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Physical Geography of India and Its Influence on Regional Climate Patterns

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Abstract

India's physical geography plays a decisive role in shaping its highly diverse and regionally differentiated climate patterns. This study examines how major physiographic elements—such as the Himalayas, the Peninsular Plateau, the Indo-Gangetic Plain, coastal plains, and surrounding oceans interact with atmospheric processes to regulate temperature, precipitation, and wind systems across the subcontinent. Special attention is given to orographic controls on rainfall, land–sea thermal contrasts, and the modulation of monsoonal circulation by terrain configuration. The analysis highlights how mountain barriers influence moisture transport, how plateaus and plains modify surface heat fluxes, and how coastal and island systems interact with ocean–atmosphere dynamics, including cyclones and monsoon variability. In addition, the study situates regional climate patterns within broader oceanic influences such as the El Nino–Southern Oscillation and the Indian Ocean Dipole. By synthesizing geomorphological, climatic, and atmospheric perspectives, the paper underscores the central importance of physical geography in producing India's spatial climate variability. The findings contribute to a deeper theoretical understanding of land–atmosphere interactions and provide a foundation for interpreting contemporary climate variability and long-term climatic responses across different regions of India.

Keywords: Physical geography; Indian climate; Monsoon system; Orographic effects; Regional climate patterns; Ocean–atmosphere interaction; Topography

1. Introduction

India's vast and varied physical geography has critical implications for regional climate systems. A detailed analysis of terrain configuration permits the proposal of specific mechanisms through which topographical features influence climate and an evaluation of how these processes generate spatial patterns in rainfall, temperature, and wind. Regional variation across four broad landform types—the Peninsular Plateau, the Indo-Gangetic Plain, the Thar Desert, and the Coastal Plains and Islands—further highlights how specific terrain features shape climatic regimes.

Geography and climate interact in two main ways. First, physical geography exerts direct control over climatic variables. Thus, high-elevation areas experience cold climatic conditions, with the amount of precipitation received often correlating with proximity to moisture-laden airflows. Second, physical geography impacts circulation patterns, driving the land-sea breeze and seasonal wind systems. Examination of these mechanisms across diverse regions clarifies their role in land-atmosphere interactions throughout the subcontinent and illustrates the overarching importance of terrain configuration in determining climate. A flexible approach is adopted that permits the integration of climatic regions, climatic averages, and duration of rainfall season, and analyses are grounded in data collected from multiple sources to ensure robustness (Tripathi et al., 2019).

2. Tectonic Framework and Geomorphology

The tectonic framework and geomorphology set major influences on Indian regional climate. India occupies an area of converging and diverging plate boundaries, with the converging boundary along the Himalayan front to the north and diverging boundaries in the Indian Ocean. The North Indian mountains represent an orogenic system that determines climate in northern India. The Indian plate is saturated with sediment and is dynamically controlling the Indo-Gangetic structure, which is supported by the Himalayas. The India–Eurasian convergent boundary is characterized by active tectonism represented by major uplift and a range of fault systems. The plateau surface and associated fault system shape the upper-level atmosphere and pressure patterns over the region, while surface anomalies in heat drainage generate monsoon winds and cyclonic storms. The Indian plate is however losing its integrity through crustal thinning due to rifting and the development of the mid-ocean ridges in the Indian Ocean. Movement of the system involves configuration of plate margin settings and coupled mass transport.

The orographic system appears to control the spatial and temporal distribution of added rain and snowfall in the region. The Western and Eastern Ghats, along with the Himalayas and other minor mountain ranges in Central India, enhance the monsoon, while similar systems in the eastern parts of the peninsula use the wind to create a rain shadow. Hence a slope staircase is apparent where the moisture-laden southwest winds first reach.

3. Plateaus, Plains, and Coastal Configurations

Robust climatic regimes—resulting from the combined influence of the Godavari and Krishna rivers and proximity to the Bay of Bengal—are modified by land use (dry land, agriculture, irrigation) and urbanization. Drought is rare and summers hot; air mass temperature and moisture content vary from south-east to north-east. Topographically, the dominant features in the north are the Indo-Gangetic Plains, which narrow towards the east, and the Himalayas. Geomorphologically, three major plates (the Peninsular Plateau, the Indo-Gangetic Plain, and the eastern Coastal Plain, with Koromandel Coast and Sundarbans) and land-lake configurations (the Andaman–Nicobar Islands) from the Peninsular Plateau and South-Western Deccan region project a climate of the Monsoons and have a rain-shadow area that alters the heat and moisture supply over Eastern and South-Central India (the Western Ghats) during the South-Western Monsoon and influences the cyclones that sweep over the eastern Coastal Plain and affect Madhya Pradesh, Virar, West Bengal, and Orissa. During the North-East Monsoon, the eastern Coastal Plain receives considerable rain.

The Peninsular Plateau—the highest segment of Indian land—is flanked on the west by the Western Ghats, which protect the Deccan from the cool moist winds of the Arabian Sea. Whereas the Western Ghats cool the humid winds, the rivers originating from the Western Ghats (the Godavari, Krishna, and Kaveri) increase the sur-face temperature and humidity in the rain-shadow area to engage Yahnel in assisting the North-East Monsoon, Both the Western Ghats and the Peninsular Plateau and eastern Coastal Plain receive rain from the South-West Monsoon. The Western Ghats sustain dense Evergreen Forests, while those of the South-Western Deccan—washed directly by the South-Western Monsoon and receiving additional rain from the North-East Monsoon—are largely Deciduous, Cutting across the North-East Monsoon-dominated Eastern Coastal Plain is the very fertile Sundarbans, which support rice cultivation without irrigation during all years.

3.1. The Peninsular Plateau and Western Ghats

The Peninsular Plateau has a general elevation of about 600 m, with a range of 100 to 2000 m, while the Western Ghats shows a mean elevation of 1300 m, ranging from 400 to 2800 m (B. Singh et al., 1994). In the southwestern monsoon season, the Peninsular Plateau experiences enhanced orographic rainfall due to its interaction with the moist southwesterly winds. The region receives an average of 800–1200 mm of rainfall in the south and 600–800 mm in the west. A considerable portion of the plateau on the leeward side of the Western Ghats and the interior plains are deciduous, while the wet areas in the Western Ghats and the southwest portion of the plateau are densely wooded and evergreen. The Western Ghats form a significant climatic boundary between the western and eastern coasts of peninsular India. These mountains influence the rainfall distribution and the pattern of trees and forests over the adjoining regions of the South Indian peninsula. The Peninsular Plateau is one of the large plateaus of the world and occupies about 1.5 million km2 of India. The plateau is bounded by the Sahyadri mountains (Western Ghats) on the west, the Eastern Ghats and the Chotanagpur uplands on the east, the Satpura range on the north, and the Kaimur hills on the northeast. The Himalayas, which include the Pir Panjal and Zanskar ranges, influence rainfall over the western Himalayan region to some extent.

3.2. The Indo-Gangetic Plain and the Himalayan Foreland

The Indo-Gangetic Plain is one of the most densely populated regions in the world. The basin is relatively deep and is heavily loaded by sediment (on an average 5–7 km) supplied by rivers originating from the Himalayas and the peninsular India. Permanent snowmelt from the upper reaches of the Himalayan rivers after the retreat of the SW monsoon sustains first surface and then groundwater flow through the entire Indo-Gangetic Plain during the dry period. Consequently, flood–drought cycles that are observed in the nearby Himalayan Foreland and Peninsular India are almost absent. Even during the earlier years of irrigation development as much as 94,000 km^2 of command area was irrigated, about 2.8 times the design stable area of 33,900 km^2 of available groundwater security area. The Dimensional flood risk atlas, 2014 elaborates the flood and drought risk area of the Indogangetic Plain, Bharatpur in Rajasthan receives the lowest rainfall and about 78.4% area is prone to drought, while Bahraich in U.P. receives maximum rainfall and about 14.4% area is prone to drought. The importance of these studies lies in the fact that increases in surface water use has implications for the future deployment of groundwater, which is affected by a multitude of factors. Depletion of water table over the entire area of ha has been recorded (Srivastava et al., 2015) for 107, 325, 886 and 1595 blocks based on field observation and computer simulation model.

3.3. Coastal Plains and Islands

The Coastal Plains and Islands of India comprise dynamic barrier systems responding to wave action and sea-level patterns. Along the eastern coastline, barriers are susceptible to flooding during storm surge, while semi-enclosed bays support potential cyclone formation. The eastern coastal stretch hosts the country's largest lagoons, nurtured by shallow continental shelves, and experiences an anomalously dry period. Conversely, the western coast benefits from an active monsoon season, with sea-surface cooling favoring the development of intense northeast monsoons, although westward-moving depressions generate copious thundershower activity. These Hydro-Meteorological features engender extensive ecosystems, such as the Sundarbans delta, which provides crucial livelihood support for many.

Coastal-upwelling-induced biological productivity significantly influences the economy of Tamil Nadu, Kerala, and southwestern Sri Lanka. The Coastal Plains and Islands zone plays a pivotal role in shaping climatic conditions within the peninsula. Sea-level fluctuations can induce significant climatic impacts, particularly among the smaller landmasses. Islands are exposed to tropical cyclones and their associated effects, including rain and adverse weather. Stability and security in these regions demand predictable, favored conditions, supported by the transport of large volumes of water for heat and moisture storage.

4. Major Ocean-Atmosphere Interactions

India’s climate, one of the most variable on Earth, is heavily influenced by ocean-atmospheric interactions. The monsoon system, characterized by a distinct wet season and a continuation of the dry season, is a prominent westerly wave phenomenon that starts on the west coast and moves inland, followed by progressive changes in the large-scale circulation (McPhaden et al., 2009). Interannual variations in the monsoon, which significantly impact society and agriculture, are largely driven by the El Niño–Southern Oscillation. In addition, the Indian Ocean Dipole and its positive and negative phases alter the distribution of rainfall across the continent.

Monsoonal precipitation is influenced by oscillatory mechanisms connected to climate and water vapor transport. Sea-surface temperature anomalies act as a physical relay, modifying land–sea thermal contrasts during these cycles. The monsoon circulation trend may be fingerprinted by changes in land-sea temperature contrast at the time of monsoon onset and during the active phase.

4.1. The South Asian monsoon system

Monsoon is a seasonal reversal in the wind direction that governs Indian climate, and is defined as a wind system that changes direction seasonally (C. Clemens et al., 2021). South Asia experiences one of the most dramatic seasonal reversals in the world, with large volumes of moisture-laden air arriving from the southwest during the summer monsoon season. This seasonal transformation, which dictates the agricultural calendar, has significant socioeconomic consequences. The onset and withdrawal of the Indian summer monsoon are governed by land-sea temperature contrasts arising from differential solar heating during the premonsoon season. North India heats up more rapidly than the surrounding sea surface, generating medium- to large-scale sea-breeze circulations that modulate the southwest monsoon on two overlapping temporal scales. Fresh sediment core records reveal that the timing and extent of the southwest Indian summer monsoon has remained relatively stable over the last 150 thousand years, while the intensity, driven primarily by sea-surface temperature (SST) gradients and the extent of the land-sea temperature contrast, has varied by more than 50% worldwide.

4.2. El Nino–Southern Oscillation influence on Indian rainfall

The Indian monsoon experiences extreme interannual variability associated with the El Niño-Southern Oscillation (ENSO). El Niño coincides with reduced rainfall whereas La Niña enhances it (Chakraborty & Singhai, 2021). The ENSO influence on the monsoon is further complicated by the duration and season of occurrence (A Hill et al., 2024). The intra-seasonal break-period characteristics of the monsoon and inter-seasonal rainfall within the transition zone between winter and summer dominate year-to-year variability but exhibit little systematic dependence on ENSO.

Monthly rainfall data for the Southern Western Ghats have shown that during El Niño years, months preceding the monsoon exhibit reduced rainfall while the monsoon itself experiences a distinct increase. The Eastern coastal region and the Northern Western Ghats show excessive rainfall during La Niña compared to non-La Niña conditions. Remote sensing imagery of surface-sensible-heat flux indicates quasi-periodic shifts are part of a natural cycle at various time scales. Thermal-wave propagation models for soil-moisture-drought-monitoring countries and varying sea-air temperature are complementary to monitoring and provide timely prediction cycles—remotely. These phenomena illustrate terrain–climate interactions linking geography to atmospheric response.

The Indian monsoon system is influenced by oceanic – atmospheric interactions rather than crustal or coastal links with immediate effect. Proposals for integrated e-governance address these information gaps in atmospheric research and supply sustainable parameters throughout life – without inhibition or obtrusiveness – and assist monitoring of over-exploited resources to secure the standard of living. Downscaling enhances general-climate predictions through numerical modelling.

4.3. Indian Ocean Dipole and regional variability

The Indian Ocean Dipole (IOD) is a sea surface temperature (SST) anomaly in the equatorial Indian Ocean, occurring in positive, negative, or neutral phases. During a positive IOD, SST is elevated in the western Indian Ocean while being suppressed in the eastern counterpart. The inverse occurs during negative IOD conditions. The IOD influences ocean-atmospheric interactions and modulates environmental factors in the region. Its impact affects precipitation in southern and central India and cyclone activity in the Bay of Bengal.

In southern India, a positive IOD leads to a 10–30% increase in rainfall during summer, while a negative IOD reduces monsoon precipitation (Ng et al., 2018). Positive IOD prevails at the onset of summer, whereas negative IOD dominates the advancement of winter rain over India. Negative IOD corresponds with an increase in pre-monsoon cyclones in the Arabain Sea, whilst a positive IOD causes a reduction in the Bay of Bengal and shifts landfall towards Myanmar.

5. Regional Climate Patterns across India

Through the Indian subcontinent, distinct climate regimes emerge along latitude, topography, and proximity to water bodies. Five major regions exhibit divergent patterns: the Northern Mountain Climate featuring Trans-Himalayan influences; North Indian Plain upholding Humid Subtropical Conditions; Western Deccan reflecting Monsoon Shadow effects; Eastern Coastal Climate affected by Cyclonic Activity; and Peninsular Interior experiencing Extreme Temperature Regimes. Climatic variations stem from underlying physical characteristics, which include elevations above the dominant monsoonal flow, proximity to the Himalayas and snowmelt contributions, and more.

The Northern Mountain Climate benefits from substantial orographic cooling, signaled by the presence of glacial features and lower summer precipitation in the Trans-Himalayan regions. The North Indian Plain enjoys high average annual rainfall within the country, with monsoonal precipitation heavily concentrated during the main rainy season and a sharp longitudinal temperature gradient aligning with the Indo-Gangetic basin. The Western Deccan, located in the monsoon shadow, receives markedly lower rainfall than neighbouring regions, with droughts dictated by highly variable summer precipitation and strong surface heat flux responses to such variability. The Eastern Coastal Climate experiences cyclones that originate in the Bay of Bengal, with landfall predominantly along the coast of West Bengal to Orissa and neighbouring states. The Peninsular Interior remains the most arid part of the country, facing the hottest temperature limits and extreme heat waves, largely driven by low annual rainfall, suppressed summer pre-monsoon precipitation, and elevated land-surface temperatures and convective instability (John Bejoy & Ambika, 2023) ; S. Ross et al., 2018.

5.1. Northern Mountain Climate and Trans-Himalayan influences

The northern mountain climate region of North-West India is confined to high elevation areas of North-West Himalaya and Ladakh. Following the Kolhapur classification, it falls under the Alpine, or more precisely, Northern Mountain climate. Maximum rainy months coincide with the south-west monsoon seasons of June-September, with a small and inconstant amount of precipitation occurring in the winters of December-February, mainly in the Northern Mountain area. The maximum glacial period, as indicated from the presence of glacial deposits and landforms supported further classify the region as belonging to the Cold period (not to be confused with Cold Desert arid climate). The source of moisture for this period and for the present-day monsoon regime is also inferred (Sharma & Phartiyal, 2018).

5.2. North Indian Plain and Humid Subtropical Conditions

The climatic regime of the North Indian Plain is strongly influenced by its position in the northwestern interior of the Subcontinent and the humid subtropical climate experienced in most of the region. With its maximum precipitation falling during the southwest monsoon, the amount decreases toward western and north-western sectors. A clear gradient is seen during winter along the east–west axis. Characteristics of the rain-bearing winds are gradually changed by the underlying surface in their progression inland, with consequent influences on wind direction, humidity, temperature, and rainfall. Over the Indo-Gangetic Plain, the winter months are cold, while the climatic features of the orographic region are a cooler climate with temperatures rarely exceeding 21° C in summer.

The Chamoli Glacier in the Central Himalaya is one of the most studied Himalayan glaciers, and recent studies have detected an increased sensitivity of the region's glaciers to climate fluctuations. Temperature and precipitation trends show a warming of 1.2 °C during 1970–2007. The abundance of precipitation during the Indian summer monsoon is documented, but the time series analysis for the last 30 years displays a slight decrease that is consistent with other parts of the Indian Himalayan region. However, south-western and south-eastern slopes remain rich in precipitation. Atmospheric moisture advection from both the Arabian Sea and the Bay of Bengal provide the Indo-Gangetic Plain with humid sub-tropical climatic conditions. Despite the abundance of rainfall, river floods like those in 2006, 2008, and 2009 leave behind devastating imprints. These floods, however, do not dispose residents and foreign tourists alike from visiting the Taj Mahal, which acts as a natural magnet for visitors around the globe.

5.3. Western Deccan Climate: Monsoon Shadow and Rainfall Distribution

The Western Deccan region settles under the rain shadow of the Western Ghats (V. Rajesh & N. Goswami, 2022). Significant aridity and a high risk of drought typically characterize the climate, driven in part by surface heat fluxes from the land and the heat released from adjacent water bodies during their discharge. The allotment of rainfall during the monsoon season mirrors these features, with most parts of the region receiving between 600 and 900 mm; pockets receiving between 400 and 500 mm exist in some of the western areas. Further, the south-west monsoon onset over Western India occurs in the last week of May or the first week of June; the climate is fairly cold and dry from the month of April. The drought is influenced and affected by local perturbations, extra-territorial forcing and inter-media and intra-media feedback.

5.4. Eastern Coastal Climate and Cyclonic Activity

Unusual cyclone patterns characterize the eastern coastal climate and cyclonic activity of India. The eastern coastline from the Sundarbans to Nagapattinam expects cyclone tracks that correlate with the coastal westward shift of the Bay of Bengal warm surface. Superimposed upon the Bengal currents forecasting cyclone behaviour, the ocean surface temperature (OST) shows a unique correlation between a specific range and net precipitation. Areas along the eastern coastline of India observe dramatic rainfall increases, typically related to cyclone landfall, even when outside ocular range. OST, 24° C to 30 °C, plays a fundamental contribution during the formation phase associated with the occultation of atmospheric pressure either higher or lower across the multi-dimensions (Chauhan et al., 2018).

The eastern coast of India is undergoing climatic anomalies and unexpected behaviour, with cyclone formation and trajectory shifting towards the western side of the Bay of Bengal. The eastern coastline from the Sundarbans to Nagapattinam shows cyclone tracks heavily correlated to the coastal westward shift of the Bay of Bengal warm surface current. Besides the already known cyclonic activity, pattern propagation along the eastern coastline gets reinforcement from SCI-3. Further active cyclones obtain associated with low temperature below 28 °C, and aggregated cyclonic events above the East Coast get exacerbated when SST exceeds the alignment of 28 °C system. The Ocean Surface Temperature (OST) exhibits a unique characteristic, whereby the specific range significantly correlates to precipitated rain content through a compositing average of spatial distribution and hourly temporal resolution. Surface condition along the Eastern Coast presents a profound enforcement process across the cyclone landfall. The areas around the eastern coastline and confirmation of ENSO and IOD alternative climate effects disclose no any marked influence and spatial variation connected to central Bangladesh and Bay of Bengal Tracks.

5.5. Peninsular Interior Climate and Extreme Temperature Regimes

The Deccan Plateau is enveloped by the hill ranges of the Western and Eastern Ghats and the Satpura–Vindhyan hills. These, together with the eastern Himalayas and northern Rajasthan, demarcate India’s neighbourhood climatic zones of arid, semi-arid, and mountainous. The interior regions of the southern half of peninsular India, broadly defined by the 85°E meridian and between 7°N and 30°N latitude, provide arid to hyper-arid conditions, experiencing extreme summer heat wave conditions along with droughts when Kamal and collections bye days are less than 5.0 cm and semi-arid conditions subcontinent when the period is between 5.0 cm and 25.0 cm. As per Harvard Dataverse records, very high daily temperature reaches 22° C in the pre-monsoon interior of the peninsular India other than moist coastal regions. The major synoptic systems associated with the semi-arid interior peninsular India are three intermittent structures military remain active during pre-monsoon period. These are increasing day by day since 1970.

6. Human Impacts and Climate Variability

The impacts of anthropogenic activities, including land-use change, have been tied to localized climate variability in India, including alterations in thermal regime, precipitation patterns and moisture availability (Nagaraja Balakrishnan Manikiam, 2021). Urbanization further exacerbates these effects, inducing a distinct urban heat island phenomenon paired with a decrease in local wind circulation and changes to rain-bearing systems. Simultaneously, the rise of emissions from gas and oil products is intertwined with groundwater depletion. These changes may impinge on climate resilience by determining regional climate variability, hasty demands, water supply and healthy reserves (John Bejoy & Ambika, 2023).

The regionally heterogeneous climate change noted over India remains best understood through rainfall metrics. Satellite-based precipitation estimates indicate sustained soil moisture over areas of large irrigation and cropped coverage, which supports growing-season water availability in flood-prone regions. Around the Indo-Gangetic floodplain, the flooding regime is frequently influenced by the supply of groundwater associated with the river, the connectedness between groundwater and surface-water systems and large monsoon storage policies extending irrigation. Instances of flood and drought remain a major concern; approaches that aim to understand rainfall and climate transitions would therefore support urban and regional planning, sectoral policies, adaptation measures and groundwater accounting (S. Ross et al., 2018).

6.1. Land Use Change and Albedo Effects

The energy balance of the Earth's surface is influenced by land cover and land use, with surface albedo modifications playing a crucial role in land surface conditions and local climate regulation (A. Barnes, 2010). In the United States, land cover changes from 1973 to 2000, encompassing shifts between 17 land cover classes, significantly affected the spatial distribution and inter-annual variability of snow conditions across 58 ecoregions. Consequently, annual surface radiative forcing from 1973 to 2000 was evaluated for these regions, revealing that land cover transitions strongly modulated surface energy balance and regional climate systems. The projected land cover alterations from 2000 to 2050 for 19 Eastern U.S. ecoregions indicate further substantial changes in surface properties and radiative forcing, highlighting the continuing anthropogenic modification of approximately 35% of Earth's land surface for agriculture and urbanization, which has already significantly impacted physical surface properties, including albedo. Similar land use change–albedo relationships are expected to occur in India. An increase in urban and rural housing activities has modified some of the country's urban and rural covers. As a result, it is important to consider the energy balance associated with the surface cover change and, in turn, its influence on local rainfall.

6.2. Urbanization and Localized Climatic Alterations

Urban areas facilitate economic growth and prosperity, but they also cause localized climatic alterations due to unique design and planning. Urbanization leads to a substantial increase in artificial land cover and a concomitant reduction in vegetated areas, significantly affecting the energy balance of a region. The Indian subcontinent continues to experience steady urbanization and population growth. The rapid urbanization of India has caused a remarkable change in land cover, with artificial areas increasing from 0.44% to 1.66% of the land surface between 1992 and 2006. Increased anthropogenic processes in urban areas have raised surface temperatures, further intensifying the UHI effect. The southeastern and northeastern regions of India underwent rapid growth in built-up areas. The growth in urban areas and population has a profound influence on climate, especially precipitation, which is expressed in terms of the emergence of an urban heat island effect (UHE) (Falga & Wang, 2022) and urban-rural contrast precipitation (Halder et al., 2016).

7. Conclusion

The preceding sections have traced the physical geography of India—its tectonics, landforms, and oceanographic influences—and illustrated key dimensions of its climate. Long-term oscillations in ocean-atmosphere coupling further modify the geography climate framework through large-scale alterations in the seasonal march and distribution of rainfall. Spaceborne sensors and in-situ observations enable the significant influence of human activities on surface energy and water balances to be elucidated. The Indian subcontinent supports diverse climatic regimes, each with specific geographical drivers. Surfaces range from desiccant interior plains to moist coastlines capable of generating copious rainfall. Together, the substantial impacts of terrain, ocean, and anthropogenic activities warrant that India continues to be a priority for refined climate science and sector-linked end-user applications.

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