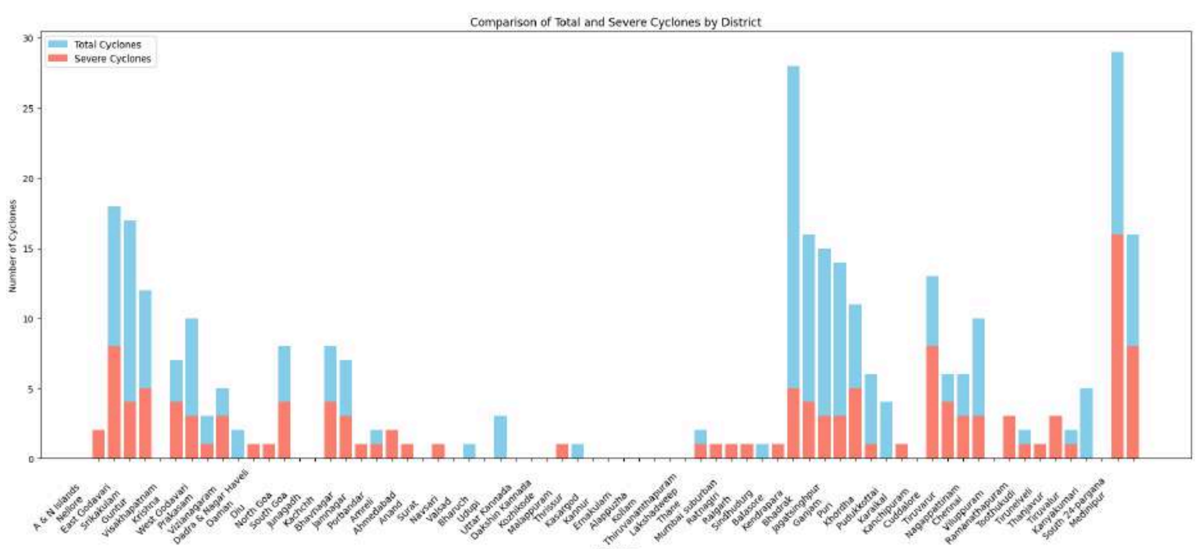
The graph shows the impact of cyclones in a few high cyclone-prone (P1) districts. It is divided into three sections: wind speed in orange, storm surge in light blue, and rainfall in green. All the values shown here are this aggregated effect whereby the wind speed is the highest effect in all the districts. Rainfall scores are relatively high. Storm surge is a very minor addition to the effects. Such districts as Kendrapara and Ganjam show higher overall impacts, indicating severe cyclonic events, while Kanchipuram has a more or less impact profile. This visualization brings into sharp focus the differing intensity cyclonic effects of the districts.



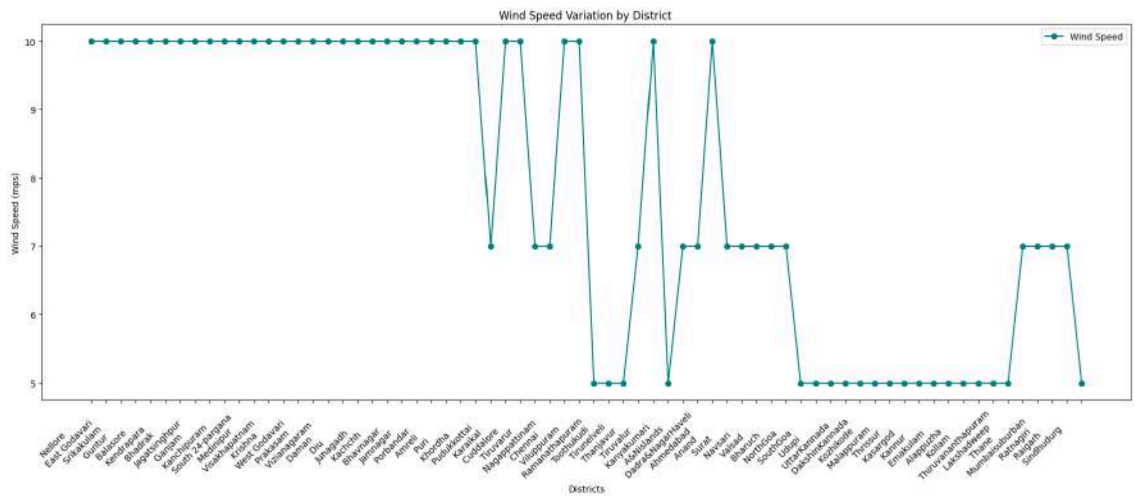
This pie chart gives a percentage of severe cyclones in five states of India. One finds that Odisha is the most affected by 25.5%, followed by West Bengal with 23.4%. Then comes Andhra Pradesh at 21.3%, while Tamil Nadu and Gujarat are relatively less influenced, at 17% and 12.8% respectively. From this, it can be found that Odisha and West Bengal are two most cyclone-affected states out of the above mentioned five states.



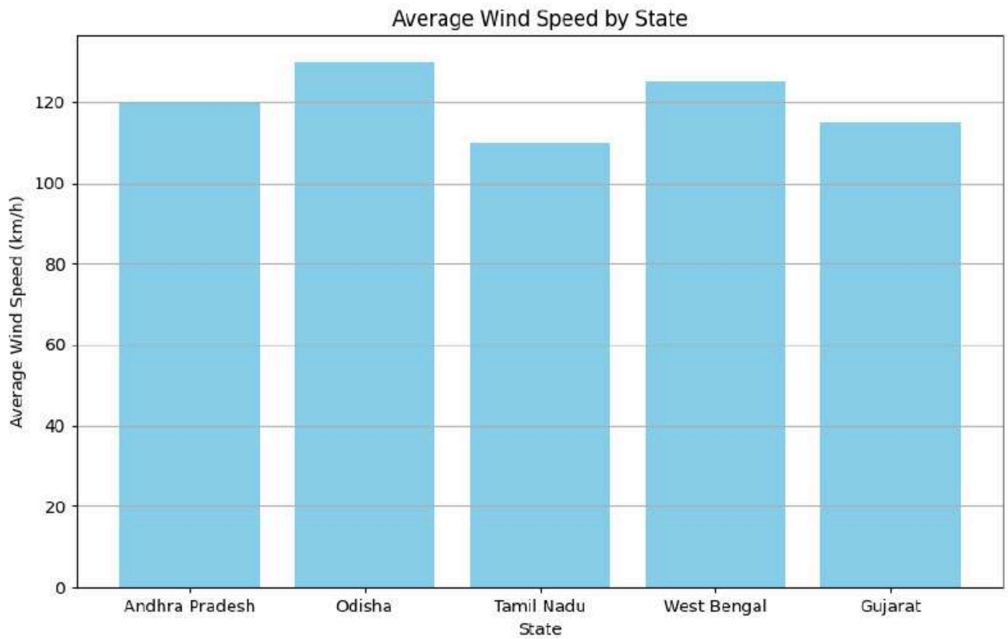
This bar graph shows a comparison of total cyclones and extreme cyclones between five Indian states. The state with the highest total cyclones includes more than 40, with a significant portion of them extreme cyclones. Andhra Pradesh and West Bengal have a similar number of total counts, slightly above 35 cyclones each, and extreme cyclones comprise a strong fraction. Tamil Nadu has fewer total cyclones, and the lowest values are found in Gujarat, both for total as well as severe categories. This visualization involves the comparison wherein, Odisha is the most vulnerable state with a high severity ratio whereas Gujarat experiences relatively lesser cyclones overall.



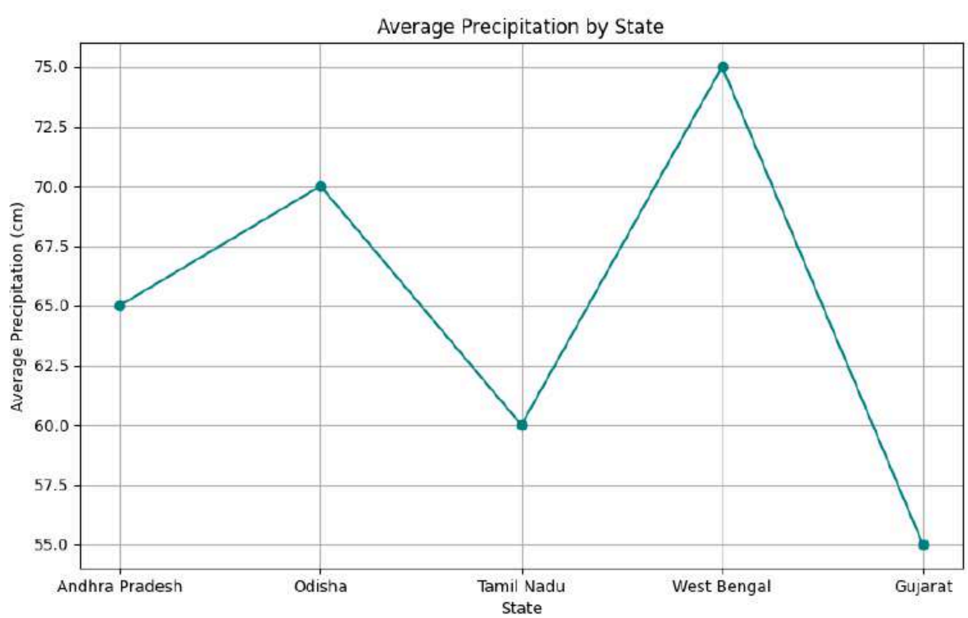
It is a bar graph representing an elaborate comparison between total and severe cyclones within various districts. Total cyclones are shown in the blue color and severe cyclones in red color, for each portion of a bar. There are some definite districts such as Andaman & Nicobar Islands, East Godavari, and Ganjam wherein there were a good number of total cyclones with an adequate percentage of severe ones. While most of the districts in Kerala and Goa have relatively fewer instances of both total and severe cyclones, this kind of granular representation focuses on the deviations of the impacts of the cyclone at the district level and underlines the areas that are more vulnerable on the coast and islands.



The graph depicts the trend of wind speed distribution among various districts. It may be noted that there exist districts where wind speed remains constant at about 10 mps; though some experienced rather irregular trends. A few districts face noticeable dips in wind speed and some points as low as 5 mps. One can see from data that though the general instability in wind speed may be expected over many portions of a region, some experience considerable variability.



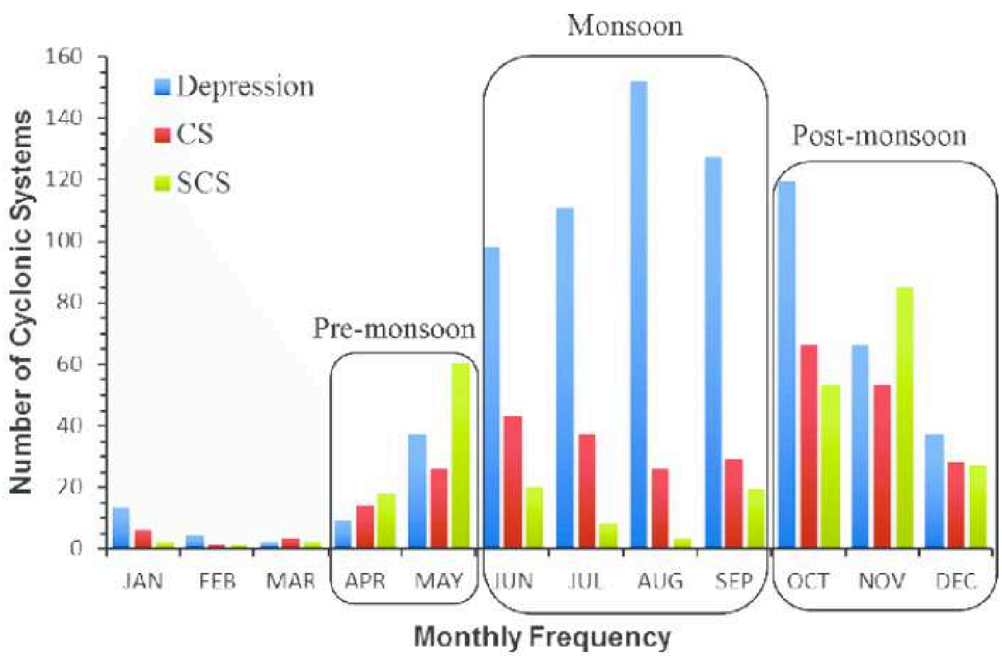
This bar graph shows a comparison of Average wind speed between five Indian states. The state with the highest wind speed includes more than 120km/h wind speed. Odisha and West Bengal have similar wind speeds, slightly above 120km/h each. Andhra pradesh has less wind speed, and the lowest wind speed isfound inTamil Nadu. This visualization involves the comparison wherein, Odisha is the most vulnerable state with a high severity ratio whereas Tamil Nadu experiences relatively lesser wind speed overall.



This line graph shows a comparison of Average precipitation between five Indian states. The state with the highest precipitation includes nearly 75cm precipitation.Gujarat has the lowest precipitation. This visualization involves the comparison wherein, West Bengal is the most vulnerable state with a high precipitation whereas Gujarat experiences relatively lesser precipitation overall.

3.4.2 Observations

Cyclone Frequency and Intensity: The study revealed that the eastern coast of India has experienced a huge number of cyclones during the past century, and the highest number of genesis of cyclonic disturbances occurs over Bay of Bengal. On average, five to six cyclonic disturbances originate every year over the North Indian Ocean and are more concentrated during the pre-monsoon period (April-May) and post-monsoon period (October-November). These storms hit the states of Odisha and Andhra Pradesh with full force, major cyclones landing on the shore at least once a few years.



[Monthly frequency of cyclonic disturbances in North Indian Ocean region during 1891-2015]

Climate Change and Cyclone Intensity: An important takeaway from this research paper in terms of the augmenting intensity of cyclones in recent years is that it relates to climatic change. Cyclonic storms like Amphan and Phailin, which had wind speeds higher than 200 km/h, caused destruction. These strong storms are said to be the consequences of climate change, primarily because of increased sea surface temperatures, causing the development of stronger cyclonic storms. The warmer ocean feeds the cyclone storm with more energy, increasing wind speeds and the storm surge[study].

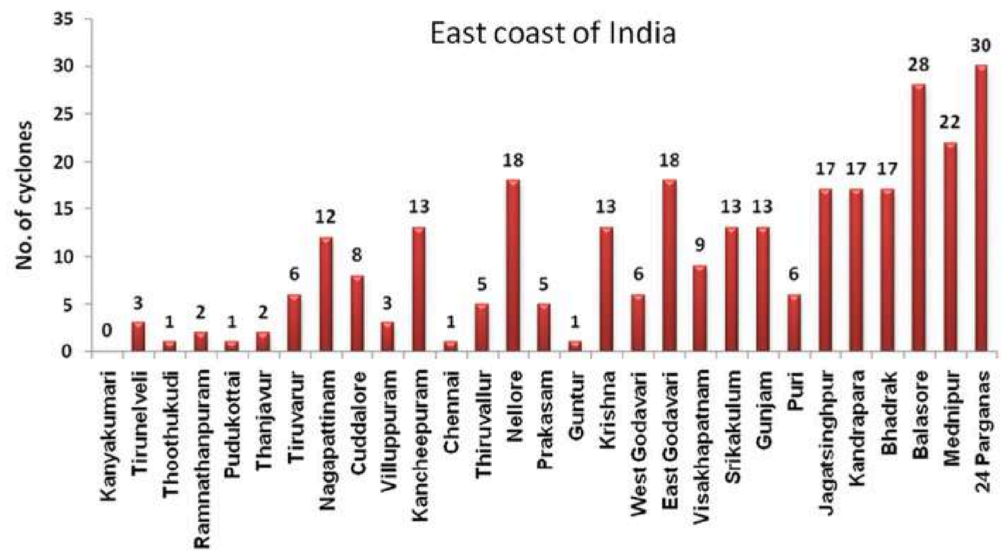
Table 3. Decadal Pattern of Cyclonic events according to severity in BoB Basin.

Decades	Cyclonic Storm (CS: 62–88 km)	Severe cyclonic storm (SCS: 89–118 km)	Very severe cyclonic storm (VSCS: 119–165 km)	Extremely severe cyclonic storm (ESCS: 166–220 km)	Super cyclonic storm (SuCS: > 220 km)
2001–2010	9	6	3	3	0
2011–2020	8	3	6	3	1

Source: Computed by Authors from RSMC-IMD e-Atlas.

[fig-2]

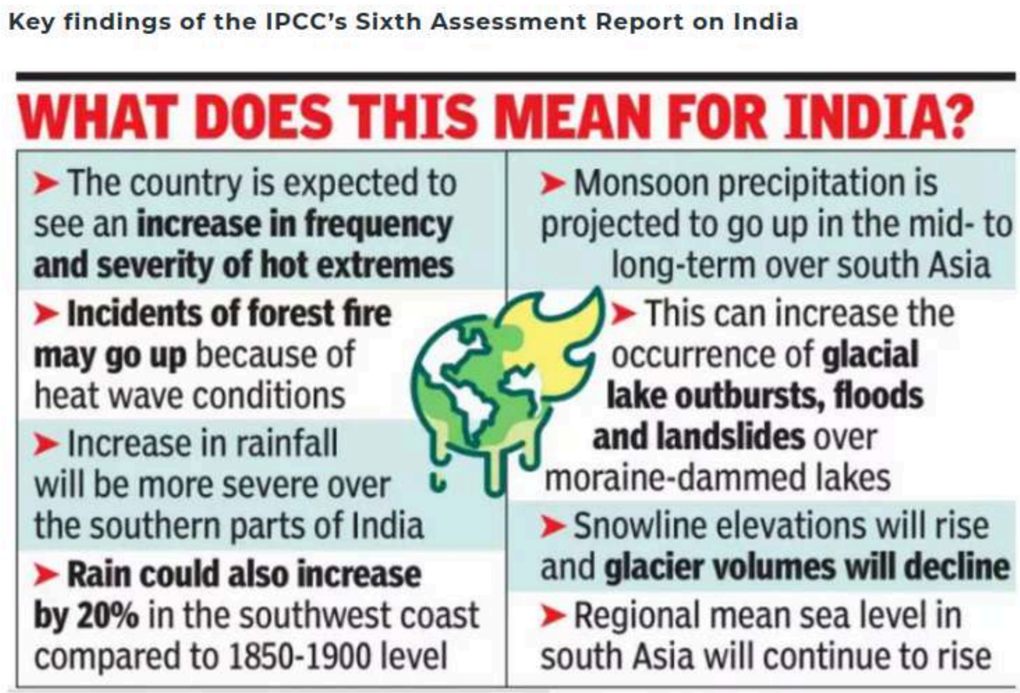
Hazard-Prone Districts: The composite rating system revealed that Balasore, Jagatsinghpur, and Kendrapara districts in Odisha and Nellore, East Godavari in Andhra Pradesh are categorized as "very high" category cyclone-prone areas. These districts have experienced several severe cyclonic conditions. Some of the areas recorded storm surges up to 7 meters. Coastal districts of West Bengal including South 24-Parganas and Medinipur, are also identified as high-risk due to their dense population and low-lying geography.



[Frequency of land falling cyclonic storms district-wise during 1891–2018]

Preparedness and Mitigation: Though NDMA and State Governments have seen tangible improvements in cyclone forecasting and early warning systems, much remains to be done. Timely evacuation of vulnerable populations definitely made Cyclone Amphan a less deadly event than those reported in earlier cyclones, such as the 1999 Odisha Super Cyclone. Still, the need for improving infrastructure, especially cyclone shelters and resilient housing, remains significant in the most vulnerable districts.[Amphan-2020].

Comparison with Other Studies: Other international agencies, including the World Meteorological Organization and the Intergovernmental Panel on Climate Change, also touted the growing peril posed by the rising frequency of occurrence of tropical cyclones under climate change. In 2021, IPCC issued its Sixth Assessment Report, and the conclusion is that more extreme and intense cyclones are going to be felt throughout the century; specifically, the Indian Ocean is highly exposed. These findings are in concurrence with the results of this study, that is, risk of cyclone decreases both due to natural variability and as a direct response of human-induced climate change.



[The IPCC's Sixth Assessment Report (2021)]

3.5 Earthquakes

3.5.1 Dataset Visualization

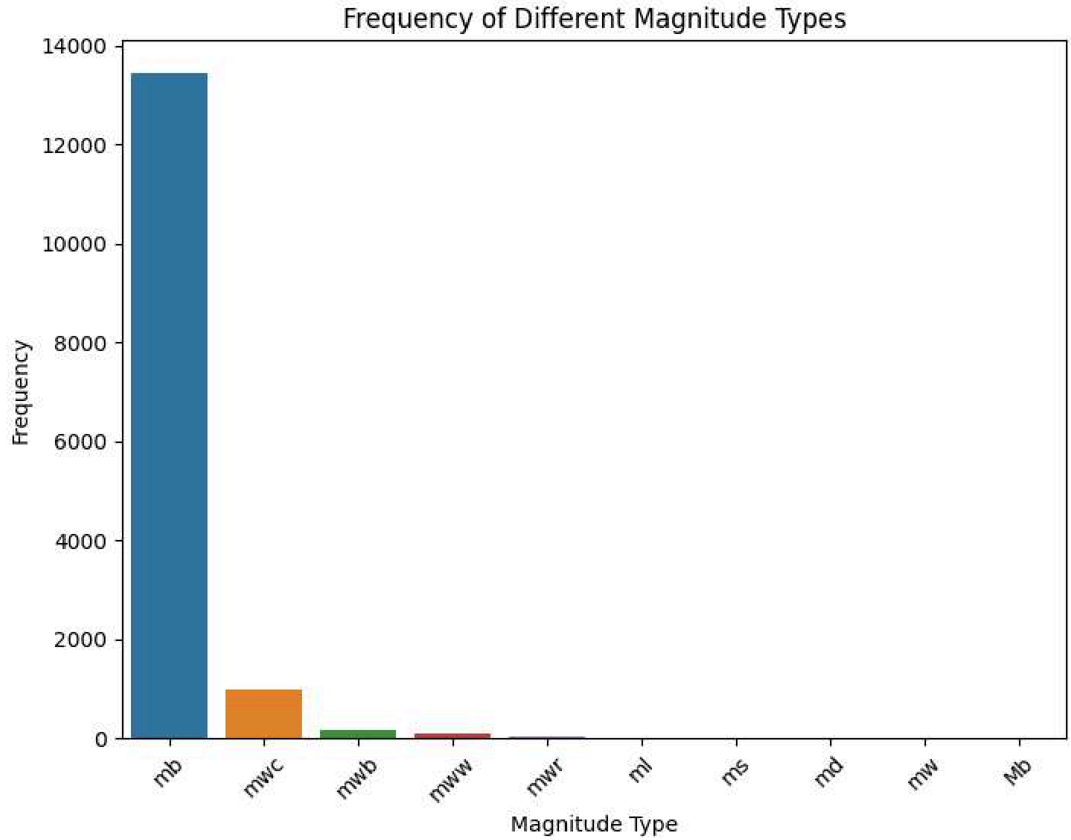


Fig 1: Frequency of Different Magnitude Types

This bar chart shows the frequency distribution (y-axis) of different magnitude classification types (x-axis). The 'mb' (body wave magnitude) type overwhelmingly dominates with about 13,000 occurrences, while other types like 'mwc', 'mwd', and 'mww' are much less frequent. This distribution suggests that body wave magnitude is the most commonly used measurement method for earthquakes in this region, possibly due to the type of seismic monitoring equipment available or the nature of the earthquakes.

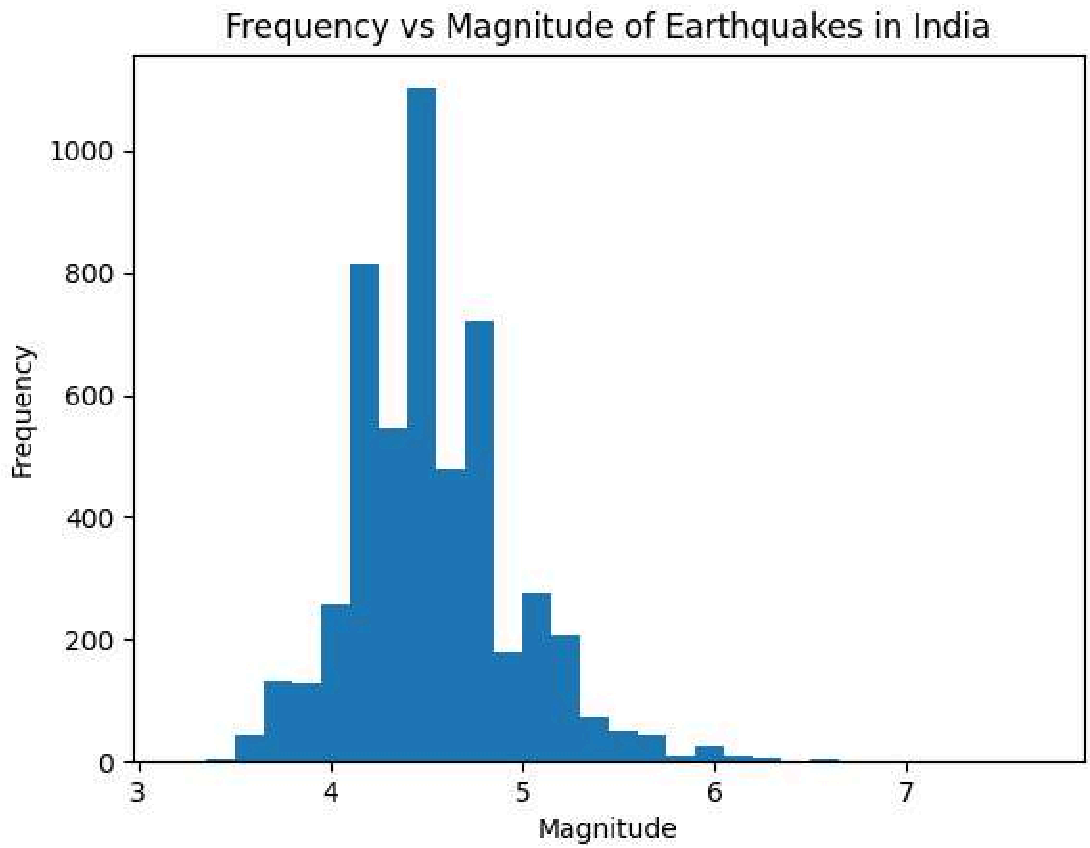


Fig 2: Frequency vs Magnitude Distribution

This histogram shows the frequency distribution (y-axis) of earthquakes by magnitude (x-axis, ranging from 3 to 7). The distribution follows a classic bell curve shape but is slightly skewed, with the peak occurring around magnitude 4.5-5.0. This is typical of earthquake distributions, where moderate-magnitude earthquakes are most common, while very low and very high magnitude events are less frequent. The sharp drop-off after magnitude 6 illustrates the relative rarity of high-magnitude earthquakes.

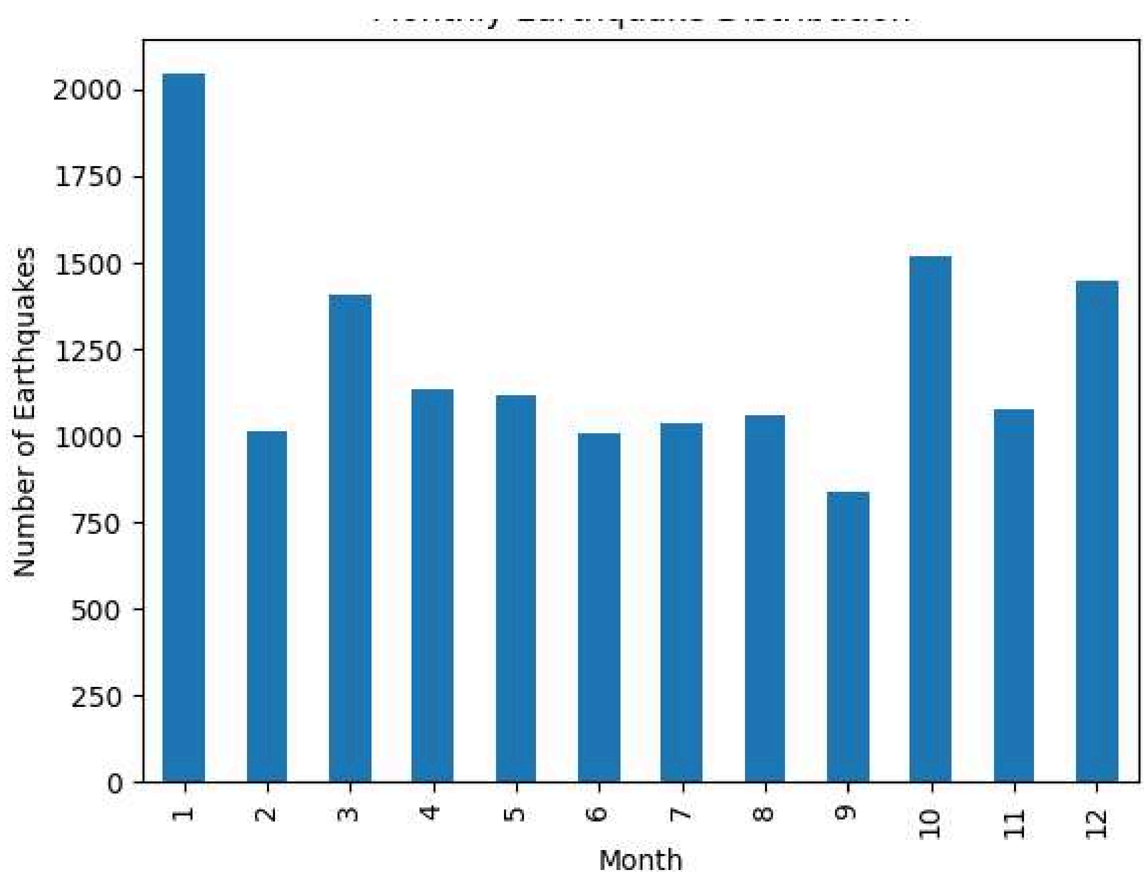


Fig 3: Monthly Earthquake Distribution

This bar chart displays the number of earthquakes (y-axis) by month (x-axis, 1-12). January (month 1) shows the highest frequency with about 2,000 earthquakes, while October (month 10) and December (month 12) also show relatively high frequencies around 1,500 earthquakes. September (month 9) shows the lowest activity with less than 1,000 earthquakes. This monthly variation could be related to seasonal factors like monsoons, groundwater levels, or other environmental conditions.

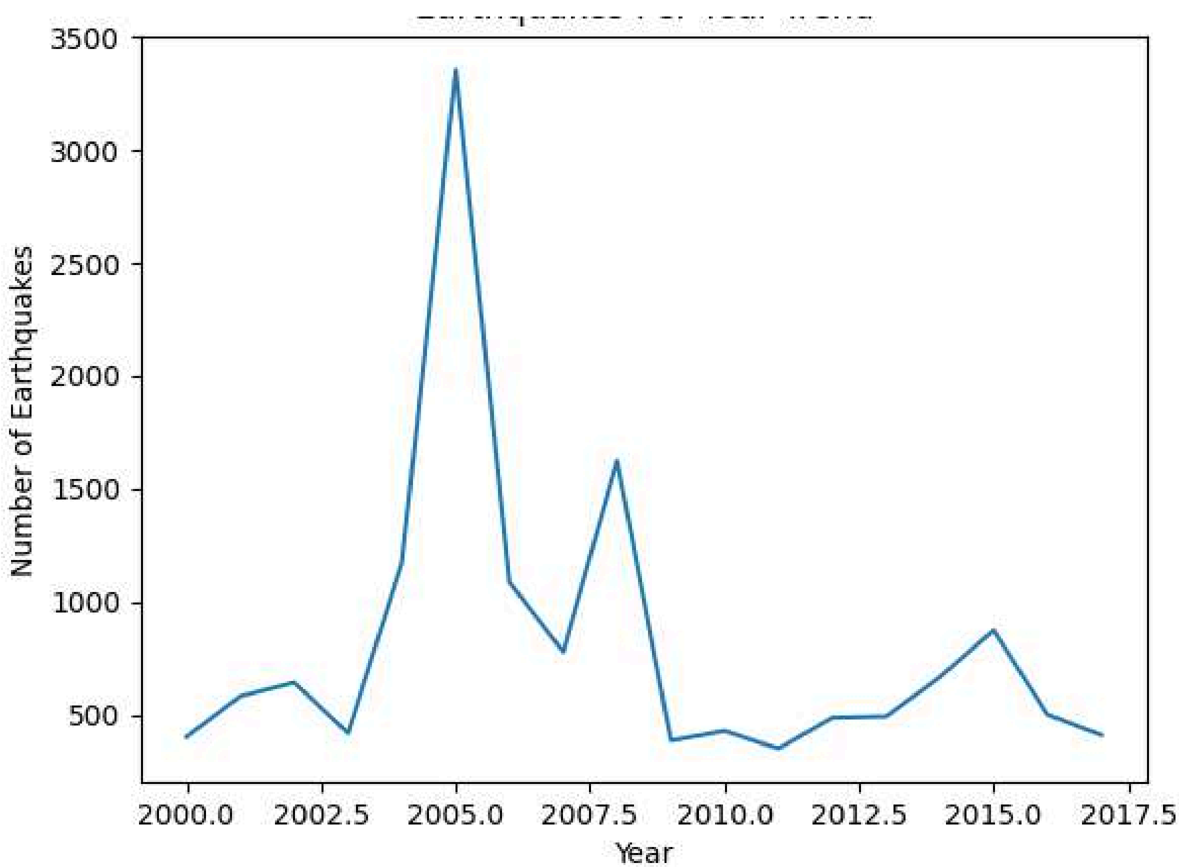


Fig 4: Earthquakes Per Year Trend

This line graph shows the number of earthquakes (y-axis) over time from 2000 to 2017.5 (x-axis). There's a dramatic spike around 2005 with over 3,000 earthquakes recorded, followed by another significant peak around 2009 with about 1,500 earthquakes. After 2010, the frequency stabilized to lower levels, averaging around 500-800 earthquakes per year. This pattern might reflect major seismic events that triggered numerous aftershocks during those peak periods.

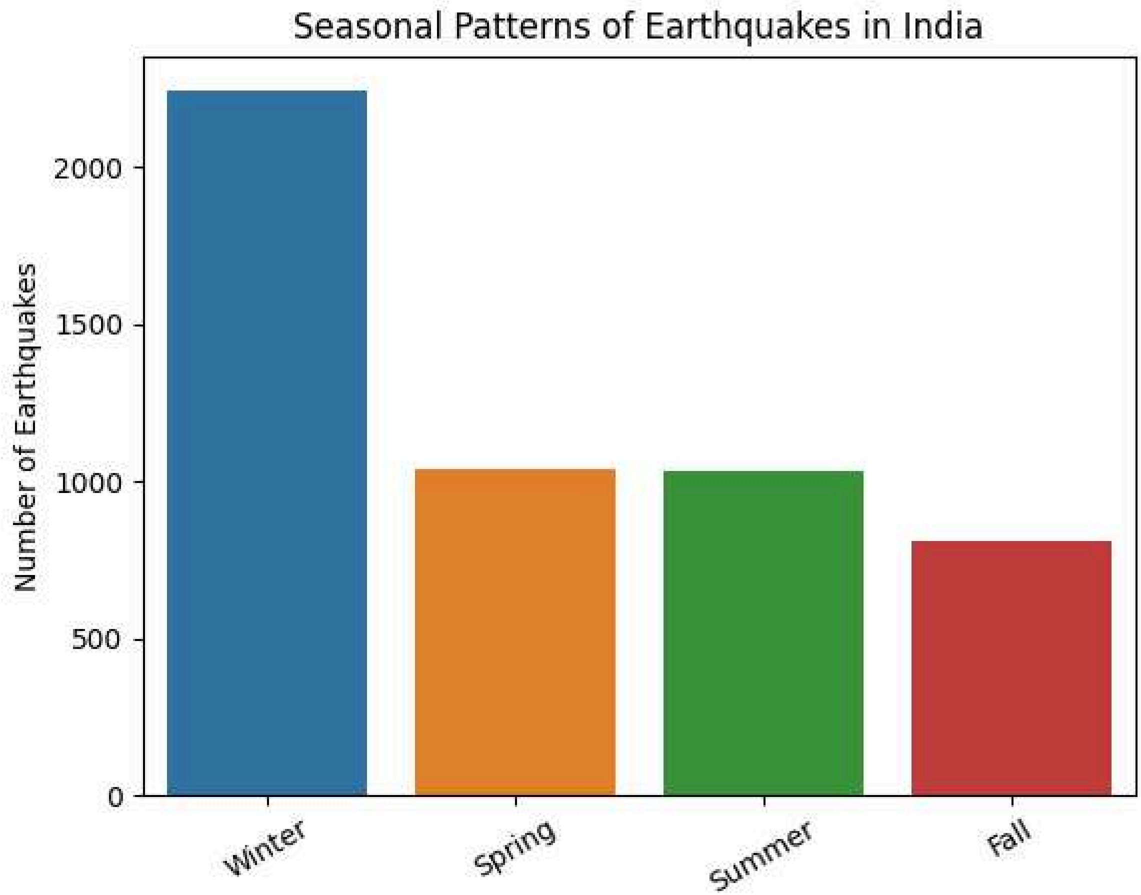


Fig 5: Seasonal Patterns

This bar chart displays the number of earthquakes (y-axis) across different seasons (x-axis). Interestingly, winter shows the highest frequency with over 2000 earthquakes, followed by spring and summer with approximately 1000 each, and fall with the lowest frequency at around 800. This seasonal variation could be due to various factors like atmospheric pressure changes, groundwater variations, or other environmental factors affecting seismic activity.

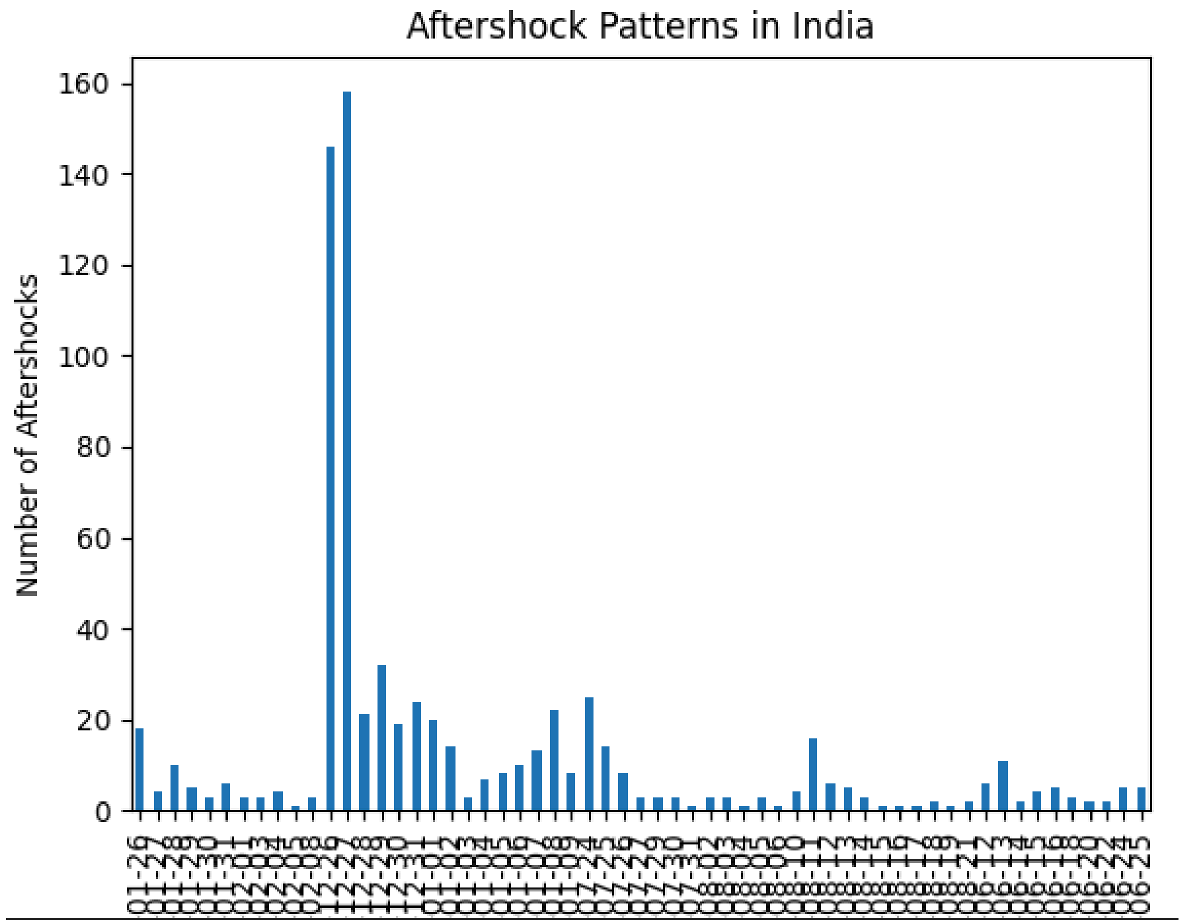


Fig 6: Aftershock Patterns

This bar chart shows the number of aftershocks (y-axis) over what appears to be a time series (x-axis). There's a notable spike showing over 140 aftershocks at one point, likely following a major earthquake. The pattern shows how aftershock frequency typically peaks immediately after a major event and then gradually decreases over time, which is a common seismological pattern.

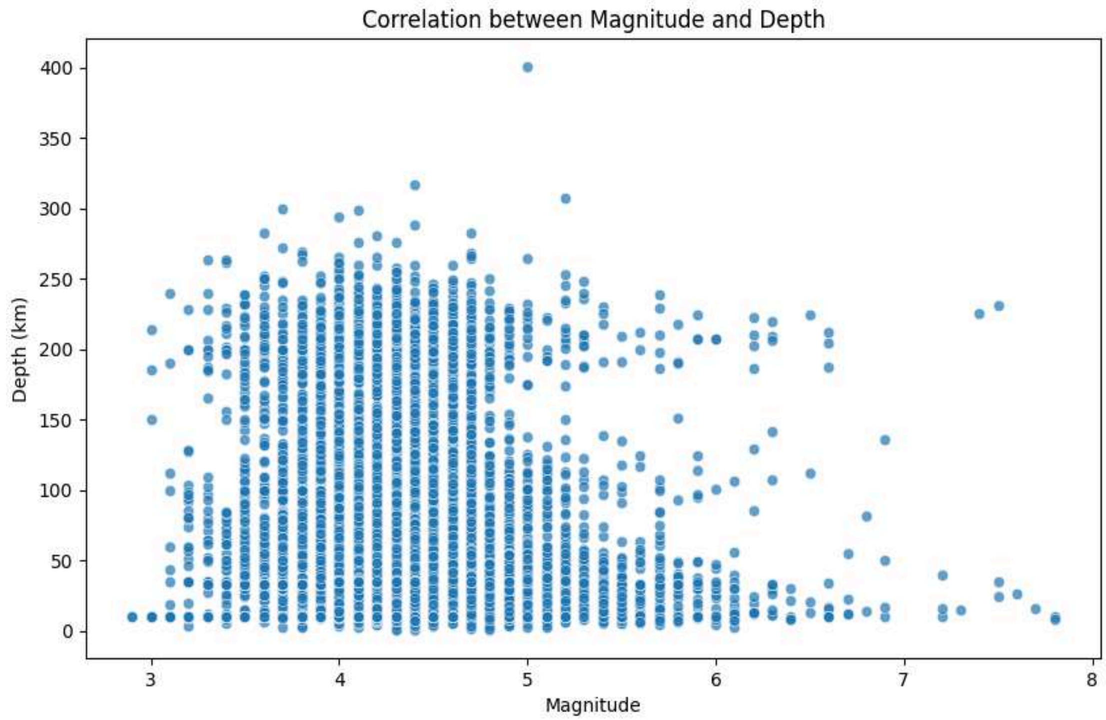


Fig 7: Magnitude-Depth Correlation

This scatter plot examines the relationship between earthquake magnitude (x-axis, ranging from 3 to 8) and depth (y-axis, 0-400km). The blue dots show an interesting pattern: there's a wide range of depths for earthquakes with magnitudes between 3-5, but higher magnitude earthquakes (>6) tend to occur at shallower depths. This suggests that some of the most powerful earthquakes in India are typically shallow events.

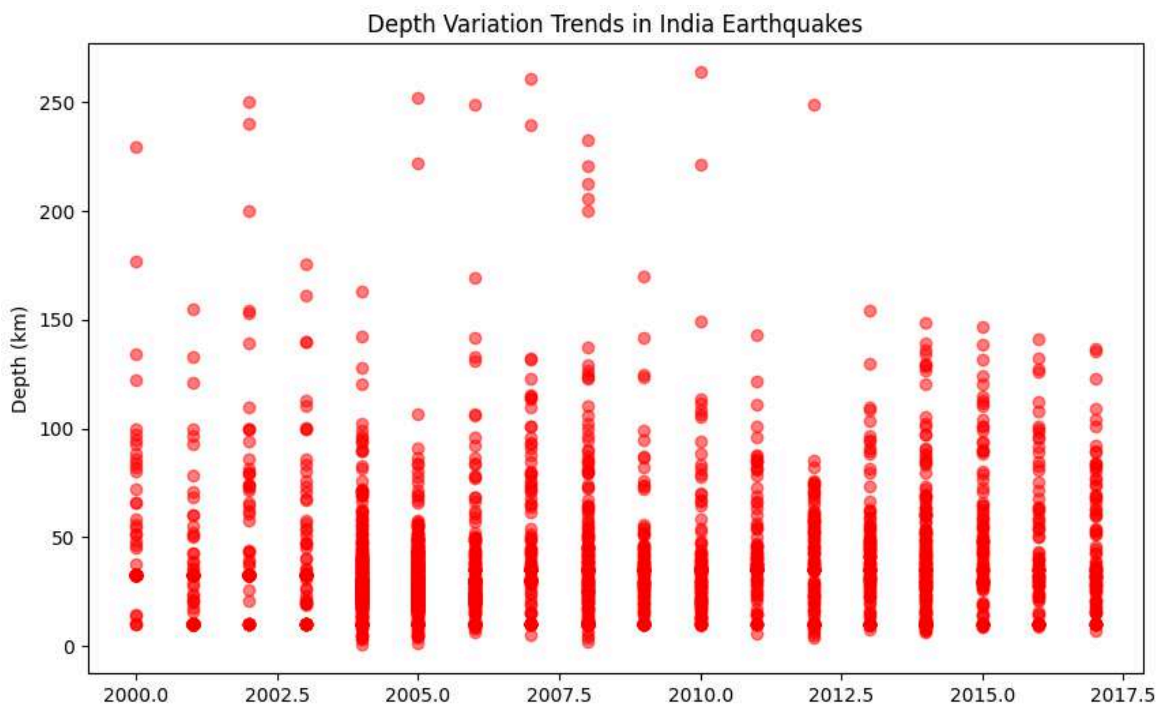


Fig 8: Depth Variation Trends

This scatter plot shows earthquake depths (y-axis, measured in kilometers from 0-250 km) over time (x-axis, from 2000 to 2017). Each red dot represents an individual earthquake. The plot reveals that most earthquakes in India occur at depths between 0-100km, with some deeper events reaching up to 250 km. There's a consistent pattern of shallow earthquakes throughout the time period, while deeper earthquakes (>150km) are less frequent.

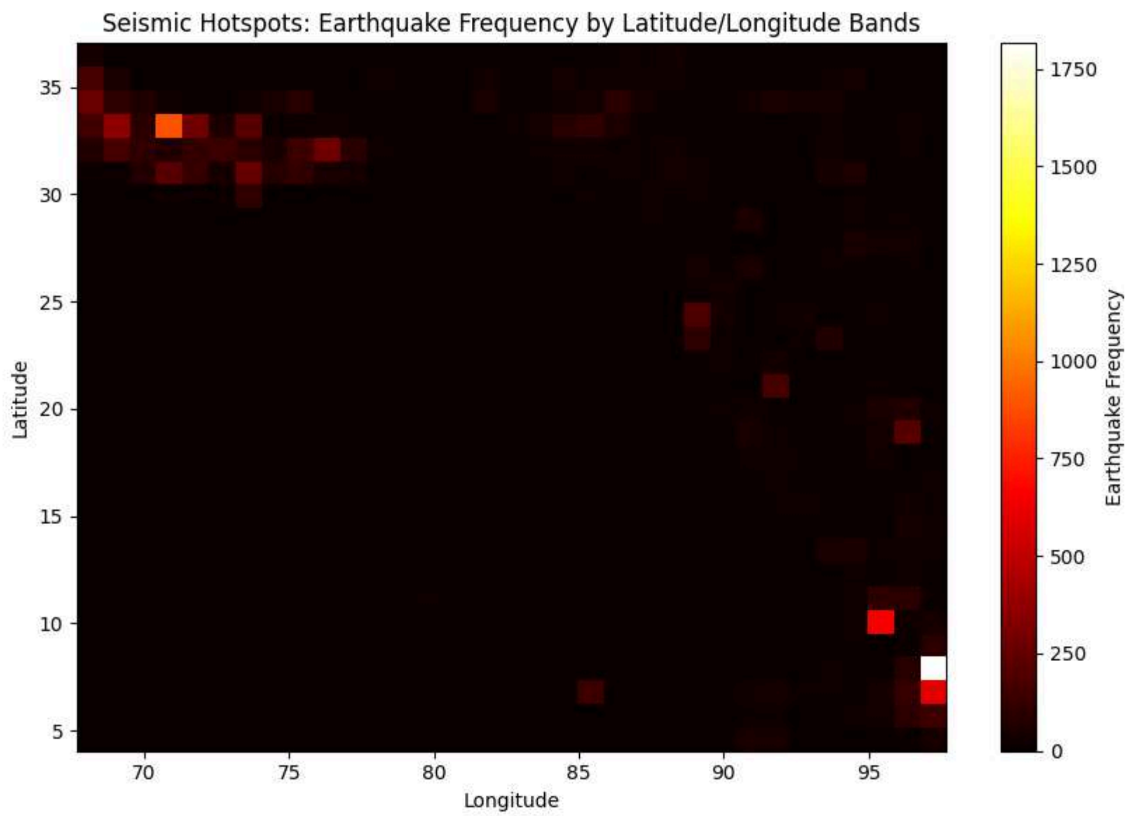


Fig 9: Seismic Hotspots Map

This heatmap shows earthquake frequency across different latitude (y-axis, ranging from 5° to 35°) and longitude (x-axis, ranging from 70° to 95°) bands in

India. The color intensity indicates the frequency of earthquakes, with darker reds showing fewer earthquakes (0-500) and brighter colors showing higher frequencies (up to 1750). The map reveals that certain regions, particularly in the northern latitudes (around 30-35°), experience more frequent seismic activity.

3.6 Landslides

3.6.1 Dataset Visualization

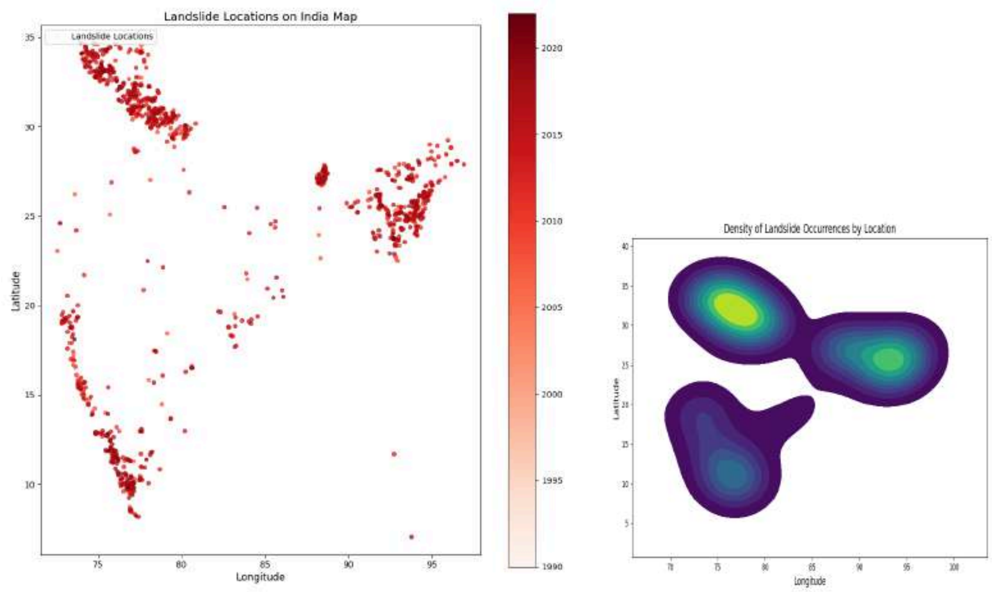


Fig 1: Scatterplot of Landslides in India

Observation: This scatterplot shows location of landslides over years in India and density plot showing its spread over the region.The major regions are Himalyan,North-Eastern and Deccan which are classified as susceptible landslide zones in India. Reasons being - Natural (Excessive Rainfall, tectonic activity, topography) and Anthropogenic (Deforestation, Construction activities)

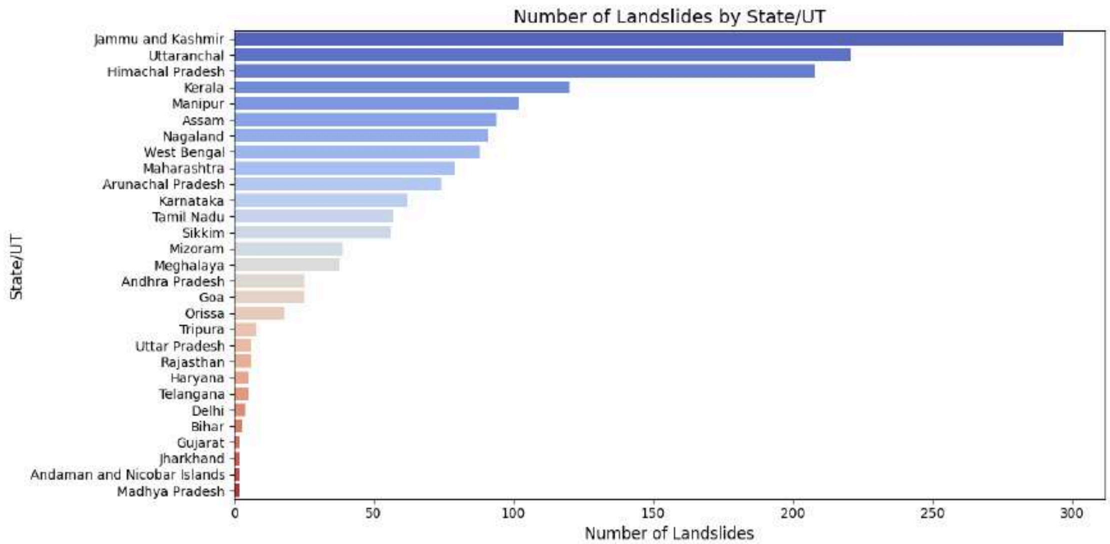


Fig 2: StateWise distribution of Landslides in India over years

Observation: This bar chart shows the number of landslides by Indian state or Union Territory . Jammu and Kashmir with highest number , reason being in Himalayan region more susceptible to earthquakes due to tectonic activity resulting in landslides. Madhya Pradesh has least landslides due to its predominantly flat terrain and absence of major hilly or mountainous regions prone to such disasters.

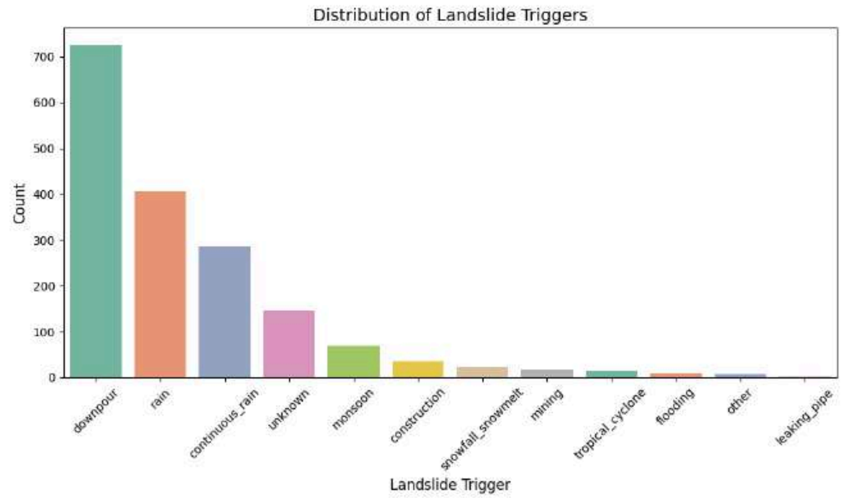


Fig 3: Causes of Landslides in India

Observation: The bar charts highlight different causes and sizes of landslides. Intense and sustained rainfall events are the primary cause, contributing to the highest number of incidents, while seasonal patterns, rather than isolated rainfall events, account for a moderate number of cases. Anthropogenic activities such as construction and mining appear to have fewer incidents associated with them

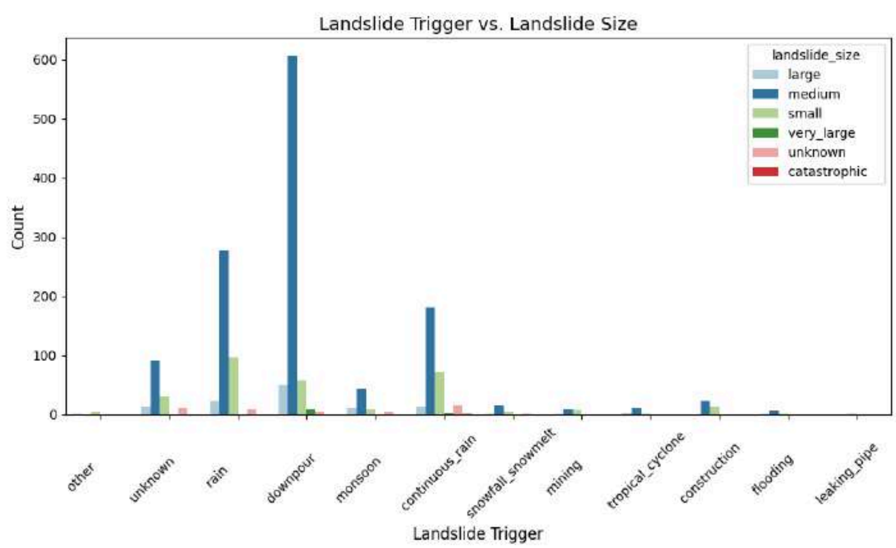


Fig 4: Relation between landslide cause and their size in India

Observation: Medium-small landslides are predominantly linked to excessive rainfall, reflecting its ability to destabilize smaller regions. Large landslides are rare and typically associated with extreme triggers, while small landslides occur more frequently due to minor causes, showcasing variability in impact.

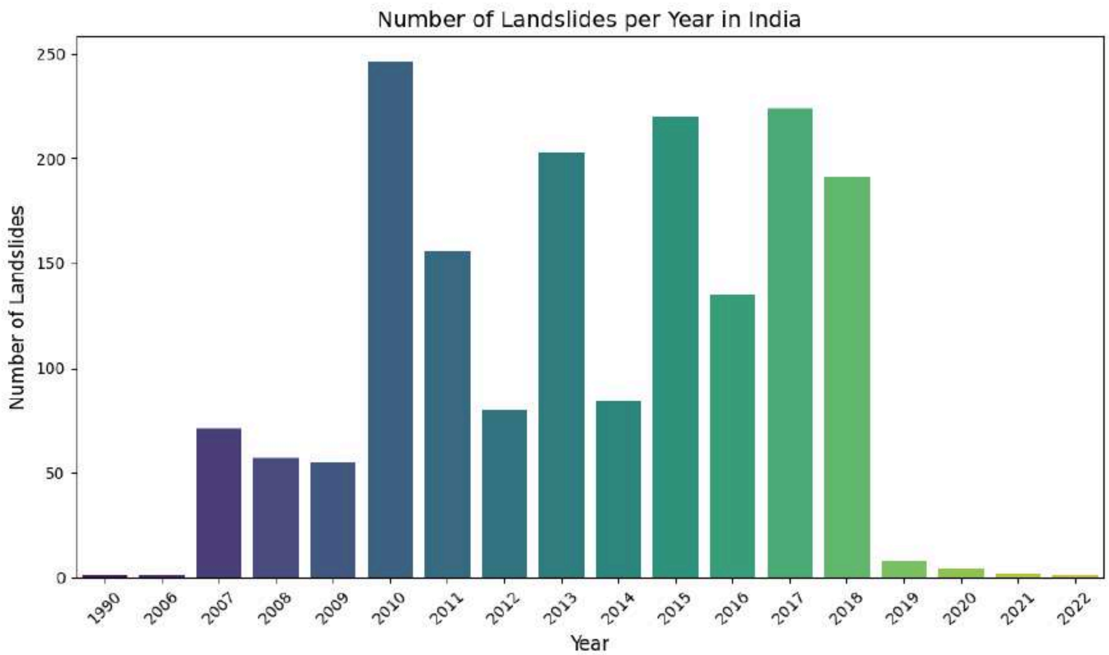


Fig 5: Yearwise distribution of Landslides in India

Observation: The bar chart shows the number of landslides over the years in India, with 2010 recording the highest count and 1990 the least. The reason for the significant rise in 2010 is attributed to the discharge of the River Kosi, which surged from a pre-monsoon level of 0.07m^3/sec on 20th June 2010 to a peak of 618.1 m^3/sec on 18th September 2010. This flood surge caused severe bank erosion, leading to a higher number of landslides. Additionally, the period from 2010 to 2017, particularly from June to September, witnessed a higher number of landslides, primarily due to the monsoon season, which spans these months, resulting in excessive rainfall and subsequently triggering landslides. The heatmap further reflects this seasonal trend.[source]

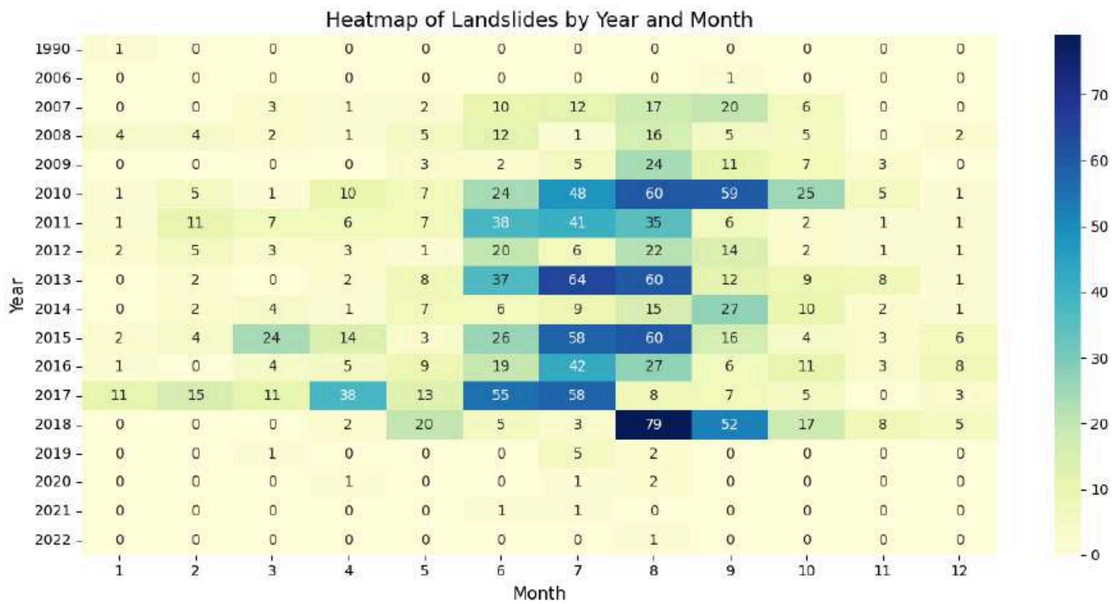


Fig 6: Heatmap of landslides by year and month in India

Observation: The heatmap highlights the seasonal and yearly variation in landslide occurrences, with a clear peak during the monsoon months (June to September), particularly in years like 2010, 2013, 2017, and 2018. This pattern is likely due to heavy rainfall saturating the soil, a key trigger for landslides. Minimal activity is observed from November to March, corresponding to the dry season. The rising frequency in recent years could be attributed to climate change causing intense rainfall, deforestation, and increased reporting in vulnerable areas.

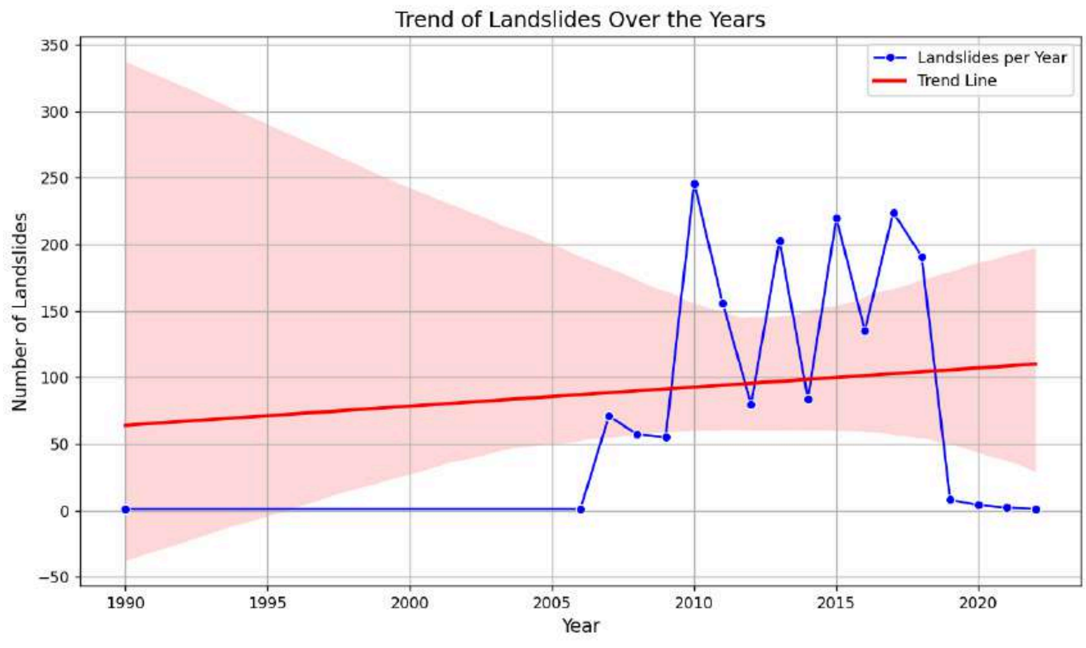


Fig 7: Trend of Landslides in India

Observation: There is a slight upward trend in landslides over the years, indicating a possible increase in frequency, likely driven by climate change and extreme weather events along with human activities.

3.7 Discussions

Climate change and environmental disasters in India are causing serious problems. Rising temperatures and unpredictable weather are affecting the country in many ways. These changes are impacting farming, making cities less prepared for extreme events, and affecting the daily lives of millions of people. This discussion looks at how these challenges are playing out across India and how they are shaping the future of the nation.

Temperature Trends and Implications

India has experienced significant warming over the past century, with an accelerated increase in recent decades. This rise is not uniform; the Northern regions, particularly semi-arid areas, have warmed more sharply than the southern peninsula. The period before the monsoon season, which has seen the most pronounced temperature increase, now brings more frequent and intense heat waves, especially affecting urban centers. These heatwaves are more than just uncomfortable; they pose severe health risks, disrupt daily life, and even threaten economic productivity. As temperatures continue to climb, there is an urgent need to invest in adaptation strategies—cooling infrastructure in cities, community health interventions, and revised labor policies to protect outdoor workers.

Rainfall Variability and Its Far-Reaching Effects

India's economy and food security heavily depend on the monsoon, yet rainfall patterns are becoming increasingly erratic. Extreme rainfall events have surged in recent years, causing flash floods in one region while leaving another in drought. This inconsistency strains water resources, challenges agricultural planning, and creates cascading economic impacts. Central and southern India, in particular, have faced devastating consequences from these changes. The 2018 Kerala floods serve as a sobering example, showing how extreme weather, compounded by land-use changes and rapid urbanization, can bring entire communities to a standstill. Looking ahead, it is crucial to develop predictive models tailored to local contexts to help communities better prepare for and respond to rainfall variability.

Floods: A National Crisis

Floods have become an almost yearly crisis in many parts of India, with states like Uttar Pradesh, Bihar, and Assam bearing the brunt. The geographical diversity of India, with its vast river systems and variable topography, means that flooding takes different forms in each region. In coastal Andhra Pradesh and Odisha, cyclonic storms and heavy monsoons swell rivers and inundate coastal areas. In Bihar, river overflow from the Himalayas turns plains into flood zones. The impact on lives, property, and infrastructure is staggering, as floods destroy homes, wash away crops, and disrupt transportation and communication networks. The sheer scale of the issue demands a multi-faceted response, from building embankments and reservoirs to better land-use planning and effective early-warning systems. The government's efforts, such as the National Disaster

Management Authority's initiatives, are steps in the right direction, but a more cohesive and localized approach is needed to address this annual calamity comprehensively.

Cyclones and Coastal Vulnerability

India's long coastline leaves it highly vulnerable to cyclones, particularly on the eastern coast. Cyclones like Amphan in 2020 and Hudhud in 2014 have left deep scars on coastal communities, with impacts felt in lives lost, property destroyed, and ecosystems disrupted. The intensity of these storms has been exacerbated by climate change, with warmer sea temperatures fueling stronger cyclonic events. Unlike earthquakes or other instantaneous disasters, cyclones provide a window of preparation due to advances in forecasting, allowing for evacuations and preventive measures. However, the scale of destruction often leaves lasting economic and psychological impacts. Strengthening coastal defenses, creating cyclone-resilient infrastructure, and building community awareness through regular drills are crucial steps to mitigate these impacts.

Earthquakes: A Constant Threat in High-Risk Zones

Earthquakes are an ever-present risk in seismically active regions like the Himalayas and the northeastern states. India's tectonic setting, especially where the Indian plate meets the Eurasian plate, leads to frequent seismic activity that can trigger landslides and disrupt infrastructure. The 2001 Bhuj earthquake and the 2015 Nepal earthquake are reminders of the devastating potential of seismic events. Infrastructure in high-risk areas remains a concern; buildings and roads often lack the seismic resilience needed to withstand strong earthquakes. Establishing and enforcing building codes that prioritize earthquake resilience and expanding early-warning systems where possible are essential for safeguarding lives in these vulnerable areas.

Landslides: Increasingly Triggered by Both Natural and Human Factors

Landslides, often induced by heavy rainfall, earthquakes, or human activities like deforestation and unplanned construction, have become more frequent in the

Himalayan region and Western Ghats. These mountainous areas are inherently vulnerable due to steep slopes and loose soil, but human activities exacerbate the risks. Deforestation, in particular, strips the land of the vegetation that stabilizes soil, making it more prone to sliding during heavy rains. Landslides are not only dangerous but also disruptive, often blocking roads, isolating communities, and causing fatalities. The tragedy of the 2013 Uttarakhand disaster, where landslides and flash floods claimed thousands of lives, highlights the need for an integrated approach that combines improved land management, reforestation, and better regulation of construction practices in sensitive areas.

The Path Forward: Building Resilience and Reducing Vulnerability

India's experience with environmental disasters underscores the complex interplay between natural processes and human influence. Climate change is amplifying the severity and unpredictability of these events, demanding a proactive approach to adaptation and disaster preparedness. Key measures include investing in early-warning systems, designing infrastructure to withstand extreme weather, implementing sustainable land-use practices, and educating communities on disaster preparedness. Collaboration across government levels, scientific communities, and local stakeholders is essential to build a resilient nation that can adapt to the challenges of a changing climate.

India's journey with climate change and environmental disasters highlights the urgent need for tailored, region-specific interventions. By learning from past events and proactively planning for future risks, India can strengthen its defenses against the growing threats posed by our changing environment. The solutions lie not only in technology but in community resilience, sustainable development, and a commitment to safeguarding both people and the environment.

4. Acknowledgments:

This project wouldn't have been possible without the combined efforts and support of many people and resources, and we're incredibly grateful to everyone who contributed along the way.

A special thanks goes to the data providers whose resources formed the backbone of our work. We relied on datasets from research papers, Kaggle, NASA's COOLR links, and Open Government Data platforms. These sources gave us the information we needed to create CSV files, visualize patterns, and analyze the effects of factors like temperature, rainfall, and environmental disasters in India.

We're also deeply thankful to the researchers and authors whose work inspired and informed our study. Their research gave us the tools to understand the complex challenges of climate change in India—especially the risks tied to shifting temperatures, changing rainfall patterns, and the increasing frequency of natural disasters.

This project is a result of everyone's hard work and knowledge, and we're truly thankful for their contributions.

5. References:

1. Gahalaut, V. K. (2010). Earthquakes in India: Hazards, Genesis, and Mitigation Measures. earthquakes in india hazards_genesis_and_mitigations_measures
2. Samantray, P., & Gouda, K. C. (2024). A review on the extreme rainfall studies in India. *Journal of Hydroclimatic Research and Management*. https://www.sciencedirect.com/science/article/pii/S2666592123000823
3. Lok Sabha Secretariat. (Year). *Climate Change: Its Impact and Adaptation/ Mitigation in India*. Retrieved from https://loksabhadocs.nic.in/Refinput/New_Reference_Notes/English/climate_I.pdf
4. Sanjay, J., Revadekar, J. V., Ramarao, M. V. S., Borgaonkar, H., Sengupta, S., Kothawale, D. R., Patel, J., Mahesh, R., & Ingle, S. (2020). *Temperature Changes in India*. In R. Krishnan et al. (Eds.), *Assessment of Climate Change over the Indian Region*. Indian Institute of Tropical Meteorology (IITM), Ministry of Earth Sciences (MoES), Pune,

India. Retrieved from
https://www.researchgate.net/publication/342138079_Temperature_Changes_in_India

5. Kaggle dataset titled "India Floods Inventory" provides extensive flood-related data for analysis (Aditya, 2024). https://www.kaggle.com/datasets/aditya2803/india-floods-inventory
6. Drishti IAS articles highlight key flood management strategies and challenges in India ("Flood Management in India," n.d.; "Flood Havoc in India," n.d.). https://www.drishtiias.com/daily-updates/daily-news-editorials/flood-management-in-india-1
7. Drishti IAS. "Floods Havoc in India." *Drishti IAS*, 5 July 2022, https://www.drishtiias.com/daily-updates/daily-news-editorials/floods-havoc-in-india. Accessed 18 Nov. 2024.
8. The **Flood-Affected Area Atlas** by NRSC offers detailed digital mapping of vulnerable zones (NRSC, n.d.). **https://www.nrsc.gov.in/sites/default/files/pdf/DMSP/FloodAffectedAreaAtlas_Digital.pdf**
9. Froude, M. J., & Petley, D. N. (2018). Global fatal landslide occurrence from 2004 to 2016. *Natural Hazards and Earth System Sciences*, *18*(8), 2161-2181. https://nhess.copernicus.org/articles/18/2161/2018/
10. Nadim, F., Kjekstad, O., Peduzzi, P., Herold, C., & Jaedicke, C. (2006). Global landslide and avalanche hotspots. *Landslides*, *3*, 159-173. https://link.springer.com/content/pdf/10.1007/s10346-006-0036-1.pdf
11. Jaiswal, P., Martha, T. R., & Singh, S. (2024). *Landslides disaster in India: Mitigation and their impacts* https://www.researchgate.net/publication/371077627_Landslides_disaster_in_India_mitigation_and_their_impacts
12. Singh, S. (2022). *Himalayan landslides: Causes and evolution*. https://dpnet.org.np/public/uploads/files/HimalayanLandslides-CausesandEvolution-SandeepSingh2022%20(1)%202022-08-01%2007-09-23.pdf

13. Arpitha, G. A., Choodarathnakara, A. L., & Sinchana, G. S. (2024). Landslides: A Review from the Southern Western Ghats of India. *Journal of the Geological Society of India, 100*(10), 1443–1456 https://doi.org/10.17491/jgsi/2024/173999
14. Martha, T. R., Roy, P., Jain, N., Khanna, K., Mrinalni, K., Kumar, K. V., & Rao, P. V. N. (2021). India ranks first in the world in landslide fatalities: a detailed assessment of the multi-hazard scenario. *Landslides*, 18(11), 3511–3533. https://doi.org/10.1007/s10346-021-01645-1
15. Mandal, G. S., Mohapatra, M. (2010). Cyclone Hazard Prone Districts of India: A Report. **cyclone_hazard_prone_districts_india_report**
16. IMD Cyclone Atlas (2008). Data on Cyclones 1891-2008. **imd_cyclone_atlas_1891_2008**
17. BMTPC Vulnerability Atlas of India (2006, 2019). Ministry of Urban Affairs, Government of India. **bmtpc_vulnerability_atlas_of_india**
18. Super Cyclone Amphan Barrels Down Towards Indian Coast: Some Satellite Images of the Massive Storm. Times Now News. **super_cyclone_amphan_satellite_images**
19. Frequency of Land-Falling Cyclonic Storms District-Wise During 1891-2018. ResearchGate. **Frequency_land_falling_cyclonic_storms_1891_2018**
20. Study Report: Gaja Cyclone 2018. NDMA. **gaja_cyclone_2018_study_report**
21. Monthly Frequency of Cyclonic Disturbances in the North Indian Ocean Region during 1891-2015. **Monthly_frequency_cyclonic_disturbances_north_indian_ocean**
22. Intensity of Severe Cyclonic Storms Increasing in North Indian Ocean Region Study. India Today. **intensity_increase_severe_cyclonic_storms_north_indian_ocean**
23. IPCC Sixth Assessment Report. **ipcc_sixth_assessment_report**
24. Number of Crossed Cyclones Through the Coastal States for 2006-2020. **crossed_cyclones_coastal_states_2006_2020**
25. Lee, J., Singh, A. (2020). Trends and Impacts of Tropical Cyclones in the Indian Ocean: A Regional Study. **Trends_impacts_tropical_cyclones_indian_ocean**
26. Hussain, S., Zakaria, M., & Hoque, M. (2023). *Navigating the impact of climate change in India: A perspective on climate action (SDG13) and sustainable cities and communities (SDG11). Frontiers in Sustainable Cities*

https://www.frontiersin.org/journals/sustainable-cities/articles/10.3389/frsc.2023.1308684/full

6. Links

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