

Flood Hazard and Human Vulnerability in India: A Geographical Analysis

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Abstract

Floods constitute one of the most persistent hydro-meteorological hazards in India, yet their human consequences vary sharply across regions and social groups. This paper examines the spatial geography of flood hazard and the differentiated production of human vulnerability in India. It adopts a descriptive, analytical and comparative design based exclusively on secondary data, drawing on the Central Water Commission (CWC), India Meteorological Department (IMD), National Remote Sensing Centre (NRSC), National Disaster Management Authority (NDMA), NITI Aayog, Ministry of Home Affairs, World Bank, IPCC and peer-reviewed research. The analysis combines the hazard-exposure-vulnerability framework with social-vulnerability and Pressure-and-Release perspectives. It finds that recurrent riverine flooding remains concentrated in the Ganga-Brahmaputra plains; Himalayan regions face rapid-onset flash and compound hazards; coastal and deltaic districts experience interacting river, rainfall and cyclone processes; and urbanisation is generating new pluvial-flood risk through impervious surfaces, drainage constraints and occupation of natural storage areas. Recent research also indicates changing rainfall extremes and projected increases in widespread riverine flooding under warming, although observed rainfall-flood relationships remain spatially uneven. Human vulnerability is shaped by poverty, livelihood dependence, settlement location, housing quality, mobility, access to services and institutional capacity rather than by hazard magnitude alone. The paper concludes that flood policy should move beyond a predominantly protective engineering paradigm towards integrated floodplain governance, risk-sensitive urbanisation, resilient infrastructure, ecosystem-based measures, locally actionable early warning and social protection targeted to vulnerable groups.

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1. Introduction

Flooding is an intrinsic component of many Indian river systems and monsoon environments. Seasonal inundation contributes to sediment renewal, groundwater recharge, wetland ecology and the productivity of alluvial floodplains. It becomes a disaster, however, when hazardous water levels intersect with exposed populations and assets under conditions that limit anticipation, resistance and recovery. This distinction is fundamental to geographical analysis because the same rainfall or river stage can generate very different outcomes in places with different settlement patterns, infrastructure, livelihoods and institutional capacities. Flood risk in India is therefore best understood not as a single natural phenomenon but as a spatially differentiated interaction among hazard, exposure and vulnerability.

The physical basis of flood exposure is extensive. The Rashtriya Barh Ayog estimated about 40 million hectares as flood-prone in 1980, and this historical planning figure continues to appear in contemporary policy documents. NITI Aayog (2021), however, makes clear that it is a legacy estimate rather than a fresh national remapping. The same strategy report records that the maximum area affected by floods in any year during 1953-2010 reached about 49.815 million hectares and that the average annually affected area was about 7.17 million hectares. These figures should not be interpreted as directly comparable measures of present-day risk because they arise from different concepts: one denotes an assessed flood-prone area, while the others refer to historically reported annual impacts.

Satellite evidence provides a more explicitly spatial perspective. NRSC's Flood Affected Area Atlas of India integrates flood inundation mapped from satellite observations for 1998-2022. Its cumulative mapping identifies areas repeatedly affected by major floods and cyclones, but NRSC also cautions that the results depend on satellite availability and timing, may not coincide with peak inundation, and can miss short-duration flash floods and minor flooding (NRSC, 2023). The atlas is therefore highly valuable for identifying historical inundation footprints, but it should be combined with river-gauge records, topography, hydrological modelling and local knowledge rather than treated as a complete representation of flood risk.

Recent climate observations reinforce the importance of geographical differentiation. IMD reported that India's annual rainfall in 2025 was 110% of the 1971-2020 long-period average (LPA), while southwest-monsoon rainfall was 108% of LPA. Regional departures were highly uneven: Northwest India received 127% of its monsoon LPA, Central India 115%, South Peninsular India 110%, and East and Northeast India only 80% (IMD, 2026). National seasonal rainfall therefore cannot serve as a sufficient indicator of flood hazard. Flood generation depends on rainfall intensity, duration, spatial extent and sequencing as well as antecedent soil moisture, river discharge, catchment condition, drainage capacity and reservoir operations.

The central research problem addressed here is the gap between hazard-centred accounts of flooding and the socially differentiated geography of disaster losses. Two settlements exposed to similar inundation depths may suffer very different impacts because households differ in housing quality, land tenure, savings, mobility, livelihood security, access to transport, warning information and public services. Conversely, places historically regarded as relatively secure from major river flooding can acquire substantial flood risk through urban expansion, wetland loss, impervious surfaces and drainage obstruction. Recent national-level econometric work also shows that flood damage is associated with socioeconomic and environmental conditions, reinforcing the need to analyse vulnerability rather than hazard alone (Felix et al., 2025).

This paper addresses four objectives: to identify the principal spatial patterns and physical drivers of flood hazard in India; to examine how social, economic and settlement characteristics transform physical exposure into differentiated human vulnerability; to compare the risk profiles of riverine plains, Himalayan catchments, urban areas and coastal-deltaic environments; and to evaluate the implications of current forecasting and flood-management approaches for vulnerability reduction. Correspondingly, it asks: where are India's principal flood-hazard environments and why do they differ; which social and economic conditions intensify vulnerability; how are climate variability, urbanisation and land-use change

modifying flood risk; and what forms of governance are most likely to reduce vulnerability rather than simply attempt to control water?

conceptually, the study treats flood risk as an interaction of hazard, exposure and vulnerability, consistent with contemporary disaster-risk and climate-risk frameworks. It also draws on Cutter et al.'s (2003) social-vulnerability approach and the Pressure-and-Release framework developed by Wisner et al. (2004). These perspectives direct attention away from the question of where water accumulates alone and towards why certain groups are located in risky places, why they possess different capacities to act on warnings, and why recovery is uneven. The paper therefore approaches flooding as simultaneously a hydrological, geographical and developmental problem.

2. Literature Review

Disaster scholarship has progressively challenged the view that disasters are direct products of extreme natural events. The Pressure-and-Release model conceptualises disaster as the intersection of hazard with socially produced vulnerability, linking immediate unsafe conditions to wider political, economic and institutional processes (Wisner et al., 2004). In a flood context, residence on an eroding riverbank or low-lying urban margin is an immediate exposure condition, but it may reflect deeper constraints such as unequal land markets, insecure tenure, dependence on river-based livelihoods or exclusion from serviced housing. The framework is valuable for India because it explains why recurrent flooding can persist as a social crisis even where communities possess extensive local knowledge of the hazard.

Cutter et al. (2003) similarly demonstrated that vulnerability is multidimensional and spatially uneven. Income, age structure, housing, employment, transport access and social resources influence the capacity to prepare for, respond to and recover from hazards. Although the specific indicators developed in the United States cannot be transferred mechanically to India, the underlying argument is directly relevant: equivalent hazard intensities can generate dissimilar human consequences. Contemporary Indian studies increasingly operationalise this insight. Sharma (2024), for example, shows that social vulnerability in the north-western Himalaya is shaped by multi-hazard exposure and underlying socioeconomic characteristics, while Hazarika et al. (2026) find marked differences in flood vulnerability among districts and households in the Brahmaputra Valley, including the role of agrarian dependence, low income, institutional inaccessibility and inequitable relief.

Indian flood-management policy has long acknowledged that structural measures cannot eliminate all risk. NDMA's flood guidelines advocate an integrated combination of flood forecasting, preparedness, reservoir management, floodplain regulation, wetlands protection, capacity development and structural works (NDMA, 2008). NITI Aayog (2021) similarly argues that complete protection from floods is neither technically nor economically feasible. The unresolved policy tension is that public debate still often privileges embankments, drainage channels and river engineering, while non-structural measures such as zoning, risk communication, ecosystem restoration and social protection receive less consistent implementation.

Hydrological literature has become more explicit about the complexity of drivers. Mishra et al. (2024) review evidence showing that the Indian summer monsoon remains the primary climatic

driver of hydrological extremes, but irrigation, reservoir storage, groundwater use and other human interventions also modify hydrological behaviour. Vegad et al. (2024), reconstructing sub-basin flood risk for 1901-2020, identify particularly high flood risk in the Bhagirathi, Gandak, Kosi, lower Brahmaputra and Ghaghara sub-basins and show that reservoirs materially influence flood dynamics in several basins. Their work is significant because it moves beyond state-level generalisation and demonstrates that risk varies strongly within major river systems.

Urban flood scholarship reveals another shift in the risk landscape. Singh et al. (2023), reviewing 62 studies on urban pluvial flooding in India, found that extreme rainfall, urban development, topography and drainage were the most frequently identified causes, with municipal waste and governance also contributing. The review highlights a recurrent problem: urban flood research is concentrated in major metropolitan centres such as Chennai, Mumbai, Hyderabad, Guwahati and Bengaluru, whereas rapidly growing smaller cities receive less systematic attention. The literature also tends to emphasise environmental drivers more than distributional consequences, leaving a gap in understanding how housing inequality, informal employment, service deficits and differential mobility shape urban flood losses.

Recent nationwide evidence supports the importance of socioeconomic determinants. Felix et al. (2025), using state-level flood-damage data for 1953-2020, report that fiscal capacity, spending on natural calamities and mangrove coverage are associated with reduced flood damage, whereas population affected and damage to housing and public utilities are associated with higher losses. The study does not resolve all questions of causality, but it is important because it demonstrates statistically that flood outcomes cannot be separated from public investment and ecological conditions. At the opposite end of the scale, micro-spatial studies such as Bhuyan (2024) in Nagaon district and Hazarika et al. (2026) in Assam reveal substantial local variation that state averages can conceal.

Three research gaps follow from this literature. First, national discussions often mix historical flood-prone-area estimates with contemporary satellite or model-based evidence, creating misleading impressions of comparability. Second, physical hazard and social vulnerability are still frequently analysed separately, despite the fact that disaster risk emerges from their interaction. Third, many detailed studies are event-specific or local, making it difficult to compare riverine, mountain, coastal and urban flood environments within one geographical framework. The present study addresses these gaps through a national synthesis that keeps measurement periods explicit, avoids constructing a pseudo-precise vulnerability index from incompatible datasets, and compares multiple flood regimes through a common hazard-exposure-vulnerability lens.

3. Research Methodology

This research is a secondary-data-based, descriptive, analytical and comparative geographical study. No household survey, interview, questionnaire, field observation or experimental dataset was conducted or assumed. The paper therefore does not claim original household-level statistical estimates. Its contribution lies in synthesising official data, satellite evidence and peer-reviewed research within a consistent spatial and conceptual framework.

India constitutes the study area, but the analysis is organised around four overlapping flood-risk environments rather than treating the country as homogeneous: the large alluvial river plains of northern and northeastern India; Himalayan and sub-Himalayan catchments; rapidly urbanising metropolitan and intermediate cities; and coastal and deltaic regions. These categories are analytical rather than mutually exclusive. For example, Kolkata is simultaneously urban, deltaic and riverine, while Guwahati combines urban drainage problems with the hydrology of the Brahmaputra system.

The principal official sources are the NRSC/ISRO Flood Affected Area Atlas (1998-2022), NITI Aayog's 2021 flood-management strategy, NDMA's flood guidelines, IMD's 2025 climate statement published in 2026, and 2025 CWC flood-monitoring and forecasting information reported by the Ministry of Home Affairs. These are supplemented by the IPCC Sixth Assessment Report, World Bank urban-resilience analysis, and peer-reviewed studies on rainfall extremes, basin-scale flood risk, social vulnerability and urban flooding.

The analytical framework separates three dimensions. Hazard denotes flood-producing processes including river overflow, intense rainfall, flash runoff, drainage congestion, coastal surge and interacting compound events. Exposure refers to people, settlements, infrastructure, crops and economic activities located where these processes can cause damage. Vulnerability refers to susceptibility and the capacity to anticipate, cope, recover and adapt. Vulnerability is further interpreted through sensitivity factors such as fragile housing or dependence on daily wages, and capacity factors such as transport, savings, shelters, health services, warnings and effective public institutions.

The study uses thematic comparison instead of constructing a composite national vulnerability index. This decision is methodological: available indicators originate from different years, spatial units and definitions, and combining them into a single score would create false precision. The analysis therefore emphasises patterns that are consistently supported across independent sources. Important limitations remain. Satellite inundation can miss short-duration events; administrative damage statistics are affected by reporting practices; and national or state-level data can conceal major differences within districts and neighbourhoods. The absence of a new fully comparable national population census after 2011 also limits fine-scale demographic comparison. Conclusions are therefore framed as evidence-based geographical interpretations rather than universal causal estimates.

Table 1. Major Flood-Hazard Environments and Human Vulnerability Mechanisms in India

Environment	Illustrative areas	Dominant processes	Key vulnerability mechanisms
Large river floodplains	Assam, Bihar, eastern Uttar Pradesh, West Bengal and major Ganga-Brahmaputra tributaries	Monsoon discharge, overbank flooding, channel migration, erosion	Dense settlement, agrarian dependence, repeated asset loss, insecure land

Environment	Illustrative areas	Dominant processes	Key vulnerability mechanisms
Himalayan and foothill catchments	Uttarakhand, Himachal Pradesh, Sikkim, Arunachal Pradesh and adjoining foothills	Intense rainfall, flash runoff, landslides, debris flows and compound events	Short warning time, valley concentration, road isolation, difficult evacuation
Urban areas	Major metropolitan and rapidly expanding cities	Short-duration intense rainfall, impervious surfaces, drainage congestion, loss of storage areas	High density, informal housing, service deficits, transport and infrastructure disruption
Coastal and deltaic areas	West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Gujarat and other coastal districts	River flooding, intense rainfall, cyclone impacts, surge and tidal interaction	Low elevation, coastal livelihoods, salinity, drainage obstruction and compound exposure

Note. Analytical synthesis based on NRSC (2023), NDMA (2008), NITI Aayog (2021), Vegad et al. (2024), Singh et al. (2023) and related literature.

4. Analysis and Discussion

4.1 Spatial Geography of Flood Hazard

India's flood geography is best understood as a mosaic of distinct but connected hazard regimes. The most persistent riverine environment occurs across the Ganga-Brahmaputra-Barak plains. Large monsoon discharges, tributary confluences, channel migration, sediment transport, erosion and extensive low-lying floodplains create recurrent inundation. The attractiveness of fertile alluvial land simultaneously encourages dense rural settlement and agriculture, so exposure is structurally embedded in the regional economy. Vegad et al. (2024) identify the Bhagirathi, Gandak, Kosi, lower Brahmaputra and Ghaghara among the sub-basins with the highest flood risk, reinforcing the importance of the northern and northeastern river systems.

Within this broad belt, mechanisms differ. In Assam, the Brahmaputra's braided morphology, bank erosion and channel instability mean that land loss and repeated displacement can be as consequential as temporary inundation. The 2026 household study by Hazarika et al. shows how exposure combines with agrarian dependence, limited income and uneven institutional access to produce differentiated vulnerability across Dhemaji, Lakhimpur, Morigaon, Nalbari and Barpeta. In Bihar and eastern Uttar Pradesh, the interaction of Himalayan tributaries, low gradients, embankments and densely settled floodplains produces a different risk profile. These examples demonstrate why state-level labels such as 'flood-prone' are too coarse for effective planning.

A second hazard regime is associated with the Himalaya and foothills. Steep relief, narrow valleys and rapid runoff shorten warning times, while intense precipitation can interact with landslides, debris flows, river blockage, glacial or moraine-dammed lakes, road construction and hydropower infrastructure. Flash floods differ fundamentally from slowly rising plains

floods because the time available for evacuation may be measured in hours rather than days. Multi-hazard vulnerability is therefore especially important in mountain regions, where damage to a single road or bridge can isolate settlements and disrupt rescue, health care and supply chains (Sharma, 2024).

A third regime is urban pluvial flooding, in which rainfall exceeds drainage and storage capacity without requiring a major river to overflow. Conversion of soil and wetlands to impervious surfaces accelerates runoff; construction can block natural drainage; and solid waste can reduce hydraulic capacity. Singh et al. (2023) found that extreme rainfall and urban development dominate the Indian literature on pluvial-flood causes, followed by topography and drainage deficiencies. Urban flooding is therefore partly a product of the built environment itself.

The fourth major environment comprises coastal and deltaic districts. Odisha, West Bengal, Andhra Pradesh, Tamil Nadu and parts of Gujarat can experience combinations of intense rainfall, river flooding, high tides, cyclone-related surge and poor drainage. Compound events are particularly important because elevated coastal water levels can impede river and storm-water outflow. The same coastal wetlands and mangroves that provide ecological services can also moderate flood and surge impacts; nationwide analysis by Felix et al. (2025) associates greater mangrove coverage with lower flood damage, although such relationships remain context-dependent and should not be interpreted as a universal protective coefficient.

4.2 Rainfall Extremes, Catchment Conditions and Climate Change

Flood-generating rainfall cannot be represented adequately by seasonal totals. Flood response depends on rainfall intensity, duration, spatial coherence and antecedent catchment conditions. A season close to average can contain a small number of exceptionally intense episodes that cause severe flooding, while a season with above-average rainfall can produce limited flooding where rainfall is temporally dispersed or storage is high. This distinction helps explain why national rainfall anomalies and local flood disasters may appear contradictory.

Evidence from observed rainfall records shows important changes. Roxy et al. (2017) documented a threefold increase in widespread extreme-rain events over central India during 1950-2015. Dash et al. (2009) identified changes in rain-event characteristics, while Mishra et al. (2024) review evidence of increasing hydrological extremes alongside substantial regional heterogeneity. These findings support a move away from planning assumptions based solely on historical averages. Drainage design, culverts, embankment freeboard, bridge openings and reservoir rules require periodic reassessment because the statistical properties of rainfall and runoff are not necessarily stationary.

At the same time, simple narratives that equate more extreme rainfall with more flooding are misleading. Nanditha and Mishra (2024) show that observed increases in extreme precipitation have often occurred in spatially fragmented patches and therefore do not consistently translate into basin-wide river floods. Flood generation depends on the areal extent of extreme precipitation relative to the catchment, antecedent moisture and hydrological connectivity. Their climate-model and hydrological simulations nevertheless project robust increases in widespread floods across seven major Indian river basins under warming, suggesting that future risk may intensify as extreme precipitation becomes both more frequent and spatially extensive.

IMD's 2025 rainfall illustrates the importance of regional contrasts. The country as a whole received 110% of annual LPA and 108% of southwest-monsoon LPA, but the East and Northeast region received only 80% of its monsoon LPA while Northwest India received 127% (IMD, 2026). A national surplus thus coexisted with regional deficiency. Flood planning should therefore use basin- and sub-basin-scale information, short-duration rainfall intensity and soil-moisture conditions rather than relying on national seasonal categories.

Climate change acts as a risk multiplier rather than a complete explanation for observed flood losses. The IPCC (2022) assesses South Asia as a region of high human vulnerability and projects intensification of heavy precipitation in a warming climate. Yet exposure is also being altered by urban growth, infrastructure construction and floodplain occupation, while dams and reservoirs can either attenuate or redistribute flood peaks depending on storage and operations. Flood risk must therefore be interpreted as a coupled climate-development process rather than attributed to climate change alone.

4.3 Human Vulnerability and Unequal Consequences

the social geography of vulnerability explains why similar floods produce unequal losses. A household with reinforced housing, diversified income, savings, a vehicle, insurance, digital warning access and alternative accommodation can often absorb a flood shock more effectively than a household dependent on daily wages, living in fragile housing and unable to leave livestock, tools or informal employment behind. The physical hazard may be shared, but sensitivity and coping capacity are not.

Income matters both before and after a flood. Lower-income households may occupy lower-cost land in flood-prone locations and have less ability to flood-proof dwellings, store essential goods above expected water levels or finance evacuation. After inundation, the same households may lack savings or formal credit and can enter cycles of debt. Flood losses also include interruption of work, school and health care, not only damage to buildings. Informal workers and small businesses are especially vulnerable because income can stop immediately when roads, markets or electricity fail.

Mobility and social characteristics further shape vulnerability. Older people, children, persons with disabilities and households without access to private transport may face greater evacuation barriers. Gender relations can influence control over financial resources, caring responsibilities, privacy and sanitation in shelters, and access to official relief. These factors are rarely visible in satellite flood maps. The geographical implication is that exposure mapping must be combined with social data and local consultation if it is to identify who is most at risk rather than merely where water is likely to go.

Repeated flooding can produce cumulative vulnerability. Communities with long experience of seasonal floods often possess valuable knowledge of evacuation routes, safe elevations and asset protection. Yet repeated damage can also exhaust savings, reduce productive assets, interrupt education and encourage distress migration. Resilience should therefore not be inferred simply from continued residence in a floodplain. Hazarika et al. (2026) show that communities with recurrent flood experience can still face severe vulnerability when livelihood options and institutional support remain weak.

4.4 Rural Floodplains, Agriculture and Livelihood Risk

Rural floodplains present a particular policy dilemma because the same environments that create hazard often support productive agriculture. Farmers may cultivate flood-prone alluvial land precisely because soils are fertile, moisture is available and river access supports irrigation, fisheries or livestock. Relocation may lower physical exposure but simultaneously damage livelihoods and social networks. Effective risk reduction must therefore distinguish between flood-compatible land use and highly vulnerable settlement or infrastructure rather than assume that all floodplain occupation can be eliminated.

Agricultural losses vary with timing, depth, duration and crop stage. Inundation before sowing, during crop establishment, shortly before harvest or after harvested produce has been stored on farms creates different consequences. Riverbank erosion imposes a more permanent form of loss because land itself disappears. In the Brahmaputra and parts of the Ganga system, repeated erosion can lead to serial displacement in which households move short distances multiple times while remaining economically tied to the river corridor.

Rural vulnerability can be reduced even where floods cannot be prevented. Raised grain and fodder storage, flood-resilient drinking-water points, livestock evacuation arrangements, crop diversification, flood-tolerant varieties, accessible insurance, resilient rural roads and shelters can reduce sensitivity. Forecast information also needs to be translated into decisions relevant to farmers: when to move livestock, whether to harvest early, which route remains passable and how long elevated water levels may persist. These measures illustrate the shift from flood control to living with residual risk.

4.5 Urban Flooding and the Production of New Risk

Urbanisation is creating flood exposure faster than conventional hazard maps can be updated. Pluvial flooding can emerge in locations without a history of major river flooding when intense rainfall coincides with impervious surfaces, low-lying construction, undersized drains, blocked culverts and the loss of lakes or wetlands. The hazard is therefore co-produced by rainfall and urban form. This is why cities such as Mumbai, Chennai, Hyderabad, Bengaluru, Guwahati and Delhi appear repeatedly in flood research despite having very different physical settings.

Urban vulnerability is highly unequal. Informal settlements may combine dense occupancy, weak structures, insecure tenure and inadequate drainage or sanitation, while residents have limited ability to move elsewhere. Yet higher-income districts are not immune: basement parking, underground transport, electricity substations, hospitals, data systems and commercial districts can generate high economic losses when drainage fails. Poverty and economic exposure are therefore distinct dimensions of risk, even though poorer groups generally possess fewer resources for recovery.

The World Bank (2025) argues that India's continued urban expansion creates a critical opportunity to avoid locking future populations and infrastructure into climate risk. This is particularly important because large amounts of urban infrastructure required for coming decades have yet to be built. Risk-sensitive zoning, protection of natural drainage, minimum floor elevations in suitable locations, resilient transport and power systems, and maintenance

of storm-water networks can therefore prevent future exposure more effectively than retrofitting after development has occurred.

4.6 Forecasting, Governance and the Transition to Risk Reduction

India has substantially expanded technical flood monitoring and forecasting. Ministry of Home Affairs information reported that in 2025 the Central Water Commission provided flood forecasts at 350 stations, comprising 200 level-forecasting and 150 inflow-forecasting stations. CWC also maintained 1,543 flood-monitoring stations and telemetry at 1,121 locations. During the 2025 flood season up to 30 November, 11,687 forecasts were issued and 11,203 were within the prescribed accuracy limits, an overall accuracy of 95.86% (Ministry of Home Affairs, 2025). These figures demonstrate considerable national technical capacity.

Forecast accuracy, however, is only one part of an effective early-warning system. A warning creates little benefit if exposed people do not receive it, cannot understand what it means locally, do not trust it or lack the means to act. Effective last-mile warning requires translation from river level or rainfall probability into anticipated impacts: which roads will close, which settlements should evacuate, where shelters are open, what livestock arrangements exist and which groups need assisted evacuation. Impact-based forecasting is therefore a social and geographical communication problem as well as a technical one.

Land-use governance remains a critical weakness because warning cannot compensate indefinitely for the continued production of exposure. NDMA (2008) and NITI Aayog (2021) both support floodplain regulation and non-structural measures, yet implementation varies between states and cities. The persistence of construction in natural drainage corridors and repeatedly inundated zones indicates a gap between policy principle and spatial planning practice. Enforcement is politically and socially difficult, especially where low-income households have few alternatives, which is why zoning must be paired with affordable housing, tenure-sensitive relocation where unavoidable, and livelihood support.

Structural measures remain necessary but should be understood as risk-reduction infrastructure rather than guarantees of safety. Embankments, reservoirs, drainage channels and river-training works can lower the probability or depth of flooding under certain conditions, but every structure has design limits and maintenance requirements. Protective infrastructure can also create a false sense of security that encourages additional development behind defences. Residual-risk planning, evacuation arrangements and transparent communication of design limits are therefore essential.

A more mature flood-governance framework requires multiple scales of action. Basin institutions are appropriate for upstream-downstream hydrology, reservoir coordination and sediment issues; states and districts manage emergency response and many land-regulation functions; municipalities control much of urban drainage and development; and communities possess crucial information on local inundation routes, vulnerable households and feasible evacuation. Dynamic risk mapping should connect these scales. Historical figures such as the 40-million-hectare flood-prone estimate remain useful as policy history, but contemporary planning increasingly needs satellite archives, high-resolution terrain, current settlement data and regularly updated infrastructure layers.

Table 2. Selected Verified Flood-Related Indicators Used in the Analysis

Indicator	Value	Reference period/source	Interpretive caution
Historical flood-prone planning estimate	About 40 million ha	Rashtriya Barh Ayog estimate (1980), cited in NITI Aayog (2021)	Historical baseline; not a current remapping
Maximum area reported affected in a year	49.815 million ha	1953-2010 series reported by NITI Aayog (2021)	Not directly comparable with flood-prone-area estimate
Average annual area reported affected	About 7.17 million ha	1953-2010 series reported by NITI Aayog (2021)	Long-period historical impact statistic
NRSC flood atlas coverage	1998-2022	NRSC (2023)	Satellite-derived cumulative historical inundation; event capture depends on image availability
India annual rainfall	110% of 1971-2020 LPA	IMD climate statement for 2025 (published 2026)	National annual aggregate
Southwest monsoon rainfall	108% of LPA nationally; NW 127%, Central 115%, South Peninsula 110%, East & Northeast 80%	IMD (2026), 2025 monsoon	Shows strong regional contrast
CWC flood-forecast stations	350 (200 level, 150 inflow)	2025	Ministry of Home Affairs (2025)
CWC monitoring / telemetry	1,543 monitoring stations; 1,121 telemetry locations	2025	Ministry of Home Affairs (2025)
CWC forecast performance	11,687 forecasts; 11,203 within accuracy limits (95.86%)	2025 flood season to 30 Nov	Ministry of Home Affairs (2025)

Note. Values are presented with their original reference periods to avoid treating historical planning statistics as current estimates.

5. Conclusion

The geographical evidence examined in this study indicates that flood risk in India is produced by the interaction of hydrological processes, settlement patterns and unequal social capacity. Recurrent riverine flooding remains prominent across the Ganga-Brahmaputra plains; Himalayan catchments are characterised by rapid-onset and compound hazards; coastal districts face interacting river, rainfall and cyclone-related processes; and rapid urbanisation has intensified pluvial flooding where drainage and natural storage have been reduced. These contrasts show why a single national measure of flood proneness cannot represent India's diverse risk environments.

Human vulnerability is equally differentiated. Income, housing quality, land tenure, livelihood dependence, mobility, access to services, savings and institutional support strongly influence the consequences of inundation. Recent scholarship also confirms that flood losses cannot be interpreted from precipitation alone: antecedent catchment conditions, river regulation, urban land-use change and the spatial organisation of exposure alter the relationship between extreme rainfall and damaging floods. Climate change is therefore best treated as a risk multiplier operating through already unequal landscapes of exposure and vulnerability.

The policy implication is a shift from an exclusive emphasis on flood control towards integrated risk reduction. India's expanding forecasting and telemetry systems provide an important technical foundation, but their value depends on impact-based warnings, effective last-mile communication and the ability of exposed populations to act. Floodplain regulation, risk-sensitive urban development, resilient infrastructure, protection of natural drainage and storage areas, livelihood-sensitive adaptation and targeted social protection should operate together rather than as isolated interventions.

This study is limited by its reliance on secondary datasets produced at different spatial and temporal scales and by the absence of a uniform national household-level vulnerability dataset. Future research should integrate high-resolution flood depth and duration models with contemporary demographic, housing, livelihood and infrastructure data, while longitudinal studies could clarify how repeated flooding affects debt, migration, health, education and asset recovery. The central conclusion is that effective flood management in India requires mapping not only where water spreads, but also where exposure and limited adaptive capacity convert flooding into recurrent human loss.

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