

## Climate Change and its Impact on Regional Patterns in India

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### ABSTRACT

Climate change has emerged as one of the most critical global challenges of the twenty-first century, with developing countries like India experiencing its impacts in a highly uneven and region-specific manner. Owing to its vast geographical diversity, dependence on the monsoon system, agrarian economy, long coastline, and Himalayan ecosystems, India is particularly vulnerable to climate-induced disruptions. This paper examines the impact of climate change on regional climatic patterns in India, focusing on variations in temperature, rainfall, frequency of extreme weather events, and their socio-economic consequences. Using secondary data from authoritative sources such as the India Meteorological Department (IMD), IPCC reports, and government publications, the study analyses region-wise changes across the Himalayan region, coastal belts, central and north-western India, and the eastern and north-eastern states. The findings indicate a consistent rise in average temperatures, increasing incidence of heat waves, erratic monsoon behaviour, accelerated glacial retreat, rising sea levels, and intensified cyclonic activity. These changes have significantly affected agriculture, water availability, human health, livelihoods, and regional development patterns. The paper highlights that climate change impacts are not uniform but deeply intertwined with regional geography, socio-economic structures, and adaptive capacity. It concludes by emphasising the need for region-specific climate adaptation strategies, strengthened policy frameworks, and sustainable development planning to enhance resilience and mitigate long-term risks.

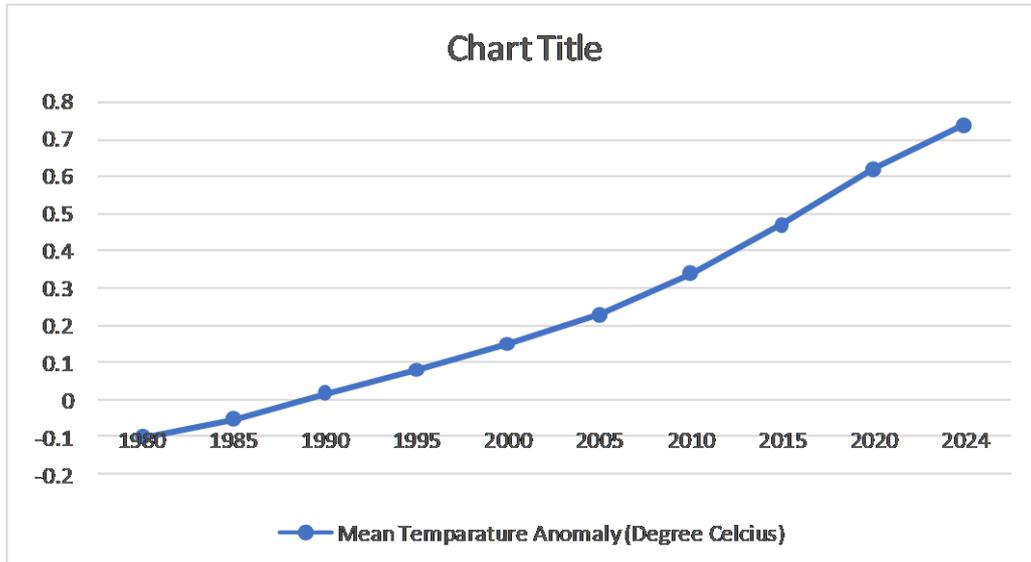
**Keywords:** Climate Change, Regional Climate Patterns, Monsoon Variability, Heatwaves, Glacier Retreat, Coastal Vulnerability, India, Sustainable Development, Climate Adaptation.

### Introduction

Climate change refers to long-term alterations in temperature, precipitation patterns, and the frequency of extreme weather events, primarily driven by anthropogenic activities such as fossil fuel combustion, deforestation, and industrialisation (IPCC, 2023). While climate change is a global phenomenon, its impacts are spatially uneven, disproportionately affecting developing economies with high climate sensitivity and limited adaptive capacity. India, owing to its vast geographical diversity, monsoon-dependent economy, extensive coastline, and densely populated agrarian regions, stands among the most climate-vulnerable countries in the world (World Bank, 2021).

Over the past few decades, India has witnessed a discernible rise in mean surface temperatures, increased occurrence of extreme heat events, erratic monsoon behaviour, accelerated melting of Himalayan glaciers, and intensification of cyclonic activity along its eastern and western coasts (IMD, 2022; IPCC, 2023). These climatic changes have not only altered natural ecosystems but have

also significantly influenced regional livelihoods, agricultural productivity, water availability, health outcomes, and patterns of economic development. Importantly, the manifestation of climate change in India is not uniform; instead, it varies markedly across regions due to differences in topography, climatic zones, land-use patterns, and socio-economic conditions.



**Figure 1: Trend in Annual Mean Surface Temperature in India (1980–2024) India Meteorological Department (IMD), Climate Change Assessment Report**

Source: Curated by the author

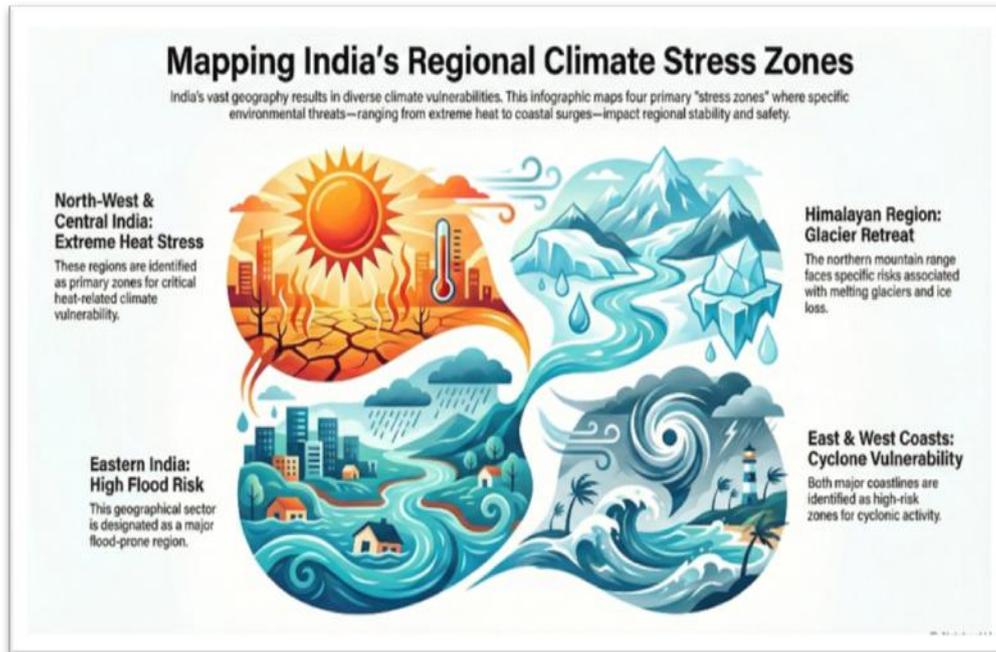
India’s climatic sensitivity is largely rooted in its dependence on the southwest monsoon, which governs agricultural cycles, water resources, and rural livelihoods. Studies indicate that monsoon rainfall has become increasingly erratic, characterised by delayed onset, shorter duration, intense rainfall spells, and prolonged dry periods (Goswami et al., 2006; Kulkarni et al., 2020). While some regions experience excessive rainfall and flooding, others face recurrent droughts, underscoring the growing spatial imbalance in precipitation patterns.



**Figure 2: Changing Monsoon Behaviour in India**

Source: Curated by the author with the help of NotebookLM

The Himalayan region, often referred to as the “water tower of Asia,” is experiencing rapid glacial retreat due to rising temperatures, posing serious risks to long-term water security for northern and peninsular river systems (Bolch et al., 2019). Simultaneously, India’s coastal regions are increasingly exposed to sea-level rise, saline intrusion, and more intense cyclones, particularly along the Bay of Bengal, which has emerged as a hotspot for climate-induced disasters (Mishra et al., 2022).



**Figure 3: Regional Climate Stress Zones in India**

Source: Curated by the author with the help of NotebookLM

Against this backdrop, the present study aims to examine how climate change is reshaping regional climatic patterns across India and to analyse its differentiated impacts on various regions and sectors. By adopting a region-specific perspective, the paper seeks to move beyond aggregate national trends and highlight the need for geographically tailored climate adaptation and mitigation strategies aligned with sustainable development goals.

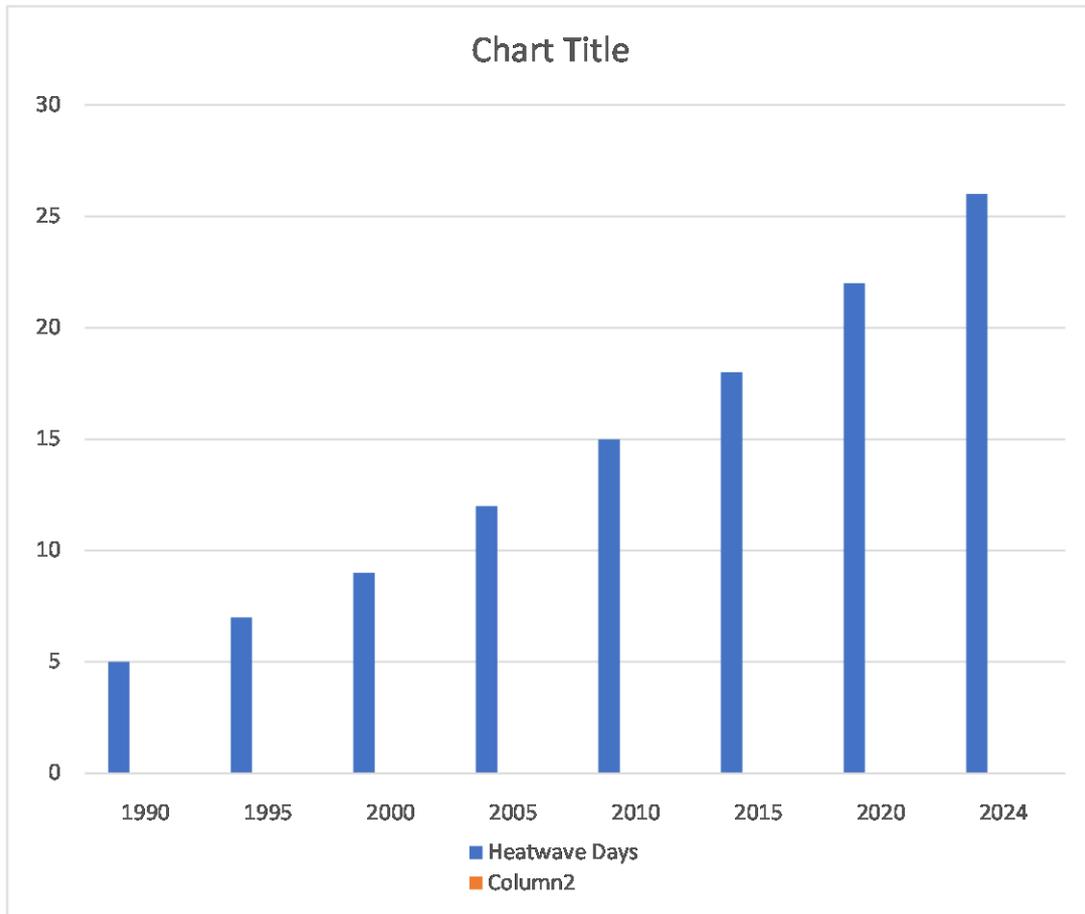
### Regional Climate Changes in India

India’s climate change experience is marked by strong regional heterogeneity, shaped by variations in geography, altitude, proximity to oceans, land-use patterns, and socio-economic conditions. While national-level indicators point towards rising temperatures and increasing climate variability, the intensity and nature of these changes differ significantly across regions. Understanding these regional patterns is crucial for designing effective adaptation and mitigation strategies.

- **North-Western and Central India: Rising Temperatures and Heat Extremes**

North-western and central India including Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, and parts of Uttar Pradesh have emerged as hotspots of extreme heat. Observational data from the India Meteorological Department (IMD) indicate a sharp increase in the frequency, duration, and intensity of heatwaves in these regions since the early 2000s (IMD, 2022). Maximum temperatures exceeding 45°C have become increasingly common during pre-monsoon and early summer months, posing severe risks to human health, agriculture, and labour productivity.

Several studies attribute this trend to a combination of global warming, reduced soil moisture, declining vegetation cover, and rapid urbanisation, which intensifies the urban heat island effect (Mishra et al., 2020). Central India, once considered climatically moderate, has experienced some of the fastest increases in extreme temperature events, disrupting traditional cropping cycles and increasing evapotranspiration rates.



**Figure 4: Increase in Heatwave Days in North-West and Central India (1990–2024)**

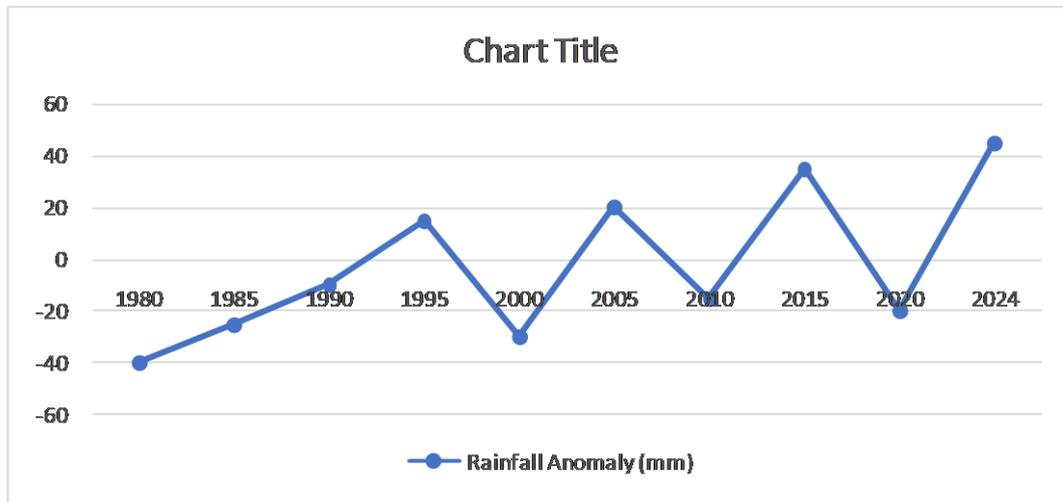
Source: Curated by the author

The socio-economic implications of rising heat stress are particularly severe in these regions due to the high concentration of outdoor workers in agriculture, construction, and informal sectors. According to the International Labour Organization (ILO, 2021), India faces significant productivity losses due to heat stress, with central and north-western regions accounting for a major share. Thus, climate change in this region manifests not merely as rising temperatures but as a multidimensional development challenge.

- **Indo-Gangetic Plains and Northern India: Monsoon Variability and Agricultural Stress**

The Indo-Gangetic Plains, spanning Punjab, Haryana, Uttar Pradesh, Bihar, and parts of West Bengal, constitute India's agricultural heartland and are highly sensitive to monsoon behaviour. Climate change has altered both the temporal and spatial characteristics of the southwest monsoon, resulting in delayed onset, erratic rainfall distribution, and increased incidence of extreme precipitation events (Goswami et al., 2006; Kulkarni et al., 2020).

While aggregate monsoon rainfall at the national level may not show drastic long-term decline, regional disparities have intensified. Some areas experience excessive rainfall over short durations leading to floods, while others suffer prolonged dry spells within the same monsoon season. Such intra-seasonal variability adversely affects crop sowing, irrigation planning, and yields, particularly for water-intensive crops such as rice and wheat.



**Figure 5: Monsoon Rainfall Anomalies in the Indo-Gangetic Plains (1980–2024)**

Source: Curated by the author

In addition, rising night-time temperatures have been shown to reduce wheat yields in northern India by accelerating crop maturity and reducing grain-filling duration (Lobell et al., 2012). Groundwater depletion, compounded by climate variability, further aggravates water stress in the region. Consequently, climate change threatens not only regional food security but also national agricultural stability.

- **Himalayan Region: Glacier Retreat and Water Insecurity**

The Himalayan region plays a critical role in regulating India's climate and hydrology. Often described as the "Third Pole," the Himalayas are experiencing accelerated warming at rates higher than the global average, leading to rapid glacier retreat and changes in snow cover (Bolch et al., 2019). Studies indicate that Himalayan glaciers have lost a significant proportion of their mass over the past few decades, with implications for long-term river flows in the Indus, Ganga, and Brahmaputra basins.

Initially, increased glacial melt may augment river discharge, raising the risk of glacial lake outburst floods (GLOFs). However, in the long run, declining glacier volume threatens dry-season water availability for millions of people downstream (Immerzeel et al., 2020). These changes directly affect agriculture, hydropower generation, and drinking water supply in northern and north-eastern India.

Beyond physical impacts, climate change is also influencing socio-cultural systems in the Himalayan region. Increased water stress, land degradation, and disaster risks have triggered migration from mountain villages, leading to socio-economic marginalisation and loss of traditional livelihoods (Sharma et al., 2021). Thus, climate change in the Himalayas represents both an environmental and human security concern.

- **Coastal Regions: Sea-Level Rise and Intensifying Cyclones**

India's extensive coastline of over 7,500 kilometres makes coastal regions particularly vulnerable to climate change. Rising sea surface temperatures in the Indian Ocean have contributed to the intensification of cyclonic storms, especially in the Bay of Bengal, which accounts for a disproportionate share of severe cyclones affecting India (Mishra et al., 2022).

Recent decades have witnessed an increase in the frequency of very severe cyclonic storms, accompanied by higher wind speeds, storm surges, and intense rainfall. Eastern coastal states such as Odisha, Andhra Pradesh, and West Bengal are especially exposed, though western coastal regions are not immune. Sea-level rise further exacerbates risks by increasing coastal erosion, saline intrusion into groundwater, and permanent inundation of low-lying areas.



**Figure 6: Cyclone-Prone Zones and Sea-Level Rise Risk along India’s Coast**

Source: Curated by the author

- **High Risk (Cyclone + SLR) – East Coast**
- **Moderate Risk – West Coast**
- **Very High SLR Risk – Island regions**

Coastal ecosystems such as mangroves, coral reefs, and wetlands which act as natural buffers are also under stress due to rising temperatures and human pressures. The degradation of these ecosystems reduces natural resilience, increasing the vulnerability of coastal communities dependent on fisheries, agriculture, and tourism.

- **Eastern and North-Eastern India: Floods, Landslides, and Ecosystem Stress**

Eastern and north-eastern India experience high rainfall and are increasingly affected by extreme precipitation events linked to climate change. States such as Assam, Meghalaya, and Bihar face recurrent flooding, riverbank erosion, and landslides, leading to displacement, loss of livelihoods, and infrastructure damage (Das et al., 2020).

Climate change has intensified rainfall variability in the Brahmaputra and Barak river basins, increasing both flood magnitude and unpredictability. The fragile ecosystems of the North-East, characterised by high biodiversity and sensitive terrain, are particularly vulnerable to these changes.

**Table 1: Climate-Induced Risks in Eastern and North-Eastern India**

Region	Major Climate Risk	Key Impacts
Assam	Extreme floods	Displacement, crop loss
Bihar	River flooding	Infrastructure damage
Meghalaya	Intense rainfall	Landslides, erosion

These regions also face governance and infrastructure challenges, which limit adaptive capacity and magnify the adverse impacts of climate change.

### **Sectoral Impacts of Climate Change in India**

The regional manifestations of climate change in India have translated into profound sectoral impacts affecting agriculture, water resources, human health, livelihoods, and the broader economy. These impacts are closely intertwined with regional climatic patterns, socio-economic structures, and adaptive capacities. Rather than affecting sectors uniformly, climate change amplifies existing vulnerabilities, thereby deepening regional and sectoral inequalities.

- **Impact on Agriculture and Food Security**

Agriculture remains one of the most climate-sensitive sectors in India, employing a significant proportion of the population and contributing substantially to rural livelihoods. Changes in temperature and rainfall patterns, particularly erratic monsoon behaviour and increased frequency of extreme events, have adversely affected crop productivity and agricultural stability across regions (Mall et al., 2006).

Rising temperatures, especially in north-western and central India, have led to increased heat stress on crops such as wheat, resulting in shortened growing periods and reduced yields. Empirical studies suggest that a rise in night-time temperatures alone can significantly lower wheat yields by accelerating crop maturity and reducing grain-filling duration (Lobell et al., 2012). Similarly, excessive and concentrated rainfall episodes in the Indo-Gangetic Plains have caused waterlogging and crop damage, while prolonged dry spells have increased dependence on irrigation.

Climate change has also intensified the uncertainty faced by farmers. Shifts in monsoon onset and withdrawal dates disrupt sowing calendars, leading to mismatches between crop growth stages and water availability. Rainfed agriculture, which accounts for a substantial share of cultivated land in India, is particularly vulnerable to rainfall variability (Birthal et al., 2014). As a result, climate change poses a serious threat to national food security and farmer incomes, especially in already stressed agrarian regions.

**Table 2: Major Crops and Climate Stress in India**

<b>Crop</b>	<b>Dominant Climate Stress</b>	<b>Impact</b>
Wheat	Rising temperatures	Yield reduction
Rice	Erratic rainfall, floods	Crop loss
Pulses	Droughts	Production instability

- **Impact on Water Resources**

Water resources in India are increasingly under stress due to climate-induced changes in precipitation patterns, glacier melt, and rising temperatures. The Himalayan region plays a critical role in sustaining major river systems; however, accelerated glacial retreat threatens long-term water availability, particularly during dry seasons (Immerzeel et al., 2020).

In the Indo-Gangetic Plains and peninsular India, altered monsoon rainfall has affected groundwater recharge patterns. Intense short-duration rainfall often leads to surface runoff rather than effective groundwater replenishment, exacerbating water scarcity despite episodes of heavy rain (Rodell et al., 2009). Regions such as north-western India, already facing groundwater depletion due to over-extraction, are particularly vulnerable to climate variability.

Urban water systems are also under stress as rising temperatures increase water demand while erratic rainfall undermines supply reliability. Climate change thus compounds existing water governance challenges, increasing the risk of water conflicts and inequitable access.

- **Impact on Human Health**

Climate change poses growing risks to public health in India, with heat stress, vector-borne diseases, and water-related illnesses emerging as major concerns. The increasing frequency and intensity of heatwaves in north-western and central India have resulted in higher incidence of heat-related illnesses and mortality, particularly among outdoor workers, the elderly, and economically marginalised populations (IMD, 2022; WHO, 2021).

Rising temperatures and changing rainfall patterns have also expanded the geographical range of vector-borne diseases such as malaria and dengue. Increased flooding in eastern and north-eastern regions raises the risk of waterborne diseases due to contamination of drinking water sources. These

health impacts place additional pressure on already strained public health systems, particularly in rural and disaster-prone regions.

- **Impact on Livelihoods and Labour Productivity**

Climate change significantly affects livelihoods, especially those dependent on climate-sensitive sectors such as agriculture, fisheries, forestry, and informal labour. Heat stress has been shown to reduce labour productivity, particularly in physically demanding outdoor occupations (Kjellstrom et al., 2016). According to the International Labour Organization (ILO, 2021), India faces substantial economic losses due to reduced work capacity caused by rising temperatures.

Coastal communities dependent on fisheries are affected by warming ocean temperatures, changing fish migration patterns, and increased cyclone activity. Similarly, mountain communities in the Himalayan region face declining agricultural productivity and increased disaster risks, leading to out-migration and loss of traditional livelihoods (Sharma et al., 2021).

- **Impact on Infrastructure and Urban Systems**

Urban areas in India are increasingly vulnerable to climate change due to rapid urbanisation, high population density, and inadequate infrastructure. Heatwaves exacerbate the urban heat island effect, increasing energy demand for cooling and placing stress on power systems. Extreme rainfall events overwhelm urban drainage systems, leading to flooding, property damage, and disruption of economic activity, as witnessed in cities such as Mumbai, Chennai, and Bengaluru (Hallegatte et al., 2017).

Coastal infrastructure is particularly at risk from sea-level rise and storm surges, which threaten ports, roads, housing, and industrial zones. The economic costs of climate-related disasters have risen sharply, diverting resources from development to disaster response and recovery.

- **Economic Implications and Developmental Challenges**

The cumulative sectoral impacts of climate change pose significant challenges to India's economic growth and development trajectory. Climate-induced disruptions in agriculture, health, labour productivity, and infrastructure result in direct economic losses and long-term developmental setbacks. Studies suggest that climate change could reduce India's GDP growth by exacerbating inequality, increasing poverty, and straining public finances (World Bank, 2021).

Importantly, the economic burden of climate change is unevenly distributed, with poorer regions and vulnerable populations bearing a disproportionate share of the costs. This underscores the need to integrate climate resilience into development planning and sectoral policies.

### **Climate Change, Land Use Transformation, and Ecosystem Stress in India**

- **Introduction to Land Use Change and Climate Interaction**

Climate change in India is not only manifested through rising temperatures and erratic rainfall patterns but is also deeply intertwined with land use and land cover (LULC) transformations. Rapid urbanisation, agricultural intensification, industrial expansion, deforestation, and infrastructure development have significantly altered India's natural landscapes over the past few decades. These changes, in turn, exacerbate climate vulnerabilities by disrupting ecological balance, reducing carbon sinks, and intensifying extreme weather impacts.

Land use change operates both as a driver and a consequence of climate change, creating a feedback loop that magnifies environmental stress. The Intergovernmental Panel on Climate Change (IPCC, 2022) highlights that land systems are central to climate mitigation and adaptation, particularly in developing countries like India where livelihoods are closely tied to natural resources.

- **Deforestation, Forest Degradation, and Carbon Sink Stress**

Forests play a critical role in climate regulation by acting as carbon sinks, supporting biodiversity, regulating hydrological cycles, and sustaining indigenous and forest-dependent communities. India's forest cover, while showing marginal numerical increases in recent assessments, masks significant qualitative degradation, fragmentation, and regional imbalances.

According to the India State of Forest Report (ISFR), forest cover growth is largely driven by plantations and open forests, whereas dense natural forests have declined in several ecologically sensitive regions such as the Central Indian belt, Western Ghats, and North-Eastern states. Climate-

induced stressors such as rising temperatures, prolonged droughts, forest fires, and pest infestations further weaken forest resilience.

Deforestation linked to mining, highways, dams, and urban expansion reduces ecosystem services and heightens vulnerability to floods, landslides, and heatwaves. This trend directly undermines SDG 15 (Life on Land) and weakens India's commitments under the Nationally Determined Contributions (NDCs) to enhance carbon sequestration (MoEFCC, 2021).

- **Agricultural Land Transformation and Climate Vulnerability**

Agriculture remains one of the most climate-sensitive sectors in India, employing nearly half of the population. Changes in land use such as monocropping, excessive groundwater extraction, and conversion of agricultural land for non-farm purposes have intensified climate risks.

The expansion of water-intensive crops (e.g., paddy and sugarcane) in semi-arid regions like Punjab, Haryana, and Maharashtra has contributed to soil degradation, declining water tables, and increased greenhouse gas emissions. Climate variability, particularly erratic monsoons and rising frequency of droughts, further threatens food security and farmer livelihoods.

Small and marginal farmers face compounded risks due to limited adaptive capacity, inadequate insurance coverage, and market volatility. These dynamics pose challenges to SDG 2 (Zero Hunger) and SDG 13 (Climate Action), highlighting the need for climate-resilient agricultural practices such as crop diversification, agroforestry, and sustainable water management (FAO, 2020).

- **Urban Expansion, Heat Islands, and Environmental Stress**

India's urban population has grown rapidly, resulting in widespread land conversion from wetlands, agricultural fields, and green spaces to built environments. Unplanned urbanisation has intensified the Urban Heat Island (UHI) effect, particularly in megacities such as Delhi, Mumbai, Bengaluru, and Hyderabad.

Loss of vegetative cover, increased surface sealing, and rising energy consumption contribute to elevated urban temperatures, deteriorating air quality, and heightened health risks. Climate change amplifies these impacts through frequent heatwaves, placing vulnerable populations such as the elderly, informal workers, and urban poor at disproportionate risk.

Urban flooding has emerged as a recurrent challenge due to the encroachment of natural drainage systems and wetlands, as witnessed during extreme rainfall events in cities like Chennai, Mumbai, and Bengaluru. These issues intersect with SDG 11 (Sustainable Cities and Communities) and underscore the need for climate-sensitive urban planning and nature-based solutions (UN-Habitat, 2022).

- **Coastal Land Use Change and Ecosystem Degradation**

India's extensive coastline faces growing threats from sea-level rise, coastal erosion, salinisation, and cyclonic activity. Mangroves, coral reefs, and coastal wetlands serve as natural buffers against storm surges and flooding, yet they are increasingly degraded due to land reclamation, tourism infrastructure, ports, and aquaculture expansion.

Regions such as the Sundarbans, Odisha coast, Andhra Pradesh, and parts of Gujarat exhibit high vulnerability due to the combined effects of climate change and anthropogenic land use pressures. Loss of mangroves not only weakens coastal protection but also affects fisheries, livelihoods, and biodiversity.

These challenges highlight the interconnectedness of SDG 13 (Climate Action) and SDG 14 (Life Below Water), reinforcing the urgency of integrated coastal zone management and ecosystem-based adaptation strategies (World Bank, 2021).

- **Linking Land Use Change to Sustainable Development Goals**

Land use transformations influenced by climate change have direct and indirect implications across multiple SDGs:

- **SDG 2:** Food security threatened by degraded agricultural land
- **SDG 11:** Urban resilience weakened by unsustainable land conversion
- **SDG 13:** Mitigation potential reduced due to loss of carbon sinks
- **SDG 14 & 15:** Ecosystem degradation undermining biodiversity and livelihoods

Addressing these challenges requires policy coherence, integration of climate considerations into land-use planning, and strengthening institutional coordination across sectors.

### **Policy, Governance, and Institutional Challenges in Addressing Climate Change in India**

India has made notable progress in framing climate-responsive policies, yet significant governance and institutional challenges continue to affect effective implementation. Climate governance in India operates across multiple administrative levels viz. national, state, and local, making coordination both essential and complex. While policy intent is strong, outcomes on the ground often remain uneven.

The National Action Plan on Climate Change (NAPCC) serves as the central framework guiding India's climate response through its eight National Missions. These missions address mitigation, adaptation, and knowledge generation; however, they often function in sectoral silos. Limited inter-ministerial coordination and fragmented monitoring mechanisms weaken their collective impact. Additionally, climate objectives frequently compete with short-term economic development priorities, especially in infrastructure and industrial expansion.

At the sub-national level, State Action Plans on Climate Change (SAPCCs) aim to contextualize national goals to regional realities. Although all states have prepared SAPCCs, their implementation capacity varies widely. Many states face shortages of technical expertise, inadequate funding, and weak integration of climate actions into development planning and budgeting processes. As a result, SAPCCs often remain strategic documents rather than operational tools.

Institutional fragmentation further complicates climate governance. Multiple agencies with overlapping mandates lead to accountability gaps. Urban local bodies and rural governance institutions, despite being at the frontline of climate impacts, lack financial autonomy and technical capacity to design and implement climate-resilient projects effectively.

Data and capacity constraints also limit evidence-based policymaking. Inadequate availability of localized climate data, insufficient vulnerability assessments, and limited training of officials hinder adaptive planning. Furthermore, climate finance remains skewed toward mitigation, while adaptation sectors such as agriculture, coastal protection, and urban resilience remain underfunded.

Overall, strengthening policy coherence, enhancing institutional coordination, improving data systems, and mainstreaming climate considerations into development planning are essential to improving India's climate governance outcomes.

### **Conclusion**

Climate change in India is no longer a distant or abstract concern; it is a regionally differentiated reality with profound environmental, economic, and social consequences. This study demonstrates that climate impacts in India manifest unevenly across regions, shaped by geography, socio-economic vulnerability, and governance capacity. Rising temperatures in north-western and central India, increasing monsoon variability in the Indo-Gangetic plains, glacier retreat in the Himalayan region, and heightened cyclone and sea-level rise risks along the coasts highlight the spatial complexity of climate change impacts.

The analysis underscores that climate change intensifies existing regional inequalities. Climate-sensitive sectors such as agriculture, fisheries, and water resources are particularly vulnerable, threatening livelihoods and food security. Urban and coastal regions face compounded risks due to rapid urbanization, inadequate infrastructure, and exposure to extreme weather events. These patterns emphasize the need for region-specific adaptation strategies rather than uniform national responses.

While India has established a comprehensive climate policy framework, governance and institutional challenges continue to constrain effective implementation. Fragmented institutions, capacity gaps at sub-national levels, limited access to climate finance, and insufficient integration of climate concerns into development planning weaken resilience-building efforts. Addressing these issues requires strengthening multilevel governance, improving data-driven decision-making, and enhancing the role of local institutions in climate action.

Looking ahead, India's climate strategy must prioritize regional resilience, inclusive governance, and long-term sustainability. Integrating climate adaptation with development goals, investing in climate-resilient infrastructure, and fostering participatory planning are crucial for addressing regional disparities. A forward-looking, regionally grounded approach will not only enhance India's adaptive capacity but also support equitable and sustainable development in the face of accelerating climate change.

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