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# The Coming of New Climate Regimes: Multi-Dimensional Drought Changes Across India

Arpit Tiwari et al.
Project Scientist-III
BIMSTEC Center for Weather and Climate
National Center for Medium Range Weather Forecasting
Noida, Uttar Pradesh
Email: rpttwr22@gmail.com

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## *The Indian Summer Monsoon*

- India receives ~75–80% of its annual rainfall during the Southwest Monsoon (June–September).

- National average monsoon rainfall: ~850–900 mm (varies regionally).

- Highly uneven distribution:
- 2500 mm in Western Ghats & Northeast
- <500 mm in Rajasthan & parts of NW India.

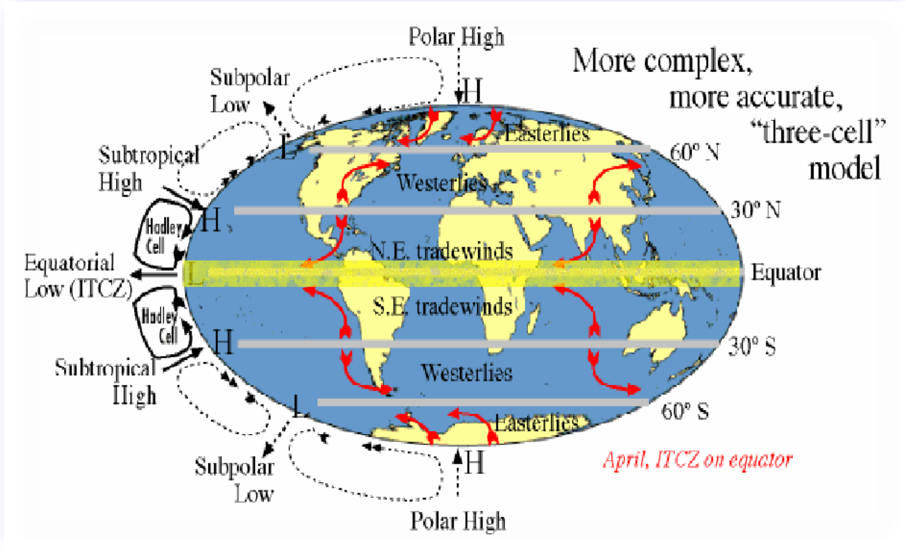
- Monsoon rainfall determines water storage, groundwater recharge, and river flow for the entire year.

# *Why Is the Monsoon So Important for India?*

- *Agriculture:* Supports ~50–55% of net sown area (rain-fed agriculture).
- *Water Resources: Recharges major river basins,* reservoir storage & groundwater recharge.
- *Energy:* Hydropower generation depends on monsoon inflow.
- *Urban Systems:* Heavy rainfall → flooding & infrastructure stress.
- *Economy:* Poor monsoon → food inflation & rural distress.
- *Ecosystems:* Forest health & biodiversity depend on seasonal rainfall.
- Impacts nearly 1.4 billion people directly or indirectly.

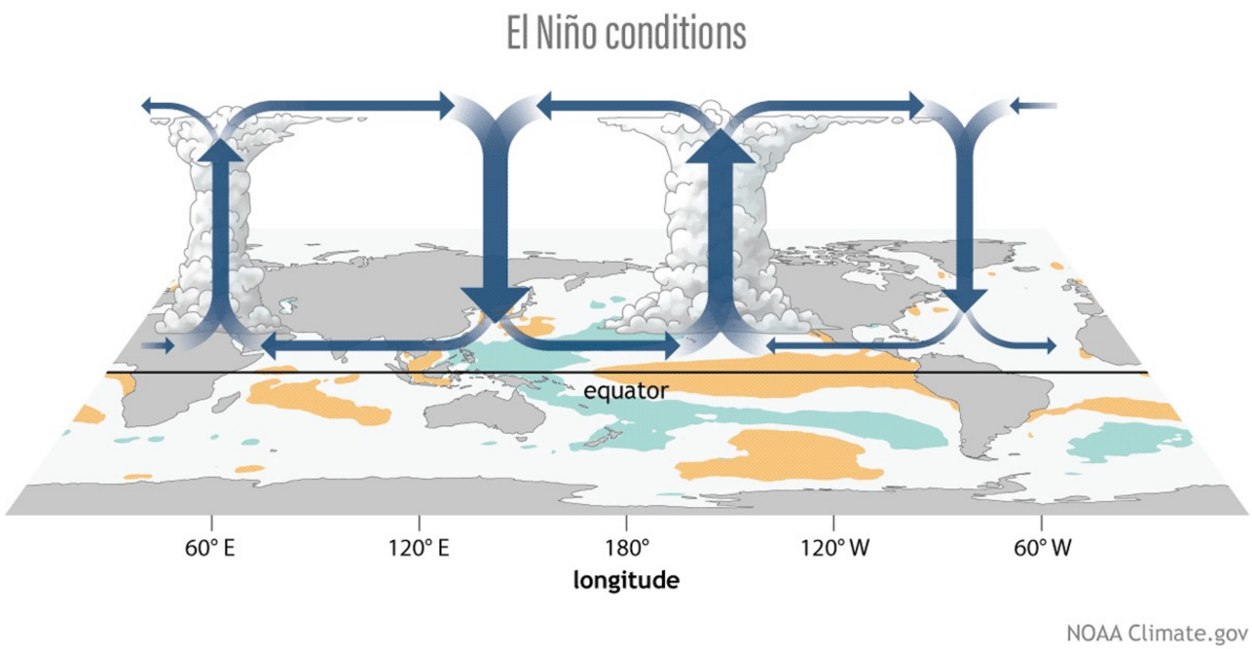
# *The Monsoon Driver:* Inter Tropical Convergence Zone (ITCZ)

- A dynamic system typically between 23.5°N to 23.5°S which follows the Sun.
- In the summer, the ITCZ migrates over Asia as the sun migrates toward 23.5ºN (the Tropic of Cancer). This causes warm, moist trade winds coming from the Indian Ocean to migrate into India.
- Due to the shift of ITCZ, the trade winds of the southern hemisphere cross the equator between 40ºE and 60ºE longitudes and start blowing from southwest to northeast due to the Coriolis force. It becomes southwest monsoon.



# *The Teleconnection:* El Niño-Southern Oscillation (ENSO)

- The Sea Surface Temperature (SST) gradient between eastern and western Pacific Ocean.
- El Niño phase: Eastern Pacific warmer than normal.
- La Niña phase: Western Pacific warmer than normal.



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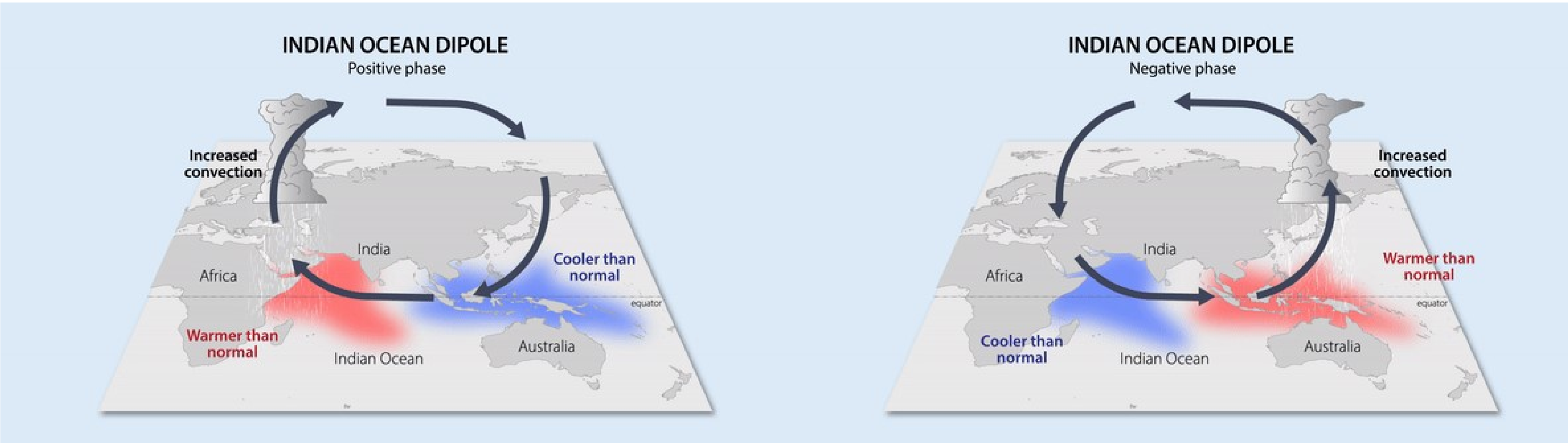
# *The Modulator:* Indian Ocean Dipole(IOD)

- The Sea Surface Temperature (SST) gradient between eastern and western Indian ocean.
- Positive phase: Western Indian ocean warmer than normal.
- Negative phase: Eastern Indian ocean warmer than normal.



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# *India's Changing Climate: Physical Mechanisms and Feedbacks*

- *Higher evaporative demand (thermodynamic effect):* Rising temperatures increase atmospheric moisture demand, enhancing evapotranspiration and drying soils even without large rainfall reductions.

- *Land–atmosphere feedback amplification:* Dry soils reduce evaporative cooling and increase sensible heating, which further raises surface temperature and intensifies drying (positive feedback loop).

- *Regional drying or wetting patterns:* Changes in surface moisture and energy balance modify local circulation and convection, causing some regions to dry while others receive intensified rainfall.

- *Emergence of novel climate states:* New combinations of temperature and rainfall outside historical ranges develop due to combined warming and circulation shifts, leading to unfamiliar climate regimes.

## *The Mechanistic Pathway*

Global warming

↓

Walker circulation modulation + ENSO variability

↓

Monsoon circulation shifts

↓

Rainfall redistribution + Higher evaporative demand (thermodynamic effect)

↓

Land–atmosphere feedback amplification

↓

Regional drying/wetting + novel climate states

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# Beyond a Simple "Yes/No" on Drought

- Traditional drought assessments, focused primarily on rainfall deficits (like the SPI), are no longer sufficient in a warming world.

- The study uses a novel framework to capture changes in three dimensions: local anomalies (SLA), the emergence of non-analogue climates (NCS), and the changing probability of extremes.

- The core investigation is to understand how and where the combined forces of temperature and precipitation change are creating unprecedented drought conditions across India's diverse geographical zones.

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# *Methodology:* A New Toolkit for a New Climate

- ***Measuring Volatility (Probability of Extremes):*** We calculate the change in the probability of local climate extremes, which reveals a significant increase in climate system volatility across India.
- ***Quantifying the Unprecedented (NCS & SLA):*** We use "Novel Climate Scores" (NCS) and "Standardized Local Anomalies" (SLA) to identify where temperature-precipitation combinations have moved completely outside the historical range (1951-80 baseline), signaling the emergence of truly new climates.
- ***Integrating Heat and Water (SPEI):*** Crucially, we integrate these metrics with the Standardized Precipitation Evapotranspiration Index (SPEI). Unlike rainfall-only indices, SPEI accounts for both water supply (precipitation) and atmospheric demand (temperature-driven evapotranspiration), making it a superior tool for capturing modern drought.
- ***High-Resolution Data:*** This analysis is powered by high-resolution (25 KM), daily gridded temperature and rainfall datasets, allowing for a robust, zone-wise assessment across six major geographical regions.

# *Extreme Event Probability:* How much has the chance of extremes increased?

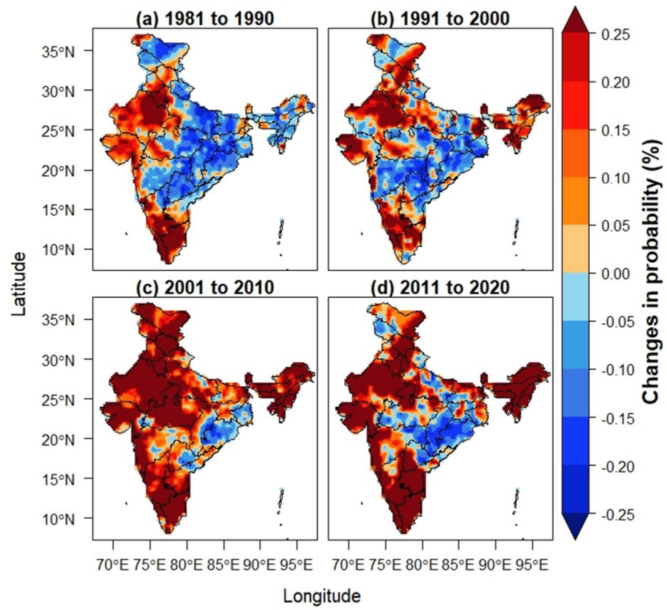
- Daily rainfall, Tmax, and Tmin data were used to compare a baseline period (P1: 1951–1980) with four target decades (P2: 1981–1990, 1991–2000, 2001–2010, 2011–2020).

- 95th and 5th percentile thresholds of P1 to identify extreme high/low events in P2 for each grid cell (Jimenez et. al, 2011).

- The joint probability of co-occurring temperature and rainfall extremes was computed as:

$$\boldsymbol{P(T \cap R) = P(T) + P(R) - P(T) \times P(R)}$$

where $P(T \cap R)$ the probability of extreme events is based on both rainfall (R) and temperature (T). $P(T)$ and $P(R)$ the probabilities of extreme events of temperature and rainfall, respectively.



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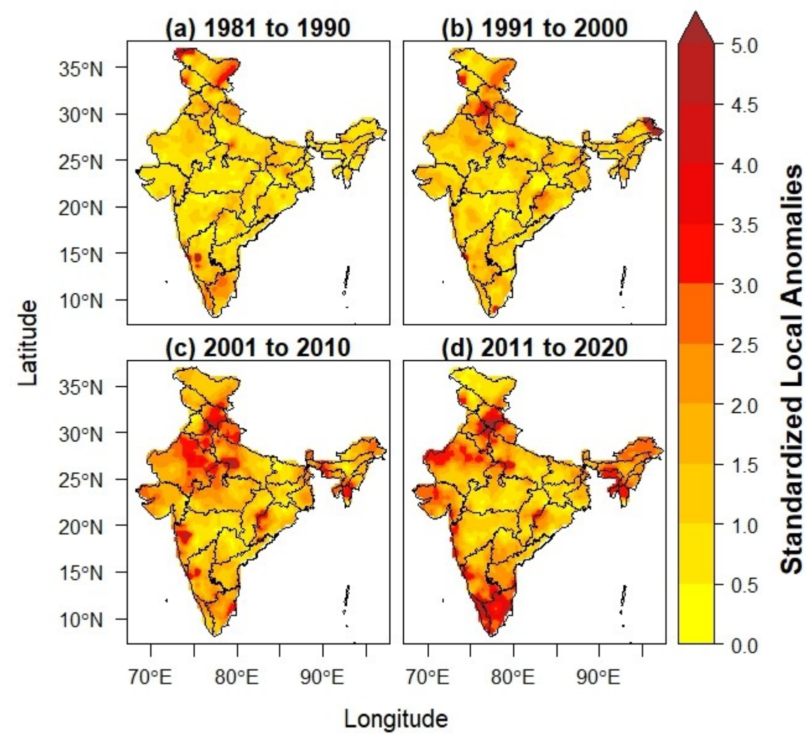
# *Local Anomalies:* How much hotter/colder/wetter than historical norm?

- Changes in climate between two periods by expressing the difference in mean climate variables (P2 − P1) relative to the interannual variability of the baseline (P1) (Williams and Jackson 2007).
- Standardized Euclidean Distance (SED) between the historical baseline (P1: 1951–1980) and subsequent target periods (P2) for each grid cell.

$$SED = \sqrt{\sum_{i=1}^{n} \frac{(A_2 i - A_1 i)^2}{S_{A1i}}}$$

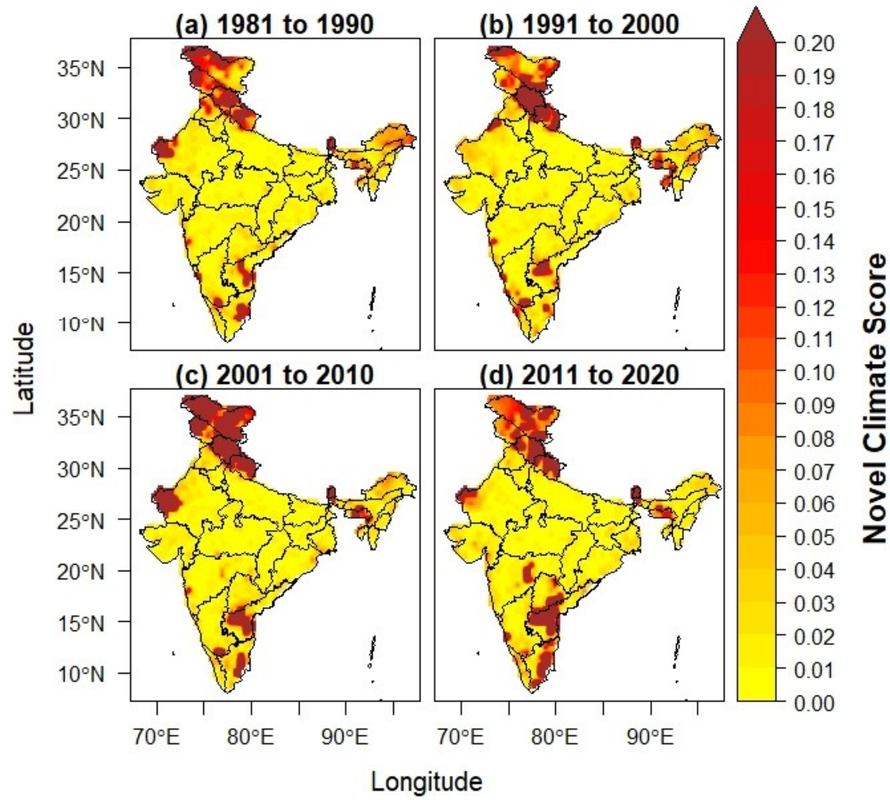
where $A_1$ and $A_2$ are the means of each climate variable *i* in the baseline (P1) and target (P2) periods, respectively, and $S_{A1}$ is the standard deviation of interannual variability for that variable during P1.

- SED quantifies the standardized anomalies of multiple



# *Novel Climates:* Are temperature-precipitation combinations completely new?

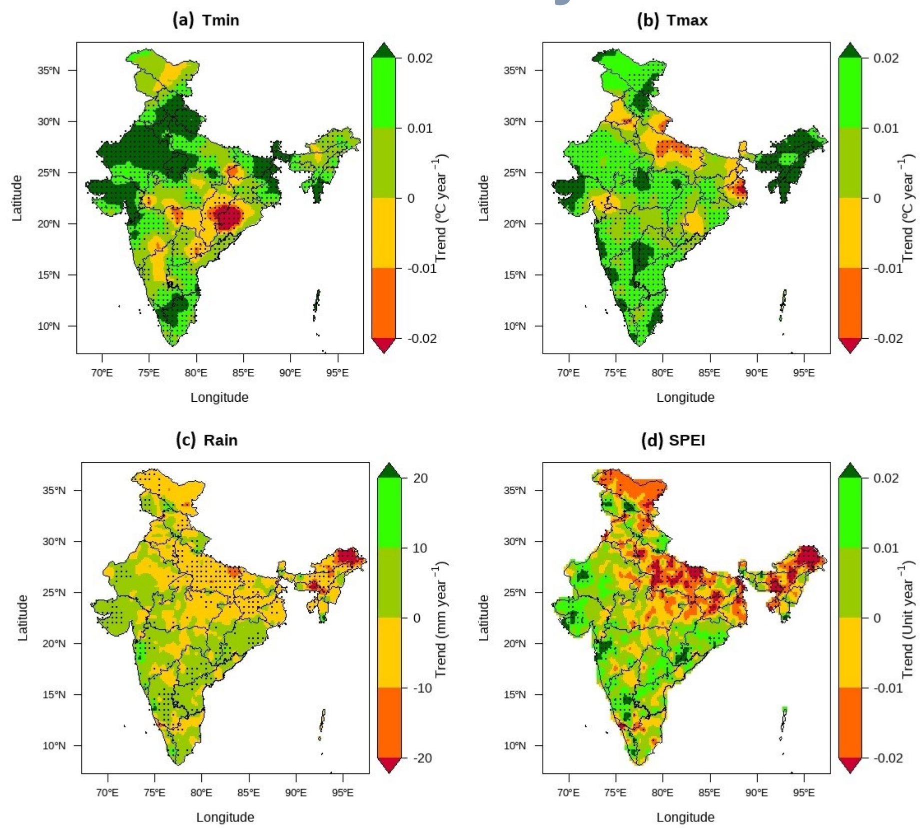
- The minimum SED across all grid cells serves as the threshold for significant changes, with higher values indicating stronger dissimilarity from baseline conditions and the absence of climatic analogues.
- This multivariate metric integrates changes in maximum temperature, minimum temperature, and rainfall, capturing the combined emergence of novel climate states beyond historical variability.



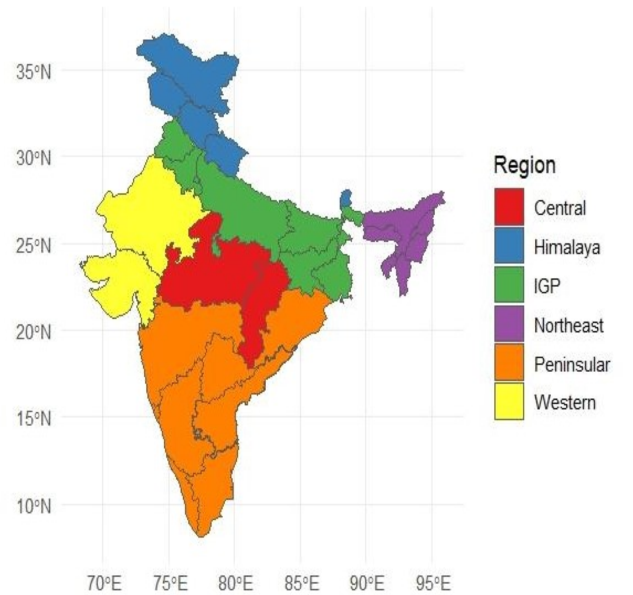
# *The Current Picture:* Trend of climate drivers and hydroclimatic indicator (1971-2020)

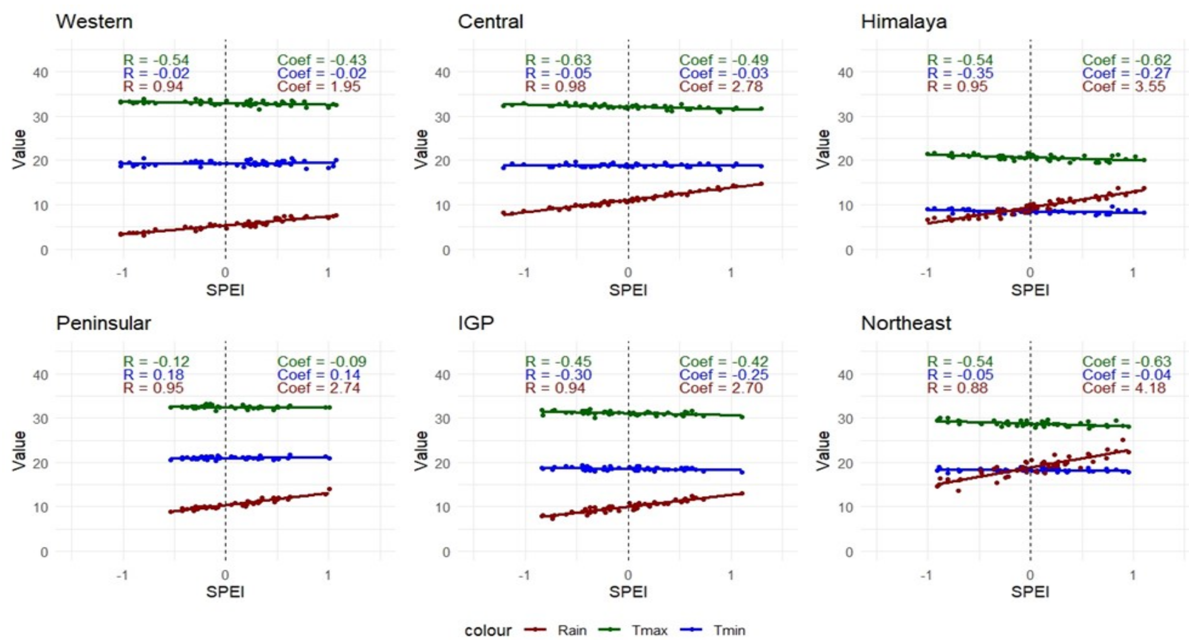
- ***The Drying North and East:*** Northeast India, the Himalayas, and the Indo-Gangetic Plain (IGP) show significant drying trends. This is linked to a combination of declining rainfall and rising maximum temperatures which intensify drought by increasing evaporative demand.

- ***The Wetter West and South:*** In contrast, Western and Peninsular India show wetting trends, primarily driven by increased rainfall and more frequent convective precipitation events.

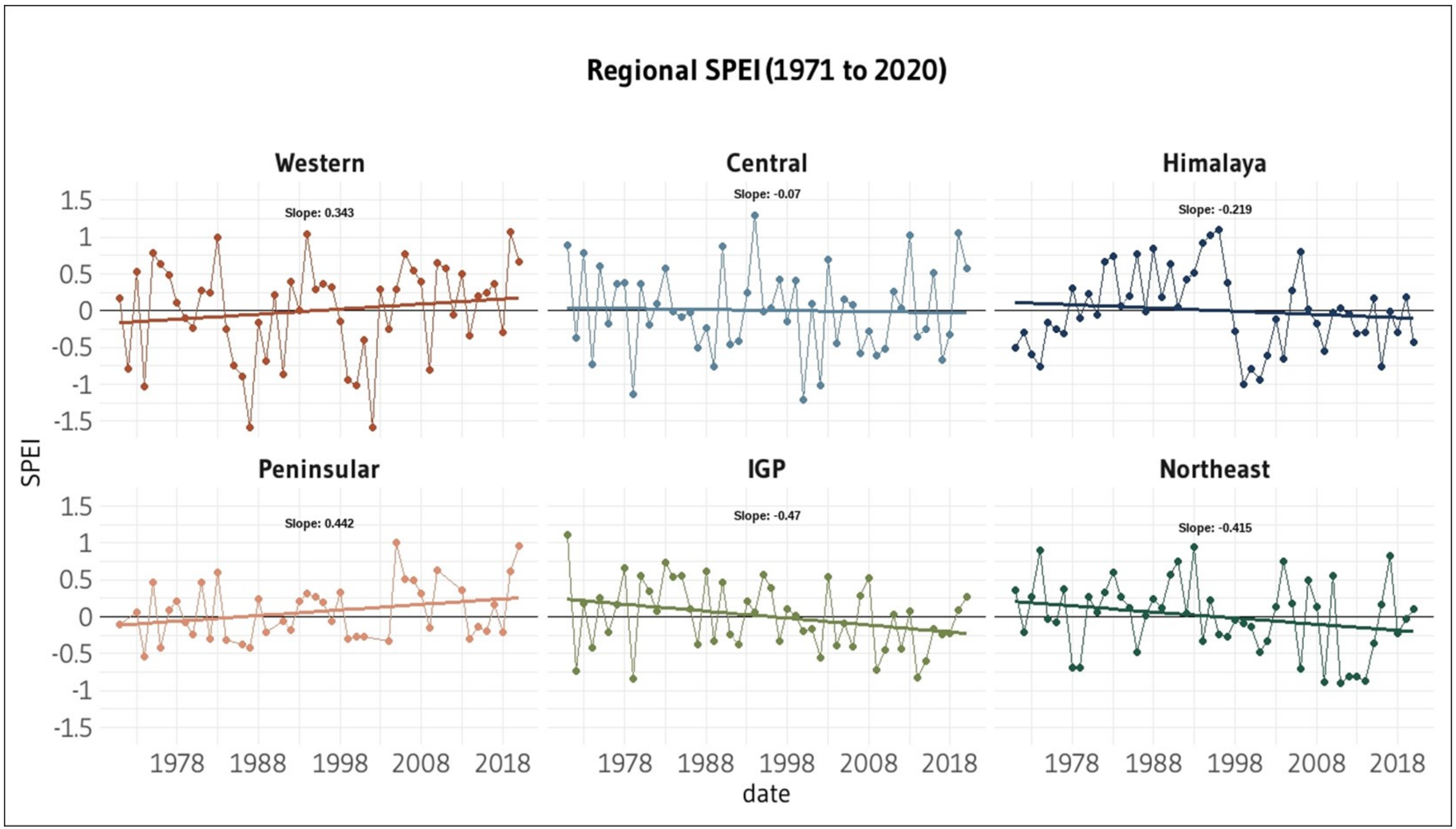


- ***Heat as the New Drought Driver:*** The study clearly shows that while rainfall is the dominant driver, high maximum temperatures are the primary intensifier of drought conditions.
- ***The Subtle Role of Minimum Temperatures:*** Even night-time temperatures have a role, showing a drying influence in the IGP and Himalayas, but a slight moistening signal in Peninsular India, highlighting the complex, region-specific impacts.



# *A Nation Divided:* The Drying vs. Wetting Paradox



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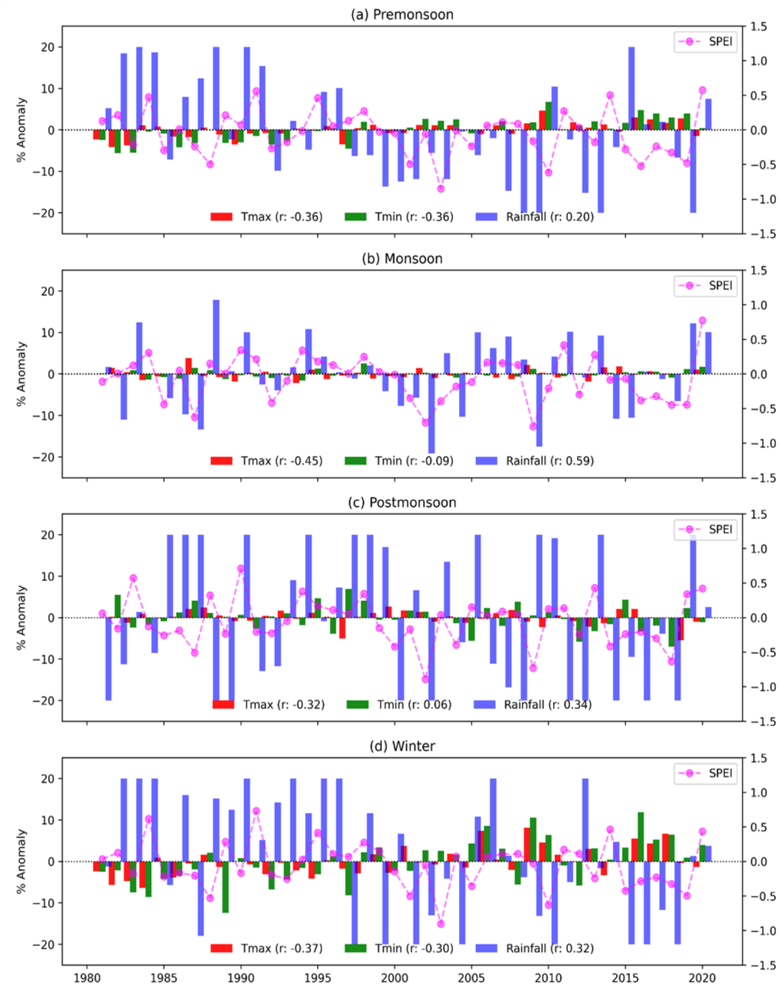
# *Seasonal Shifts in Drought Drivers*

- Pre-Monsoon (Mar-May): High maximum and minimum temperatures become the dominant driver. They dramatically increase evaporative demand, desiccating soils and vegetation even in the absence of a rainfall deficit.
- Monsoon (June-Sep): A deficit in rainfall remains the primary trigger for the onset of drought conditions.
- Post-Monsoon (Oct-Dec): Similarly, after the monsoon retreats, high temperatures can prolong and intensify the dry period by continuing to pull moisture from the ground, stressing Rabi crops.
- Winter (Jan-Feb): Western Disturbance (WD) induced precipitation in northern India may lead to wetting conditions.



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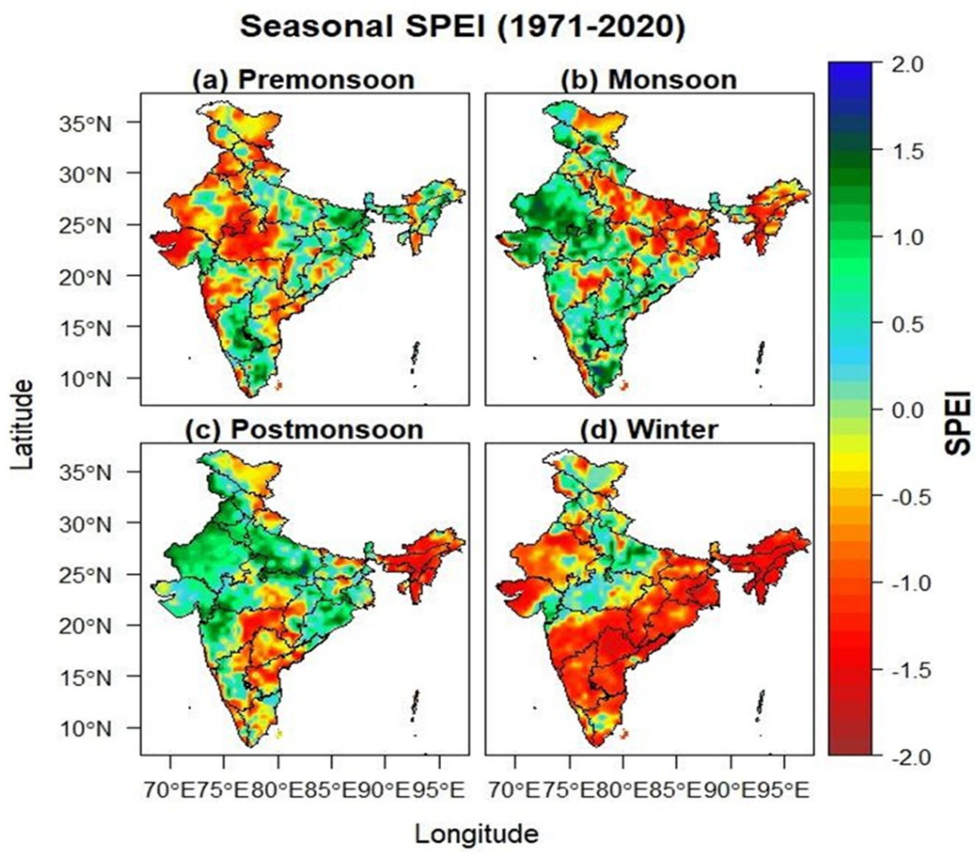

## *Policy Implications:* From Crisis Management to Proactive Adaptation

- ***Region-Specific Adaptation Plans:*** The strong regional divide in trends (drying vs. wetting) demands a shift from national, one-size-fits-all policies to finely tuned, region-specific strategies for water management and agriculture.
- ***Modernize Early Warning Systems:*** India's drought early warning systems must be upgraded to be multi-dimensional. They need to integrate forecasts of temperature, evaporative demand, and "novel climate" indicators, not just rainfall anomalies.
- ***Climate-Resilient Agriculture:*** We urgently need to develop and deploy crop varieties that can withstand "hot droughts"—combined heat and water stress. This must be paired with revising agricultural calendars and promoting water-efficient practices like micro-irrigation.
- ***Sustainable Water Management in Drying Zones:*** In the critically important but drying regions like the IGP and Northeast, policies must prioritize sustainable groundwater management, large-scale water harvesting, and a strong focus on demand-side interventions to reduce water consumption.

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# *Conclusion:* Living in the "Apocalypse"

- ***The Apocalypse is Now:*** The breaching of planetary boundaries is not a distant, future event. In India, it is manifesting today as the regionally distinct, multi-dimensional hydroclimatic shifts documented in this study.

- ***A Call for Informed Action:*** We are already living in the "new climate regimes." The challenge for policymakers, communicators, and communities is to understand the true, complex nature of these changes and act accordingly.

- ***Hope Through Understanding:*** While the findings are sobering, the detailed understanding they provide offers a roadmap. By targeting our responses precisely, we can build more effective resilience.

- ***The Role of Communication***: Translating this complex, multi-dimensional reality into compelling narratives for the public and policymakers is more critical than ever.

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# THANK YOU

**Ref:** "**Multi-dimensional changes in drought patterns across India**"

Tiwari, A., Chakravorthy, S., Nanjundan, P. *et al.* Multi-dimensional changes in drought patterns across India. *Climatic Change* **179**, 11 (2026). https://doi.org/10.1007/s10584-025-04102-3