

Flood Hazard and Vulnerability Assessment of Chitrakoot District, Uttar Pradesh: An Integrated Geographical, GIS and Remote Sensing Approach

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Abstract

Flood is one of the most important hydro-meteorological hazards affecting human settlements, agriculture, infrastructure and regional economies. Chitrakoot district of Uttar Pradesh presents a distinctive case of hydro-climatic vulnerability because it belongs to the drought-prone Bundelkhand region but simultaneously experiences recurrent riverine and flash-flood conditions during intense monsoon rainfall. The present study assesses the spatial characteristics and determinants of flood hazard and vulnerability in Chitrakoot district using an integrated geographical, GIS and remote sensing approach. The analysis incorporates the Digital Elevation Model (DEM), drainage network, physiography, river proximity, historical flood information, satellite-based flood observations and socio-economic exposure. The district's DEM indicates a marked elevation gradient, approximately from 66 m to 451 m, with relatively higher terrain in the southern part and lower terrain towards the northern Yamuna valley. This topographic configuration facilitates rapid surface runoff from elevated southern terrain towards comparatively low-lying riverine areas. The drainage system is dominated by the Yamuna and Mandakini/Paisuni systems along with Baghain, Gunta, Bardaha and smaller tributaries. The Uttar Pradesh Flood Hazard Atlas identifies 5,114 ha of flood-hazard area in Chitrakoot for 1998–2020, of which 4,129 ha (81%) falls in the very-low hazard category and 985 ha (19%) in the low-hazard category. However, the historical classification does not fully represent the potential consequences of extreme rainfall events. The August 2026 flood provides compelling evidence: the Mandakini at Chitrakoot reached a reported new high flood level of 145.60 m on 29 August 2026, approximately 2.95 m above the previous reported high level, while the water level rose by about 7.5 m within six hours. The study concludes that flood risk in Chitrakoot is spatially concentrated around river corridors, low-elevation areas, floodplains, agricultural land, settlements and tourism infrastructure. A shift from conventional relief-oriented flood management towards integrated floodplain regulation, watershed management, GIS-based risk zonation, real-time monitoring and community-based preparedness is therefore essential.

Keywords: Flood Hazard, Flood Vulnerability, Chitrakoot, Mandakini River, GIS, Remote Sensing, DEM, Flood Risk, Bundelkhand, Uttar Pradesh.

1. Introduction

Floods are among the most frequent natural hazards in the world and represent a major challenge for sust-

ainable regional development. Their impacts extend beyond temporary inundation and include agricultural losses, damage to settlements and infrastructure, disruption of transportation, soil erosion, contamination of water resources, displacement of population and interruption of economic activities. Flood risk is therefore a function not only of hydrological processes but also of topography, land use, settlement patterns, infrastructure and socio-economic vulnerability.

In India, the spatial distribution of flood risk is highly uneven. Although the major flood-prone regions are traditionally associated with the Ganga-Brahmaputra plains, localized flash floods also occur in semi-arid and drought-prone regions when high-intensity rainfall generates rapid runoff. Chitrakoot district provides an important example of this apparent hydro-climatic contradiction.

Chitrakoot is located in the Bundelkhand region of Uttar Pradesh and is characterized by undulating terrain, rocky surfaces, agricultural plains and a variable drainage system. The district is generally associated with drought, water scarcity and rainfall variability. Nevertheless, intense monsoonal rainfall can generate rapid runoff and flooding along the Mandakini/Paisuni and other drainage channels.

The Central Water Commission has specifically documented the flash-flood behaviour of the Mandakini. According to CWC, the Mandakini is a relatively small tributary of the Yamuna originating in Madhya Pradesh and joining the Yamuna near Karwi in Uttar Pradesh; despite its relatively small discharge under normal conditions, severe flash floods occur during peak rainy periods, causing erosion of ghats and adjoining land and damage to houses, agricultural land and properties.

This problem has acquired renewed significance following the extreme flood of August 2026. At the Chitrakoot monitoring station, the Mandakini reportedly reached 145.60 m at 13:00 on 29 August 2026, exceeding the earlier reported high flood level of 142.65 m. The river level increased by approximately 7.5 m within six hours before subsequently falling rapidly.

The event is particularly significant from a geographical perspective because it demonstrates that **flood frequency and flood intensity are not necessarily synonymous**. A district classified as having predominantly very-low or low historical flood hazard may nevertheless experience severe flooding under extreme hydrometeorological conditions.

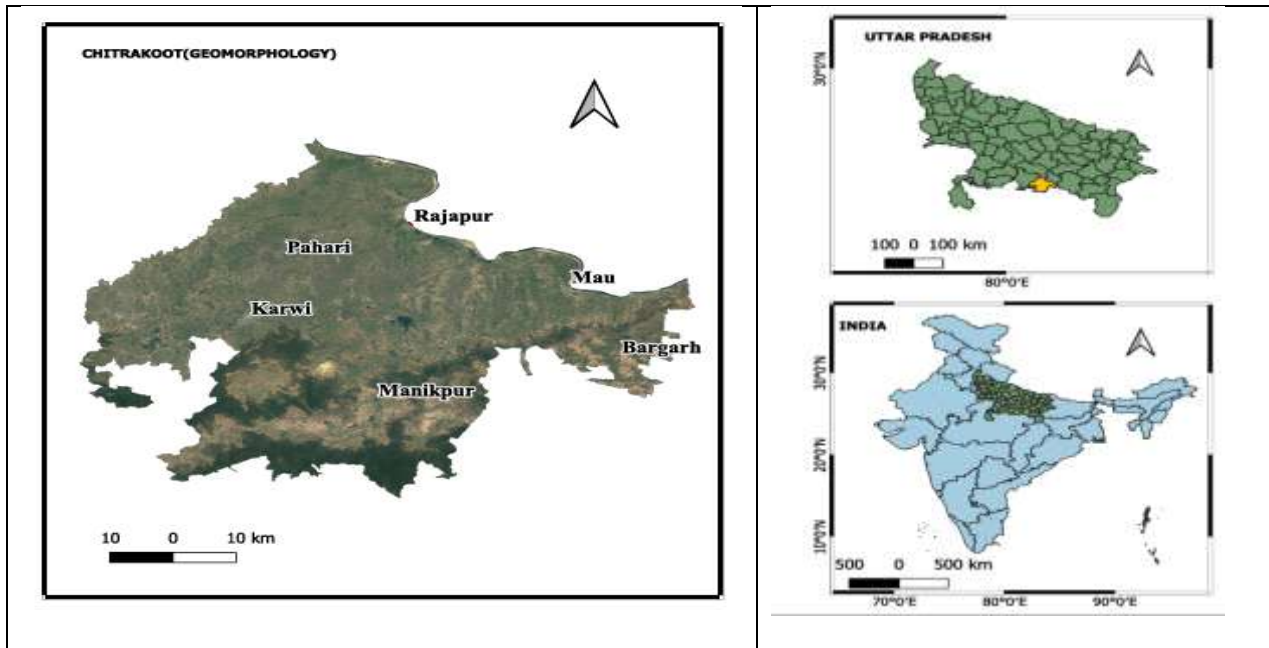
The present study therefore examines the physical and spatial determinants of flood hazard in Chitrakoot and develops a conceptual framework for integrating topography, drainage, historical inundation, land use and human exposure in flood-risk assessment.

2. Study Area

Chitrakoot district is situated in southern Uttar Pradesh within the Bundelkhand region. The district forms part of the northern Vindhyan landscape and is characterized by considerable variations in elevation, slope, drainage and landforms.

The district's river system is an important component of its geographical setting. The Yamuna forms the major northern drainage system, while the Mandakini/Paisuni is particularly important for the local flood problem. The uploaded drainage map also identifies Baghain, Gunta, Bardaha and other drainage channels distributed across the district.

The river system has considerable socio-economic importance because several settlements, agricultural areas and tourism centres have developed along or close to river corridors.



Map1.1: Location Map of Chitrakoot District.

2.1 Topographical setting

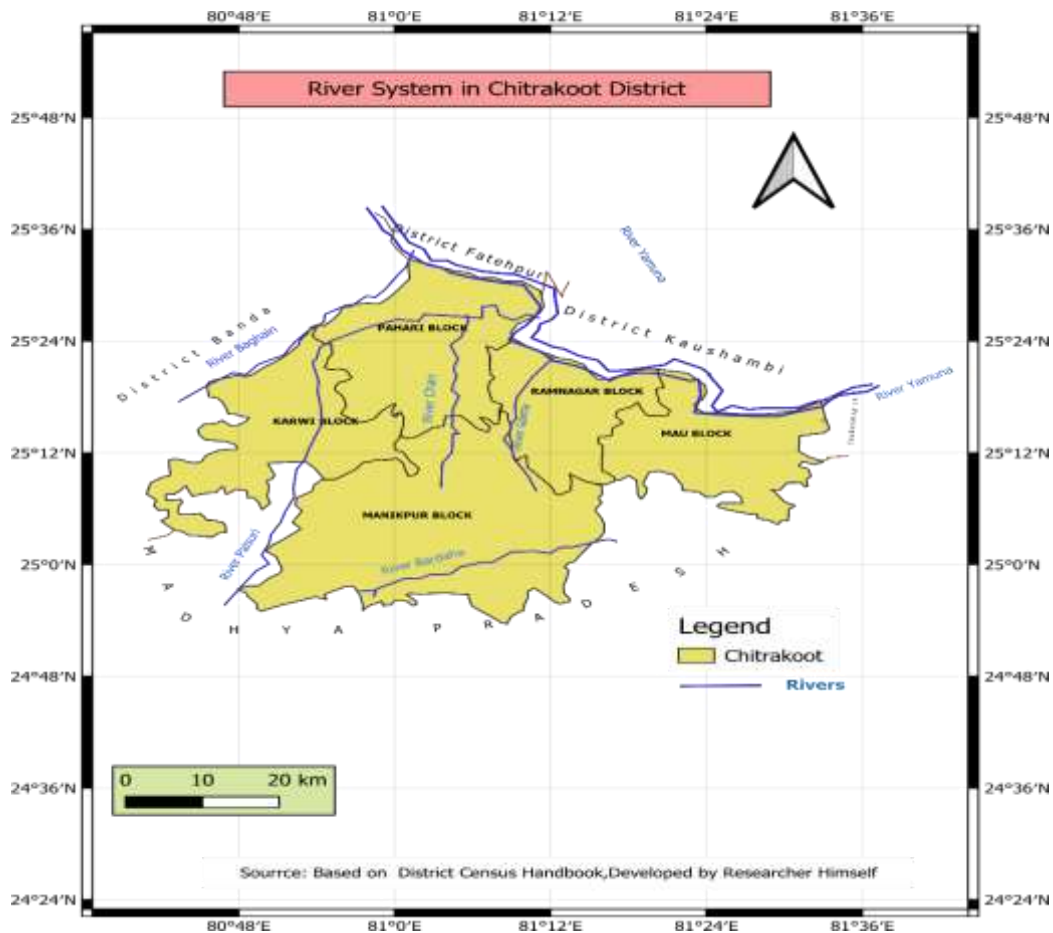
The uploaded DEM reveals a distinct elevation gradient across the district. The mapped elevation classes range approximately from **66 m to 451 m**. The lower elevations are predominantly visible towards the northern part of the district, while the southern portion contains relatively higher terrain.

This pattern has direct implications for flood behaviour. During high-intensity rainfall, elevated areas generate surface runoff which moves towards lower terrain and drainage channels. Consequently, low-lying areas adjacent to rivers may experience rapid accumulation of water.

2.2 Drainage characteristics

The drainage map demonstrates that the district is connected to a network of perennial and seasonal streams. The Yamuna forms a major northern boundary drainage feature, while the Mandakini/Paisuni crosses the central-western part of the district. Baghain, Gunta and Bardaha contribute to the local drainage system.

The interaction between topography and drainage therefore becomes fundamental for understanding flood susceptibility



Map 1.2: River System of Chitrakoot District.

3. Database and Methodology

The research follows an integrated **GIS and Remote Sensing-based flood-risk assessment framework**.

3.1 Data sources

Dataset	Purpose
Digital Elevation Model	Elevation and topographic analysis
River/drainage network	River proximity and drainage analysis
Flood Hazard Atlas	Historical flood hazard
Sentinel-1 SAR	Flood-inundation observation
Rainfall data	Extreme rainfall analysis
LULC data	Land-use exposure
Census data	Population vulnerability
Road/settlement data	Infrastructure exposure
CWC hydrological data	River-level and flood-event analysis

The Uttar Pradesh Flood Hazard Atlas prepared by NRSC provides district-level historical flood-hazard information for the 1998–2020 period.

NRSC also uses Sentinel-1A SAR data for rapid flood mapping because radar imagery is suitable for flood monitoring during cloudy monsoon conditions. NRSC flood products have included Chitrakoot among the districts covered during flood events.

3.2 GIS analytical framework

The proposed spatial analysis follows:

DEM → Elevation → Slope → Drainage → River Distance → LULC → Historical Flood → Rainfall → Population → Infrastructure → Flood Hazard → Vulnerability → Risk Zonation

The conceptual risk equation used in the study is:

Flood Risk = Hazard × Exposure × Vulnerability

where:

- **Hazard** represents the probability and intensity of inundation;
- **Exposure** represents population, agricultural land, settlements, roads and tourism facilities located in potentially flooded areas;
- **Vulnerability** represents the susceptibility of exposed populations and assets to flood impacts.

4. Results and Discussion

4.1 Spatial variation of elevation and flood susceptibility

The DEM provides a fundamental explanation of the spatial pattern of flood susceptibility. The elevation range from approximately 66 to 451 m demonstrates considerable topographic variation within a relatively compact district.

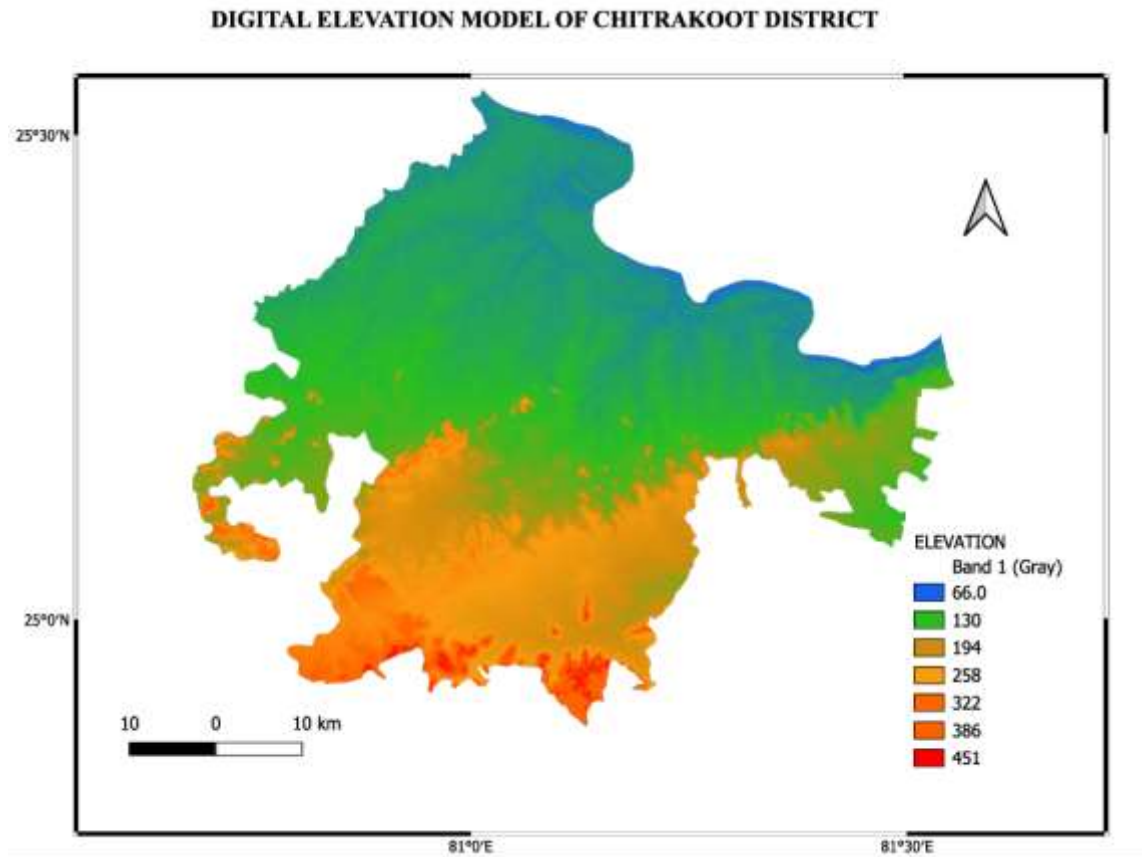
The southern part is characterized by comparatively higher terrain, whereas lower elevations occur towards the north. The Yamuna occupies the lower northern drainage environment. Between these areas, intermediate elevations and undulating terrain create numerous pathways for surface runoff.

The geographical implication is that flood susceptibility cannot be assessed solely by rainfall. The same quantity of rainfall may generate different flood responses depending on elevation, slope, drainage density and soil characteristics.

The topographic gradient can be conceptualized as:

Higher southern terrain → rapid runoff → drainage concentration → lower riverine terrain → inundation

This relationship is particularly relevant during short-duration, high-intensity rainfall.



Map 1.3: Digital Elevation Model of Chitrakoot District.

4.2 River system and flood susceptibility

The river-system map demonstrates the close relationship between human settlements and drainage channels. The Mandakini/Paisuni and Yamuna are especially significant because of their capacity to affect densely used riverine spaces.

The CWC has described the Mandakini as a relatively small river that can produce severe flash floods during the peak rainy season.

Thus, the size of a river alone cannot be used to determine flood risk. **Hydrological response time and rainfall intensity** are equally important.

4.3 Historical flood hazard

The official Flood Hazard Atlas provides an important baseline for Chitrakoot.

Flood Hazard Category	Area (ha)	Percentage
Very Low	4,129	81%
Low	985	19%
Total	5,114	100%

The data indicate that historically mapped flood hazard in the district has predominantly been classified as very low. No moderate, high or very-high category is reported in the atlas for Chitrakoot.

However, this result should be interpreted carefully. The atlas represents historical flood occurrence during 1998–2020 and therefore provides a **historical-frequency perspective**, rather than a complete representation of future extreme-event risk.

This distinction becomes particularly important after the 2026 flood.

5. The August 2026 Mandakini Flood: An Extreme Event Perspective

The August 2026 event represents a major turning point in understanding flood risk in Chitrakoot.

The Mandakini at Chitrakoot reportedly reached **145.60 m at 13:00 on 29 August 2026**, compared with the earlier reported high flood level of **142.65 m**. The difference was approximately **2.95 m**.

More importantly, the water level increased from approximately **138.10 m at 07:00 to 145.60 m at 13:00**, representing an increase of about **7.5 m within six hours**.

This exceptionally rapid rise demonstrates the flash-flood characteristics of the Mandakini system.

Table 2. Selected flood-level indicators at Chitrakoot

Indicator	Value
Previous reported HFL	142.65 m
New HFL, 29 Aug 2026	145.60 m
Increase over previous HFL	2.95 m
Level around 07:00	138.10 m
Level around 13:00	145.60 m
Rise in ~6 hours	7.50 m

The event therefore provides an important methodological lesson: **historical flood-frequency maps should be supplemented with extreme-event modelling**.

6. Remote Sensing Perspective

Remote sensing provides an important means of monitoring flood inundation over large areas.

NRSC has produced satellite-based flood-inundation maps for Uttar Pradesh using Sentinel-1A SAR imagery. Sentinel-1 is particularly useful for flood mapping because radar observations can acquire information even when optical imagery is affected by monsoon cloud cover. NRSC's 2025 rapid mapping products explicitly caution that mapped inundation may include both floodwater and accumulated rainwater and should be treated as preliminary where ground verification is unavailable.

NRSC's historical flood-monitoring records also show Chitrakoot among districts covered by Sentinel-1A SAR observations during the 2022 flood season.

Therefore, a robust Chitrakoot flood study should combine:

Historical Flood Atlas + Sentinel-1 Flood Mapping + DEM + Rainfall + River Level + LULC

rather than relying on a single dataset.

7. Flood Vulnerability of Agriculture and Settlements

Agricultural land represents an important component of flood exposure in Chitrakoot. Flooding can cause:

- crop damage;
- soil erosion;
- sediment deposition;
- loss of agricultural inputs;
- disruption of harvesting and sowing;
- damage to irrigation infrastructure.

The risk is especially high in low-lying agricultural areas adjacent to drainage channels.

Settlement vulnerability is determined by proximity to rivers, elevation, housing conditions, accessibility and availability of evacuation routes.

The problem becomes particularly significant in riverfront settlements where economic activities depend directly on the river.

8. Tourism and Cultural Vulnerability

Chitrakoot is not merely an agricultural landscape. It is a major religious and cultural destination, and the Mandakini is central to its religious geography.

Riverfront locations such as Ramghat contain temples, shops, accommodation facilities and other tourism-related infrastructure. Consequently, flooding of the Mandakini produces impacts beyond conventional residential and agricultural losses.

The 2026 flood demonstrated this vulnerability when rising water affected riverfront areas and resulted in evacuation and rescue operations.

Thus, flood-risk assessment in Chitrakoot should include a **tourism vulnerability layer**.

9. Integrated Flood Risk Zonation Framework

For a final GIS model, the following parameters are recommended:

Parameter	Weight*	Relationship
Historical flood inundation	20	Higher inundation = higher risk
Elevation	15	Lower elevation = higher risk
Distance from river	15	Near river = higher risk
Rainfall intensity	15	Higher rainfall = higher risk
Slope	10	Gentle slope = higher inundation
Drainage density	10	Higher density = higher runoff concentration
LULC	5	Built-up/agriculture = higher exposure
Population density	5	Higher population = higher exposure
Infrastructure	5	Greater infrastructure = greater potential loss

*These are **proposed analytical weights**, not observed values; they should be calibrated using actual GIS data before publication.

The resulting flood-risk classes can be divided into:

1. Very Low Risk
2. Low Risk
3. Moderate Risk
4. High Risk
5. Very High Risk

This five-class approach would provide a stronger scientific basis for identifying priority intervention areas.

10. Major Flood-Risk Zones

On the basis of the DEM and drainage configuration, the following geographical relationships emerge:

Very High/High Potential Risk

- low-lying river corridors;
- Mandakini/Paisuni floodplain;
- Yamuna-associated lowlands;
- settlements immediately adjacent to river channels;
- riverfront tourism areas;
- locations where drainage channels converge.

Moderate Risk

- intermediate elevation zones;
- agricultural areas connected to major drainage channels;
- areas receiving concentrated surface runoff.

Lower Risk

- relatively elevated southern terrain;
- areas distant from major drainage channels;
- high-elevation zones with efficient natural drainage.

These are **terrain-based interpretations from the supplied maps**, not a substitute for a statistically validated flood-risk raster.

11. Management Implications

The study suggests that Chitrakoot requires a transition from conventional flood relief to **risk-sensitive flood governance**.

11.1 Floodplain zoning

Construction should be regulated within identified flood-prone corridors. Riverfront development should be based on scientifically derived flood-return zones.

11.2 Real-time monitoring

The rapid rise of the Mandakini demonstrates the need for continuous water-level monitoring and automated warning systems.

11.3 Upstream-downstream coordination

Because the Mandakini originates in Madhya Pradesh and subsequently flows into Uttar Pradesh, flood forecasting requires coordinated information sharing between the two states. CWC identifies the river's origin in Satna district of Madhya Pradesh and its confluence with the Yamuna near Karwi.

11.4 Drainage conservation

Small streams and natural drainage channels should be protected against encroachment and blockage.

11.5 Watershed treatment

Afforestation, soil conservation, contour measures and watershed development can reduce rapid runoff from elevated terrain.

11.6 Flood-resilient infrastructure

Roads, bridges, schools, health centres and tourism facilities should incorporate flood-risk criteria in their design.

11.7 Community-based disaster management

Village-level disaster committees, evacuation routes, emergency shelters and public warning systems sho-

uld be developed in vulnerable settlements.

12. Conclusion

The present study demonstrates that Chitrakoot represents a distinctive **dual-risk hydro-climatic landscape**. Despite belonging to the drought-prone Bundelkhand region, the district possesses significant localized flood and flash-flood potential during extreme monsoonal rainfall.

The supplied DEM demonstrates a substantial elevation gradient from approximately **66 to 451 m**, with relatively elevated southern terrain and lower northern riverine terrain. The river-system map further demonstrates the spatial relationship between the Yamuna, Mandakini/Paisuni, Baghain, Gunta, Bardaha and smaller drainage channels and the district's administrative landscape.

Historical data present a relatively low flood-hazard profile: 5,114 ha has been identified as flood-hazard area, with 81% categorized as very low and 19% as low. Yet the August 2026 Mandakini flood demonstrates that extreme events can produce impacts far exceeding what a historical-frequency classification might suggest. The reported 145.60 m water level and approximately 7.5 m rise within six hours highlight the rapid hydrological response of the river system.

Therefore, the principal finding of this research is that **flood risk in Chitrakoot should be assessed through an integrated hazard–exposure–vulnerability framework rather than historical flood frequency alone**.

Future research should develop a high-resolution GIS-based flood-risk model using Sentinel-1 SAR inundation data, DEM-derived elevation and slope, rainfall intensity, river proximity, drainage density, LULC, population and infrastructure exposure. Such an approach can identify village-level risk zones and provide a scientific basis for disaster-resilient planning.

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