

Regional Patterns of Flood Hazard in India: A Geographical Study

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Abstract

Flooding in India is characterised by pronounced regional contrasts produced by variations in monsoon rainfall, river-basin morphology, topography, sediment regimes, antecedent hydrological conditions, coastal processes and human modification of drainage systems. Although the Indo-Gangetic and Brahmaputra plains have traditionally been regarded as the principal flood-prone regions, recurrent floods in peninsular basins, Himalayan valleys, coastal zones and rapidly urbanising areas demonstrate that India contains multiple and increasingly interconnected flood regimes. This paper examines the regional geography of flood hazard in India through a descriptive, analytical and comparative secondary-data approach. The principal empirical basis is the Central Water Commission's satellite-derived assessment of maximum aggregated flood-affected area for 1986–2022, supplemented by flood-forecasting records, official policy reports and peer-reviewed hydrological and geographical research. The analysis shows that 21.213 million hectares were identified within the maximum aggregated satellite-observed inundation footprint during 1986–2022. Uttar Pradesh, Bihar, Assam and West Bengal together account for approximately 58.5% of this national extent. However, absolute area alone obscures important contrasts in flood intensity, proportional spatial exposure and flood-generating processes. Himalayan-fed alluvial rivers dominate the northern and north-eastern plains, while extreme precipitation, antecedent moisture, reservoir conditions, cyclonic rainfall, urban imperviousness and short-response catchments shape hazards elsewhere. The study concludes that Indian flood hazard cannot be represented adequately through a single national flood-prone category. Region-specific, process-based mapping integrating inundation frequency, depth, duration, velocity and evolving hydroclimatic conditions is necessary for more effective flood management.

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Introduction

Floods constitute one of the most geographically extensive natural hazards in India, but their occurrence is highly uneven across space and time. India's hydrological regime is influenced by the concentration of much of its annual rainfall within the monsoon seasons, considerable interannual and intraseasonal rainfall variability, Himalayan snow and glacier-fed river systems, extensive alluvial plains, plateau river basins, coastal deltas and densely urbanised drainage environments. Consequently, the term *flood hazard* encompasses very different processes: prolonged riverine inundation in the Ganga plains, braided-channel flooding and erosion in the Brahmaputra valley, flash flooding in Himalayan catchments, monsoon and reservoir-related floods in peninsular basins, cyclone-associated flooding along the eastern coast and short-duration pluvial flooding in metropolitan areas.

A major difficulty in analysing flood geography in India is that different statistics describe different phenomena. The Rashtriya Barh Ayog historically estimated approximately 40 million hectares (Mha) as being liable to floods, while subsequent government assessments have reported annual affected area and areas afforded varying degrees of protection. These planning figures should not be interpreted as equivalent to directly observed inundation. The Central Water Commission (CWC) has more recently used Landsat imagery for 1986–2022 and Sentinel-1 and Sentinel-2 imagery for 2015–2022 to delineate the maximum aggregated spatial extent affected by flooding. This satellite-based exercise identified 21.213 Mha as the national aggregated flood-affected footprint over the 37-year period (CWC, 2024). In this formulation, an area is included if flooding was detected during the study period; the value is therefore neither the average area flooded each year nor a probabilistic return-period estimate.

This distinction is important because flood hazard is sometimes conflated with flood risk, vulnerability or reported flood damage. Hazard refers primarily to the potential occurrence and physical characteristics of a damaging flood process. Risk additionally depends on the people, assets and systems exposed to that process and their vulnerability and capacity. A sparsely settled Himalayan valley can experience a high-velocity flash-flood hazard despite a relatively small inundated area, whereas a densely built city can experience very large economic losses from geographically limited pluvial flooding. Similarly, a large state may record a high absolute flood-affected area simply because of its territorial extent, while a smaller district may have a much larger proportion of its geographical area repeatedly exposed.

The research problem addressed here therefore concerns the geographical differentiation of flood hazard rather than merely the national magnitude of flood damage. Considerable literature exists on individual events, river basins and cities, yet national discussions often continue to rely on broad classifications such as “flood-prone states” without adequately distinguishing the physical processes generating floods or the measurement methods used to delineate affected areas. Recent national remote-sensing evidence provides an opportunity to reconsider the spatial structure of Indian flood hazard alongside advances in hydrological and climate research.

The study pursues four interrelated objectives. First, it identifies the principal spatial concentrations of satellite-observed flood-affected area and compares major states and districts. Second, it explains the hydrological, geomorphological and climatic factors responsible for regional contrasts between the Ganga plains, Brahmaputra valley, peninsular river basins, coastal regions, Himalayan terrain and urban areas. Third, it evaluates evidence that significant flood hazard increasingly extends beyond traditionally recognised flood belts through extreme rainfall, antecedent wetness, urbanisation and spatially synchronised flood events. Fourth, it considers the implications of this regional differentiation for flood-hazard mapping, forecasting and management.

Correspondingly, the paper asks: Where is observed flood inundation most spatially concentrated in India? Which geographical processes account for the differences between major flood regions? To what extent does contemporary evidence challenge the conventional concentration of Indian flood hazard within the Ganga–Brahmaputra plains? And what form of flood-management approach follows from the coexistence of these contrasting flood regimes?

The conceptual argument developed throughout the paper is that regional flood hazard emerges from the interaction of **hydroclimatic forcing**, **basin and terrain responsiveness**, **river morphology and storage conditions**, and **human alteration of runoff and channels**. Heavy rainfall is therefore an important but insufficient explanation. The same rainfall magnitude may produce different flooding according to antecedent soil moisture, reservoir storage, channel capacity, floodplain occupation, catchment shape and the timing of tributary flows. CWC itself emphasises that rainfall and flood return periods cannot be assumed to correspond directly because antecedent moisture, natural and artificial storage, river routing and hydraulic structures modify runoff and inundation (CWC, 2024).

Literature Review

The literature on Indian floods reflects a gradual transition from broad flood-control and flood-prone-area estimation toward basin-scale hydrology, remote sensing, susceptibility modelling and integrated risk analysis. Earlier national policy approaches were strongly influenced by engineering measures such as embankments, drainage improvement and reservoirs. The National Disaster Management Authority (NDMA, 2008) subsequently emphasised combinations of structural and non-structural measures, while its urban flooding guidelines recognised that metropolitan flooding differs substantially from conventional riverine flooding (NDMA, 2010). NITI Aayog's national flood-management review retained the historical Rashtriya Barh Ayog estimate of 40 Mha liable to flooding but also acknowledged increasing high-intensity rainfall events, urban drainage congestion, flash floods and the occurrence of severe inundation in areas not traditionally considered flood prone (NITI Aayog, 2021).

Remote sensing has substantially altered the empirical basis of national flood assessment. Instead of depending entirely on state-reported damage or administratively compiled flooded-area

statistics, satellite observations can delineate actual water spread over long periods. CWC's 2024 assessment is particularly important because it integrates Landsat and Sentinel observations within GIS and Google Earth Engine and reports results for all 734 districts represented in the Survey of India 2019 administrative layers. Nevertheless, remote-sensing inundation mapping remains an occurrence-based representation. It does not by itself measure depth, duration, velocity, recurrence probability or damage. Consequently, a satellite-derived cumulative inundation footprint should be interpreted as one dimension of hazard rather than a complete national flood-risk map.

Climatological research also complicates conventional assumptions about Indian flooding. Roxy et al. (2017) demonstrated a threefold increase in widespread extreme rainfall events over central India during 1950–2015 despite a decline in mean monsoon rainfall over the region. Their work illustrates why seasonal rainfall totals can conceal changes in rainfall concentration and intensity. The Ministry of Earth Sciences assessment similarly documents significant changes in precipitation extremes and emphasises the importance of increasing hydroclimatic variability under continued warming (Krishnan et al., 2020).

Yet precipitation does not translate linearly into river flooding. Garg and Mishra (2019), studying the Godavari basin, found statistically significant increases in annual maximum precipitation in several upstream catchments but no corresponding statistically significant increase in annual maximum streamflow at the examined gauges. More than 80% of the extreme precipitation events that generated floods in their analysis occurred under wet antecedent conditions. Similarly, Nanditha et al. (2022) showed that Narmada floods bear combined signatures of atmospheric circulation, soil moisture and moisture-source pathways rather than being controlled by rainfall magnitude in isolation. These studies strongly support a process-based conception of flood hazard.

Research in the Himalayan foreland highlights another set of mechanisms. Sahani et al. (2023) argue that Kosi flooding cannot be explained adequately by rainfall trends alone. The geomorphological setting, heavy sediment load and embankment system influence channel behaviour, flood duration and the consequences of breaches. Their findings are especially significant because they show how interventions intended to suppress frequent inundation can alter the spatial expression of residual flood hazard. In the Brahmaputra, Rajbanshi et al. (2022) demonstrate how major floods can reorganise channels, bars and longitudinal sediment connectivity within a highly dynamic braided river system. Thus flood hazard in north-eastern India includes not only overbank inundation but also channel migration and erosion.

Peninsular India has historically received less attention in national flood narratives than the Ganga–Brahmaputra system, but recent scholarship indicates more complex behaviour. Kumar et al. (2025) found increasing spatial synchronisation of river floods across Peninsular India, including relationships that extend beyond individual basin boundaries. Their analysis suggests that managing rivers as hydrologically isolated basins may underestimate the regional scale at

which extreme atmospheric forcing produces simultaneous floods. This is particularly relevant for emergency planning because synchronous floods can place simultaneous demands on infrastructure, reservoirs and response institutions.

The 2018 Kerala floods further demonstrated that extreme multi-day rainfall, catchment wetness, topography and water-storage conditions can combine within short, steep west-flowing basins. Hunt and Menon (2020) examined the event from a climate perspective and reinforced the importance of atmospheric processes in producing exceptional precipitation. Such research cautions against interpreting low long-term flood-affected area as equivalent to negligible hazard: high-intensity events in small catchments may produce severe consequences without generating the extensive lowland footprints characteristic of northern alluvial rivers.

Urban flood scholarship introduces yet another geographical regime. Singh et al. (2023), in a systematic review of 62 studies of urban pluvial flooding in India, identified extreme rainfall, urban development, topography and drainage as the most frequently reported causal factors. Pathak et al. (2020) similarly demonstrate for Mumbai that urban flood assessment must combine hydrological and hydraulic conditions with social, economic and environmental dimensions. These studies underline that urbanisation affects not only exposure but also the hazard-generating process itself by increasing impervious surfaces, accelerating runoff, obstructing natural drainage and concentrating flows in undersized stormwater systems.

A clear research gap therefore remains between national mapping and process-oriented regional studies. Basin and city studies explain particular mechanisms in considerable detail, while national accounts often aggregate unlike flood phenomena into a single category. Conversely, the new CWC satellite assessment provides a consistent national spatial framework but does not itself explain why the mapped pattern exists. The present study addresses this gap by interpreting the latest nationwide inundation assessment through the geographical processes established in basin-scale and urban flood literature.

Research Methodology

This study adopts a **secondary-data-based, descriptive, analytical and comparative geographical research design**. No primary survey, interview, questionnaire or field observation was conducted, and no original respondent-level dataset is claimed. The study area is the territory of India, analysed with particular reference to major physiographic regions, river basins, states and districts.

The principal quantitative dataset is the Central Water Commission's *Assessment of Area Affected Due to Floods in India: Part II—Assessment at Sub-District Level* (2024). CWC used Landsat optical and multispectral imagery for 1986–2022 and Sentinel-1 microwave and Sentinel-2 multispectral imagery for 2015–2022. Flood-affected pixels were aggregated and apportioned to administrative units based on Survey of India 2019 layers. The national maximum

aggregated flood-affected extent was 21.213 Mha. The dataset covers 734 districts and 4,721 sub-districts.

The principal indicators used are: aggregated flood-affected area in Mha; each state's share of national aggregated flood-affected area; the number of districts in which more than 15% of geographical area was affected during the study period; and the proportion of districts affected at least once. State shares reported in this paper are author calculations from CWC's published state totals. They therefore do not represent a separate dataset.

For recent hydrometeorological context, the study also uses CWC's *Flood Forecasting and Warning Network: Performance Appraisal Report 2024*, published in 2025. Peer-reviewed hydrological, geomorphological and urban-flood research is used to interpret the processes behind observed regional differences. Official policy documents from NITI Aayog and NDMA provide the historical and institutional context.

The analytical framework treats flood hazard as the product of interacting physical controls rather than a single rainfall variable. Analysis proceeds through comparison of (a) hydroclimatic forcing, (b) terrain and basin morphology, (c) antecedent storage and runoff conditions, (d) river-channel and sediment dynamics and (e) anthropogenic modification of catchments, floodplains and drainage.

Three methodological limitations require emphasis. First, the CWC aggregated footprint indicates where flooding was observed during 1986–2022 but does not provide a uniform nationwide probability, depth, duration or velocity measure. Second, satellite observations differ in spatial resolution, sensor properties and data availability through time; the Sentinel radar record, particularly useful under cloudy monsoon conditions, is available only for the later part of the study period. Third, administrative aggregation can hide major within-district variation. The threshold of 15% of geographical area is useful for comparison but should not be interpreted as a universal physical definition of a flood-prone district. Accordingly, the analysis does not rank states by a single composite “risk score” and does not infer causal relationships from spatial coincidence alone.

Analysis and Discussion

National Concentration of Flood-Affected Area

The national flood pattern is simultaneously widespread and strongly concentrated. CWC found that 711 of 734 districts—approximately 97%—contained some area affected by flooding at least once during 1986–2022. Yet only 152 districts, or 20.7%, had an aggregated flood-affected footprint exceeding 15% of their geographical area, and only 21 districts exceeded 50%. This distinction demonstrates that occasional flood occurrence is geographically widespread, whereas extensive territorial inundation remains concentrated in a much smaller group of districts.

Table 1. Major State-Level Concentrations of Aggregated Flood-Affected Area, 1986–2022

State	Flood-affected area (Mha)	Share of national total (%)	Districts with >15% of geographical area affected
Uttar Pradesh	5.174	24.4	49
Bihar	2.914	13.7	35
Assam	2.477	11.7	30
West Bengal	1.840	8.7	11
Odisha	1.024	4.8	6
Madhya Pradesh	0.982	4.6	3
Maharashtra	0.888	4.2	2
Rajasthan	0.712	3.4	0
Andhra Pradesh	0.699	3.3	0
Tamil Nadu	0.665	3.1	4
Gujarat	0.588	2.8	1
Karnataka	0.536	2.5	0
India	21.213	100.0	152

Source: CWC (2024); percentages are author calculations from published state totals.

Uttar Pradesh alone represents approximately 24.4% of the national aggregated footprint. When Bihar, Assam and West Bengal are added, these four states collectively account for approximately 58.5%. The first eight states shown in the table account for about three quarters of the national total. This provides strong evidence that the traditional northern and north-eastern flood belt remains central to India's flood geography.

Absolute extent, however, cannot serve as the sole indicator of hazard. Uttar Pradesh's large total partly reflects its extensive geographical area and long network of the Ganga and its tributaries. Assam, by contrast, combines a smaller territorial area with far greater proportional inundation in many districts. CWC reports Darrang at 83.68% of geographical area affected within the 37-year aggregated footprint, Nalbari at 73.83% and Barpeta at 73.08%. Kolkata recorded the highest district-level proportion nationally at 88.71%, followed by Darrang, while South 24 Parganas recorded 69.73%.

These percentages require cautious interpretation. An 88% aggregated footprint does not mean that 88% of a district is flooded every year or simultaneously. It means that locations collectively comprising that share of the administrative area were captured as inundated at least once within the assessment period. The value therefore measures the geographical reach of observed flooding through time, not annual flood frequency.

The Ganga Plains: Extensive and Persistent Riverine Hazard

The Indo-Gangetic plain forms India's largest continuous zone of extensive riverine flood hazard. Its susceptibility results from the combination of low relief, large upstream catchments, Himalayan and peninsular tributaries, high sediment loads, monsoon concentration and extensive floodplains. The gently sloping alluvial surface permits lateral spreading of water over large areas, while tributary convergence can generate compound downstream peaks.

Uttar Pradesh has the largest absolute aggregated flood-affected area at 5.174 Mha and 49 districts exceeding the 15% threshold. The state contains not only the main Ganga corridor but the Ghaghara, Rapti, Gandak-related systems, Yamuna and numerous tributaries. Flood-generating mechanisms therefore differ substantially between eastern Uttar Pradesh, where Himalayan-fed rivers and low-relief plains are important, and the Yamuna–Betwa–Ken system farther south and west. A state-level total consequently conceals significant basin-level variation.

Bihar displays a more concentrated flood geography. Its aggregated extent of 2.914 Mha is smaller than Uttar Pradesh's, but 35 of its 38 districts exceeded CWC's 15% criterion. North Bihar is particularly susceptible because rivers including the Kosi, Gandak, Bagmati and Kamla descend from steep Himalayan catchments before entering an extremely low-gradient alluvial plain. The resulting reduction in channel slope promotes sediment deposition and channel instability.

The Kosi exemplifies why flood hazard cannot be reduced to local rainfall. Its sediment-rich system, historical channel mobility and engineered embankments together influence contemporary inundation. Sahani et al. (2023) found that rainfall changes alone were insufficient to explain observed flood behaviour and emphasised interactions among river geomorphology, sedimentation, embankments and breaches. This does not establish that embankments universally increase flood hazard; they clearly prevent routine inundation in many protected areas. Rather, it indicates that structural protection redistributes hazard spatially and creates a residual risk that may become severe when channel beds aggrade, drainage is obstructed or defences fail.

West Bengal adds deltaic, tidal and urban components to the Ganga hazard regime. Its 1.840 Mha aggregated flood footprint and 11 districts exceeding the 15% threshold reflect riverine flooding in the Gangetic plain as well as the hydrological complexity of the lower delta. The very high aggregated proportions reported for Kolkata and South 24 Parganas illustrate why the lower Ganga region cannot be understood solely as an upstream river-discharge problem. Drainage congestion, tidal influence, intense rainfall and extensive low-lying terrain increasingly interact.

The Ganga plains therefore remain India's dominant zone of extensive floodplain inundation, but even within this apparently coherent region flood processes are heterogeneous. The management implication is that broad state-level "flood-prone" classifications should be replaced by basin and

sub-basin assessments that distinguish chronic inundation, embankment-protected areas, drainage congestion, confluence effects and residual breach hazard.

Brahmaputra Valley and North-Eastern India: Proportional Inundation and Morphological Instability

Assam represents one of India's most distinctive flood environments. Its aggregated flood-affected area of 2.477 Mha is the third highest nationally, but its proportional spatial concentration is particularly striking: 30 of the state's 33 districts in the CWC administrative dataset exceeded the 15% threshold. Three Assam districts—Darrang, Nalbari and Barpeta—are among the five districts with the highest percentage of geographical area affected nationally.

The Brahmaputra differs fundamentally from many regulated or single-channel rivers. It carries very large water and sediment loads through an exceptionally dynamic braided system. Monsoon discharge, steep tributaries descending from the Himalaya and north-eastern hills, bank erosion, bar formation and channel migration continuously reshape the floodplain. Consequently, hazard includes lateral erosion and channel relocation as well as temporary water coverage. Rajbanshi et al. (2022) showed that the 2019 flood significantly altered bar and channel positions and changed longitudinal sediment connectivity. A conventional inundation map therefore captures only part of the geomorphological hazard facing settlements along the river.

The 2024 season provides a useful illustration of why regional seasonal rainfall totals should not be treated as direct flood predictors. CWC records show that East and North-East India received only 86% of its long-period-average southwest-monsoon rainfall in 2024, yet extreme flood levels were still recorded at four forecasting stations in Assam. Nationally, six stations reached or exceeded their previous highest flood levels, with the other two in Bihar. Severe flood situations occurred at 91 forecasting stations across India.

This apparent paradox is hydrologically plausible. Seasonal rainfall totals average precipitation across large areas and several months, whereas river floods may arise from short periods of concentrated rainfall in critical tributary catchments, rainfall upstream of the affected state, antecedent catchment wetness and coincident tributary peaks. The Assam example reinforces the need to analyse event sequencing and basin hydrology rather than infer flood hazard directly from seasonal rainfall anomalies.

Flood management in the Brahmaputra valley also has to account for erosion-compatible land use, mobile channels and sediment dynamics. An approach based exclusively on preventing overtopping through higher embankments can be inadequate where the river itself migrates laterally. Hazard zoning therefore requires repeated geomorphological updating rather than static floodplain boundaries.

Peninsular India: Episodic Flooding and Emerging Spatial Synchronisation

The national CWC map also demonstrates that major flood-affected areas extend well beyond the traditional Ganga–Brahmaputra belt. Madhya Pradesh recorded 0.982 Mha, Maharashtra 0.888 Mha, Rajasthan 0.712 Mha, Andhra Pradesh 0.699 Mha, Tamil Nadu 0.665 Mha, Gujarat 0.588 Mha and Karnataka 0.536 Mha of aggregated flood-affected area. These values are generally smaller than those of Uttar Pradesh, Bihar or Assam, but they represent substantial hazard across multiple central, western and southern basins.

Central India is particularly important because trends in extreme rainfall differ from trends in mean rainfall. Roxy et al. (2017) identified a threefold increase in widespread extreme rainfall events over central India during 1950–2015. The finding means that a region need not experience increasing seasonal rainfall to face stronger short-duration hydrometeorological forcing. Changes in rainfall concentration are often more relevant to flood generation than changes in seasonal totals.

Nevertheless, extreme rainfall alone does not determine river discharge. Garg and Mishra's (2019) Godavari analysis found that increases in extreme precipitation did not translate into statistically significant increases in annual maximum streamflow at all studied gauges. Wet antecedent conditions played a major role in whether extreme rainfall generated flooding. Similar conclusions emerge from the Narmada, where atmospheric drivers, soil moisture and moisture pathways jointly condition flood occurrence (Nanditha et al., 2022).

This has practical significance for central and peninsular India because many basins contain major reservoirs. Reservoirs can attenuate flood peaks when adequate storage is available, yet operational decisions become more difficult during sequences of intense rainfall when storage is already high. The relevant hazard variable is therefore not simply rainfall or reservoir release in isolation but the evolving storage-runoff system across the catchment.

Recent evidence also challenges the assumption that peninsular floods can be managed independently basin by basin. Kumar et al. (2025) report increasing spatial synchronisation of river floods extending in some cases beyond conventional basin boundaries. Large-scale atmospheric systems can produce simultaneous high flows in multiple catchments, creating a geographically extensive emergency even where each individual river is smaller than the Ganga or Brahmaputra.

Kerala illustrates the high-intensity end of the peninsular spectrum. The state's CWC aggregated footprint of approximately 0.253 Mha appears modest compared with the northern plains, but this does not indicate negligible hazard. Short, steep catchments draining the Western Ghats can respond rapidly to intense multi-day rainfall. The 2018 disaster demonstrated the interaction of exceptional precipitation with already wet catchments, steep terrain and water-storage conditions. Hunt and Menon (2020) show the atmospheric exceptionalism of the rainfall episode, while broader hydrological evidence cautions against attributing such floods to a single cause.

Thus the peninsular flood regime is distinguished less by persistent, broad floodplain inundation than by episodic high-magnitude events, catchment wetness, reservoir interactions and increasingly important spatial synchronisation.

Coastal, Deltaic and Urban Flood Regimes

India's coastal lowlands contain another important group of flood hazards. Odisha recorded 1.024 Mha of aggregated flood-affected area, while substantial extents also occur in Andhra Pradesh, Tamil Nadu, Gujarat and coastal West Bengal. Eastern coastal plains are especially susceptible where low-gradient deltaic rivers interact with intense monsoon rainfall, tropical cyclones and restricted drainage near the coast.

Odisha's Mahanadi, Brahmani, Baitarani and Subarnarekha systems combine upstream river discharge with low-lying downstream terrain. Andhra Pradesh's Godavari and Krishna deltas similarly face riverine and cyclone-related precipitation hazards. Tamil Nadu differs climatologically because a large share of its rainfall occurs during the north-east monsoon, giving the state a seasonal flood regime distinct from much of northern and central India. Consequently, national flood preparedness centred only on the June–September southwest monsoon would provide an incomplete representation of southern coastal hazard.

Urbanisation further transforms the meaning of flood hazard. Urban floods may occur within or outside major river floodplains when short-duration rainfall exceeds infiltration and storm-drainage capacity. Singh et al. (2023) found that among 62 reviewed Indian urban flood studies, extreme rainfall was the most frequently reported causal factor, followed closely by urban development; topography and drainage deficiencies were also prominent. This pattern indicates that urban expansion is not simply adding population and assets to existing hazard. By replacing permeable surfaces, narrowing channels and modifying drainage pathways, urban growth can alter runoff generation itself.

Mumbai provides a clear example of compound urban flood geography. High-intensity monsoon rainfall occurs within a highly impervious coastal metropolis where drainage can be constrained by tides and dense development. Pathak et al. (2020) demonstrate the value of integrating hydraulic flood characteristics with social, economic and environmental indicators at the urban sub-catchment scale. Similar principles apply to Chennai, Hyderabad, Bengaluru, Delhi, Guwahati and Kolkata, although their rainfall regimes, terrain and drainage systems differ.

CWC's result that Kolkata has an 88.71% aggregated flood-affected footprint should therefore not be read simply as evidence of conventional river flooding. The urban district exists within a low-lying deltaic setting where rainfall, drainage, river levels, built surfaces and regional hydrology overlap. A national classification based only on "riverine" versus "urban" flooding may miss precisely these compound situations.

Urban flood-management policy consequently requires a finer spatial scale than state or district planning. Stormwater networks, wetlands, urban lakes, flood-storage areas, land-cover change and micro-topography influence flood pathways over distances of kilometres or less. Updating urban drainage standards using changing rainfall intensities, protecting natural retention areas and maintaining unobstructed drainage may therefore be as important as traditional river embankments.

Himalayan Flash Floods, Climate Variability and the Geography of Future Hazard

The Himalayan states demonstrate another limitation of area-based comparison. CWC's aggregated flood-affected areas are only about 0.114 Mha in Uttarakhand and 0.172 Mha in Himachal Pradesh. These totals are small in comparison with Uttar Pradesh or Bihar, but mountainous flood hazard can involve high velocities, debris, landslides, narrow valley confinement and rapid onset. A relatively narrow flood corridor may therefore create exceptional destructive potential.

Cloudbursts, extreme orographic precipitation, temporary river blockages, snowmelt and glacial-lake outburst floods add processes that are uncommon in the alluvial plains. CWC consequently developed national criteria in 2024 for risk indexing of glacial lakes in the Indian Himalayan Region. Such initiatives acknowledge that monitoring mountain flood sources requires different indicators from those used to delineate broad lowland inundation.

Climate change acts as a modifier of these regional regimes rather than producing one uniform national response. Increasing atmospheric moisture capacity can intensify heavy precipitation, but the resulting flood response varies with catchment properties, soil moisture, snow and glacier conditions, reservoir storage, river morphology and land use. The MoES assessment and the observed increase in central Indian extreme rainfall support concern over non-stationarity in historical flood relationships (Krishnan et al., 2020; Roxy et al., 2017). Yet it would be methodologically incorrect to infer that every region must experience an equivalent increase in flood frequency or discharge.

The 2024 southwest monsoon illustrates the geographical variability within a single season. India as a whole received 934.8 mm of rainfall, equivalent to 108% of the 1971–2020 long-period average. East and North-East India received 86% of LPA, whereas regional totals were higher elsewhere. At the same time, CWC recorded six extreme and 91 severe flood-level situations at forecasting stations. The coexistence of these patterns reinforces the central argument that national or regional rainfall totals cannot substitute for basin-scale flood analysis.

India's operational forecasting system has expanded accordingly. CWC operated flood forecasting at 340 stations during the 2024 season, including 200 level-forecast and 140 inflow-forecast stations. The network represents an important shift toward non-structural flood management, but its value will increasingly depend on integrating weather prediction, basin hydrology, reservoir operations, remote sensing and local warning dissemination.

The geographical evidence therefore supports differentiated rather than uniform flood policy. In the Ganga plains, priorities include floodplain zoning, tributary forecasting, drainage management and careful evaluation of embankment systems. In Assam, channel migration, erosion and sediment dynamics require attention alongside water levels. Peninsular basins require multi-reservoir and increasingly multi-basin coordination during spatially synchronised extremes. Coastal cities require drainage, wetland conservation and land-use controls at sub-catchment scale. Himalayan valleys require rapid-warning systems, glacial-lake monitoring and hazard mapping that accounts for flow velocity and debris rather than inundation area alone.

Conclusion

This study demonstrates that flood hazard in India possesses a clear regional structure but cannot be reduced to a single conventional “flood-prone belt.” The latest nationwide satellite evidence confirms the continuing dominance of the Ganga–Brahmaputra system in terms of extensive observed inundation. Of the 21,213 Mha identified within CWC’s maximum aggregated flood-affected footprint for 1986–2022, Uttar Pradesh accounts for approximately 24.4%, Bihar 13.7%, Assam 11.7% and West Bengal 8.7%. Together, these four states represent about 58.5% of the national total. At the same time, flooding was detected somewhere within 97% of the 734 districts examined, showing that the geographical occurrence of flood hazard extends far beyond this core belt.

The first research question—where observed flood inundation is most concentrated—is therefore answered by a distinction between absolute and proportional concentration. Uttar Pradesh records the largest absolute extent, whereas Assam, Bihar and parts of West Bengal contain exceptionally high proportions of affected administrative territory. The second question concerning geographical controls reveals several distinct hazard regimes. Low-gradient alluvial plains, large Himalayan catchments and sediment-rich rivers dominate northern India; braided-channel dynamics distinguish the Brahmaputra; antecedent wetness, atmospheric extremes and reservoir conditions assume greater significance in several peninsular basins; cyclone and delta processes shape the eastern coast; and imperviousness and drainage transformation strongly affect urban flooding.

The third research question concerns whether flood hazard is extending beyond the traditionally recognised northern and north-eastern core. The evidence supports a qualified affirmative conclusion. The Ganga–Brahmaputra plains remain dominant in cumulative inundation extent, but research on central Indian rainfall extremes, Godavari and Narmada hydrology, Kerala floods, urban pluvial flooding and synchronised peninsular river floods shows that severe flooding elsewhere is neither anomalous nor adequately represented by the traditional national flood geography. This does not mean that every region is becoming uniformly more flood prone. Rather, the physical processes and temporal characteristics of hazard are becoming more diverse and, in some areas, more non-stationary.

The fourth research question concerns management implications. A geographically differentiated strategy is essential. A national flood map should not be treated as a static zoning exercise based on one threshold. The CWC satellite dataset provides a major advance by establishing a consistent observed inundation footprint, but future national hazard assessment should integrate **frequency, flood depth, duration, flow velocity, geomorphological instability and return-period information** with the observed spatial extent. Urban and mountain environments require additional indicators appropriate to their distinct processes.

Policy should therefore move beyond an excessive dependence on structural flood exclusion. Embankments, reservoirs and drainage works remain necessary in many locations, but they should operate within basin-specific combinations of floodplain regulation, wetland and retention-area protection, forecasting, reservoir coordination, channel monitoring, climate-informed design standards and community warning systems. The NITI Aayog recommendation to strengthen non-structural measures and advanced forecasting is consistent with such a transition (NITI Aayog, 2021).

The principal limitation of the present study is that it synthesises published secondary data rather than constructing an original event-frequency or hydraulic model. The 1986–2022 aggregated flood footprint does not identify how often each location flooded or how deep and damaging individual events were. Comparisons of absolute state totals are also affected by state size and terrain. Future research should therefore combine CWC inundation layers with gridded precipitation, gauge discharge, digital elevation models, land-use change, reservoir-operation data and event-specific satellite observations. District- and sub-district-level frequency analyses would make it possible to distinguish repeatedly flooded zones from areas affected only by exceptional events.

The broader geographical conclusion is that India does not face one flood problem. It faces interconnected riverine, braided-river, flash-flood, deltaic, reservoir-influenced and urban-pluvial hazard systems operating across contrasting physical landscapes. Recognising this diversity is fundamental to replacing generic flood-prone classifications with scientifically defensible, region-specific and dynamically updated flood-hazard management.

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