The Academic
International Journal of Multidisciplinary Research

An Online Peer Reviewed / Refereed Journal
Volume 3 | Issue 8 | August 2025
ISSN: 2583-973X (Online)
Website: www.theacademic.in

Hydrological and Terrain Parameters Influencing Flood Vulnerability in Prayagraj: A GIS-Based Study

Ms. Nisha Kumari
Research Scholar, Department of Geography, PRSU, Prayagraj, Gmail: prsunishii@gmail.com
Dr. Shweta Srivastava
Assistant Professor, Department of Geography, PRSU, Prayagraj, Gmail: shwetageo2.0@gmail.com

DOI : https://doi.org/10.5281/zenodo.17130209

ARTICLE DETAILS

Research Paper
Accepted: 26-08-2025
Published: 10-09-2025

Keywords:
Prayagraj; Flood Vulnerability; GIS; Rainfall Variability; LULC; Drainage Density; Terrain Parameters; Disaster Risk Reduction

ABSTRACT

Prayagraj, located at the confluence of the Ganga and Yamuna rivers, faces recurrent flooding due to its geomorphological setting and variable monsoon rainfall. This study adopts a GIS-based approach to explore the role of hydrological and terrain parameters in shaping flood vulnerability. Key datasets include LULC, rainfall (IDW interpolation), drainage density, slope, elevation, and aspect. Analysis shows that low-lying alluvial plains with gentle slopes and high drainage density are the most flood-prone zones. The tehsils of Meja, Karchana, and Soraon emerge as major hotspots of flood exposure. Higher elevation areas with steeper slopes are comparatively less vulnerable. Rainfall variability (2016–2023) demonstrates that above-average years, such as 2016, 2019, and 2020, correspond with more severe flooding. Even moderate rainfall years have produced urban flooding in Jhusi, Daraganj, and Jhalwa, largely due to drainage congestion and unplanned development. The study highlights the combined impact of natural terrain and anthropogenic pressures on flood risk. Findings provide insights for disaster preparedness and sustainable land-use planning in Prayagraj

Introduction:

Floods continue to be one of the most frequent and damaging natural hazards globally, with their intensity and frequency rising under changing climatic conditions (Hirabayashi et al., 2013; Mishra et al., 2022). South Asia is particularly vulnerable because of its monsoon climate and dense river networks, and India ranks among the most flood-prone countries. Recent estimates suggest that nearly 80 million people and about 12% of the national land area are exposed to flood risk every year, making it a critical environmental and developmental challenge (Gupta et al., 2021; Shukla et al., 2019). The Ganga basin, which sustains one of the largest populations in the world, has been repeatedly identified as a hotspot of vulnerability due to its flat alluvial topography, intense monsoonal rainfall, and rapid land-use changes (Kumar et al., 2021; Singh et al., 2020).Prayagraj district, located at the confluence of the Ganga and Yamuna rivers, illustrates this problem with particular severity. Its hydro-geomorphological setting makes it highly dynamic, but also exposes both rural villages and urban neighborhoods to recurrent floods. Historical records indicate that the catastrophic flood of 1978 inundated over a thousand villages, while subsequent events in 2013, 2016, 2019, 2021, and 2022 continued to affect large populations and critical infrastructure (District Flood Management Plan, Prayagraj, 2024–25). These floods not only caused agricultural losses but also triggered urban waterlogging in localities such as Jhusi, Daraganj, and Jhalwa, where inadequate drainage systems and unregulated development magnify risks (Singh et al., 2020; Gupta & Nair, 2021).Scholarly work confirms that flood vulnerability is shaped by both natural and anthropogenic processes. On the natural side, slope, elevation, drainage density, and rainfall distribution determine flood dynamics, while on the human side, land-use change, encroachment into floodplains, and poorly planned urban growth create additional pressures (Rahmati et al., 2016; Kumar et al., 2021). Advances in geospatial science have allowed researchers to integrate these parameters into multi-criteria models that identify hazard hotspots. For example, Thakur et al. (2017) demonstrated the effectiveness of combining remote sensing and GIS for flood hazard mapping in Uttar Pradesh, while recent studies highlight how urbanization and climate variability have intensified flood exposure in Indian cities (Shukla et al., 2019; Mishra et al., 2022). Despite these advances, district-level studies remain limited in the Ganga basin, and for Prayagraj specifically, systematic assessments of hydrological and terrain parameters are still lacking.The present study seeks to address this gap through a GIS-based assessment of flood vulnerability in Prayagraj. By analyzing rainfall variability between 2016 and 2023, and by integrating thematic layers including land use/land cover (LULC), rainfall interpolation (IDW), slope, elevation, aspect, and drainage density, the study aims to provide a spatial understanding of flood-prone conditions in the district. The findings are expected to contribute to both scientific knowledge and practical planning by identifying natural and human drivers of risk and supporting disaster preparedness measures.

The specific objectives of this study are:

1. To analyze rainfall variability from 2016 to 2023 and its relationship with flood events in Prayagraj.
2. To evaluate the role of hydrological and terrain parameters in shaping spatial flood vulnerability.
3. To provide insights for disaster preparedness and sustainable land-use planning in the district.

2. MATERIALS AND METHOD

2.1 Study Area:

Prayagraj district is situated in the southeastern part of Uttar Pradesh, India, between 24°47′–25°47′ N latitude and 81°19′–82°21′ E longitude, covering an area of nearly 5,482 km². The district is bounded by Pratapgarh in the north, Kaushambi in the west, Mirzapur in the south, and Bhadohi in the east. Its most defining geographical feature is the confluence of the Ganga and Yamuna rivers, popularly known as the Sangam, which makes the district a cultural and religious center while also rendering it highly flood-prone.

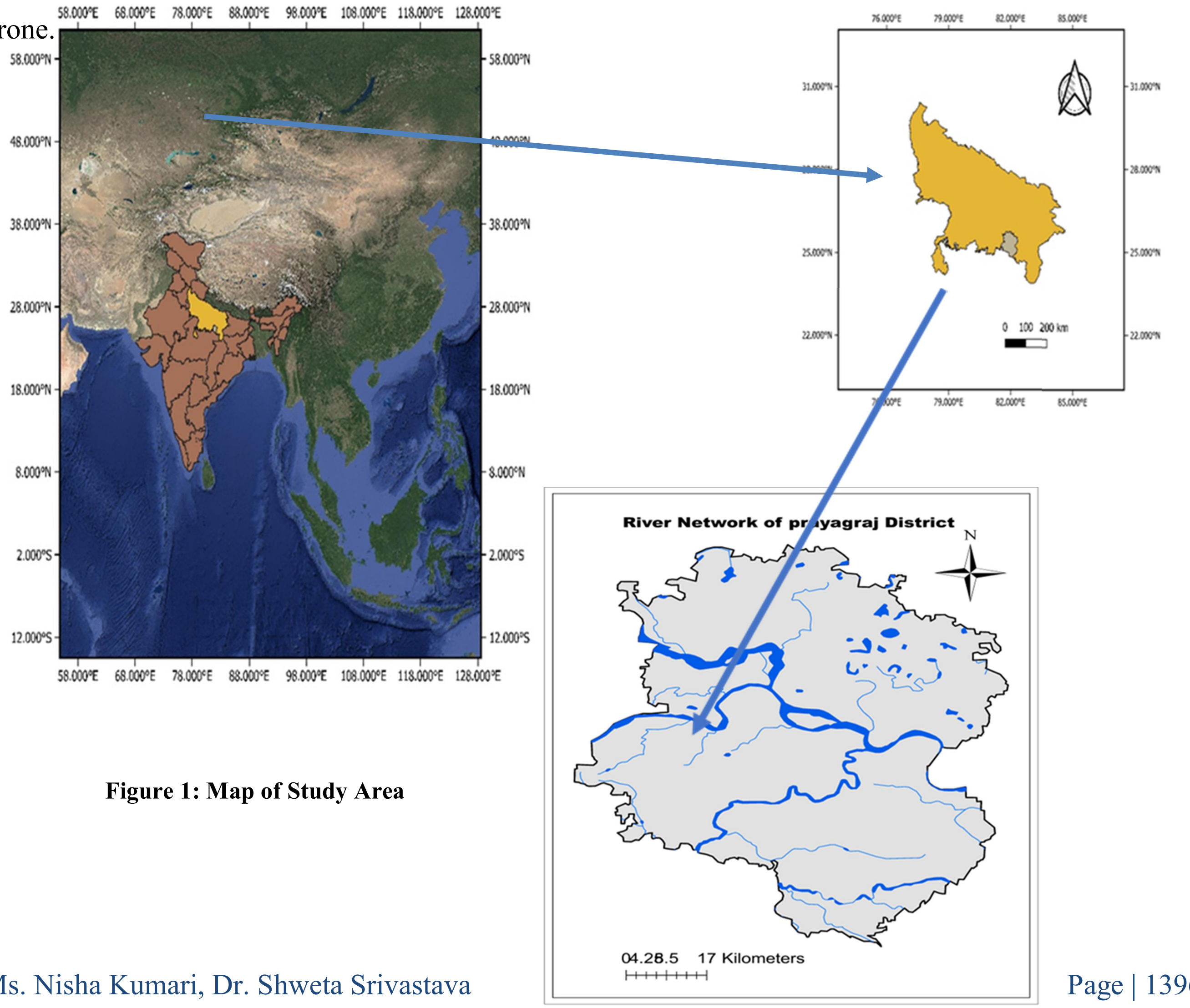

Figure 1: Map of Study Area

2.1.1 Scenarios of Floods in Uttar Pradesh State

Uttar Pradesh is widely recognized as one of the most flood-prone states of India because of its geographical location in the middle and lower Ganga basin. Almost one-third of the state, covering nearly 31 districts, faces recurring floods during the monsoon season (Gupta et al., 2021; Mishra et al., 2022). The eastern and central districts, including Gorakhpur, Bahraich, Sitapur, Gonda, Azamgarh, Ballia, and Prayagraj, are consistently identified as high-risk areas. The flat alluvial topography of the state, combined with the dense river network of the Ganga, Yamuna, Ghaghra, Rapti, and Gandak, creates widespread susceptibility to inundation (Thakur et al., 2017).

Official records suggest that on average, 6–7 million people are affected annually by floods in Uttar Pradesh. Historical flood years such as 1978, 1988, 1998, 2008, 2013, and 2019 caused extensive damage to crops, houses, and infrastructure. More than 2,500 villages have been officially classified as flood-prone, and the number is growing as rapid urbanization and encroachment extend human settlements into floodplains (District Flood Management Plan, Prayagraj, 2024–25). This state-level context highlights why district-level analyses are critical for understanding localized vulnerability.

2.1.2Flood Situation in Prayagraj

Flooding is a recurrent hazard in Prayagraj, primarily due to its physiographic setting at the confluence of the Ganga and Yamuna rivers and the presence of vast low-lying floodplains. Historical records highlight the 1978 flood as one of the most destructive, when water levels rose above 88 m and over a thousand villages were inundated, displacing nearly 3.25 lakh families. The subsequent floods of 1983 and 1984 again caused extensive damage, leading to large-scale displacement and agricultural losses. During the 1990s, events such as the 1990 and 1994 floods were of moderate intensity but still affected several hundred villages, indicating persistent exposure of riverine settlements.

The 2000s brought another phase of high-magnitude events, with the 2003 flood submerging more than 700 villages and displacing nearly four lakh people, followed by the 2006 flood, which spread across seven tehsils and devastated agricultural areas. In the last decade, the 2013 flood impacted more than 200 villages, whereas the 2019 flood inundated 179 villages, severely disrupting both rural and urban livelihoods.

More recently, consecutive floods in 2021 and 2022 have reinforced the recurring nature of the hazard. The 2021 flood affected 122 villages and over 70,000 people, while the 2022 flood persisted for nearly two weeks, inundating 158 villages across multiple tehsils. These recurring disasters underline that despite the presence of structural flood control measures, Prayagraj remains highly vulnerable due to its geomorphological position and the increasing influence of hydro-climatic variability. This trend is consistent with wider observations in the middle Ganga basin, where studies have reported an increasing frequency of floods linked to changing rainfall patterns, river dynamics, and land use alterations (Singh et al., 2020; Gupta & Mishra, 2021; NDMA, 2022; Kumar et al., 2023).

2.2 Method

This study integrates rainfall records, remote sensing datasets, and GIS-based techniques to assess flood vulnerability in Prayagraj district. Rainfall data for 2019–2023 was obtained from the District Flood Management Plan (DFMP, 2024–25), while high-resolution gridded precipitation data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) was used to prepare the rainfall distribution map. Topographic variables such as elevation, slope, aspect, and drainage density were extracted from the Shuttle Radar Topography Mission (SRTM DEM, 30 m), which provides a reliable base for terrain and hydrological modeling. Land Use and Land Cover (LULC) information was derived from Landsat-8 OLI/TIRS imagery downloaded from the USGS Earth Explorer, classified into agriculture, built-up areas, vegetation, and water bodies. Additional information, including the block-wise list of 655 flood-affected villages and river water level records of the Ganga, Yamuna, and Usri stream (2020–2023), was obtained from the DFMP (2024–25). It should be noted that although other rivers such as the Tons, Belan, and Varuna also flow through Prayagraj, their levels are not documented in the DFMP due to the absence of local monitoring stations.

The analytical framework was carried out in three stages. First, rainfall variability was assessed by comparing annual and monthly deviations between average and actual rainfall values (2019–2023), while spatial rainfall surfaces were generated using the Inverse Distance Weighting (IDW) interpolation technique in ArcGIS. Second, DEM derivatives were processed to obtain slope, elevation, aspect, and drainage density layers, and LULC was classified to highlight human activity in flood-prone areas. Finally, flood vulnerability was evaluated by analyzing the distribution of affected villages reported in the DFMP. The integration of rainfall variability, physiographic indicators, and settlement-level vulnerability provided a comprehensive understanding of flood risk in Prayagraj, offering insights into both its spatial concentration and temporal recurrence.

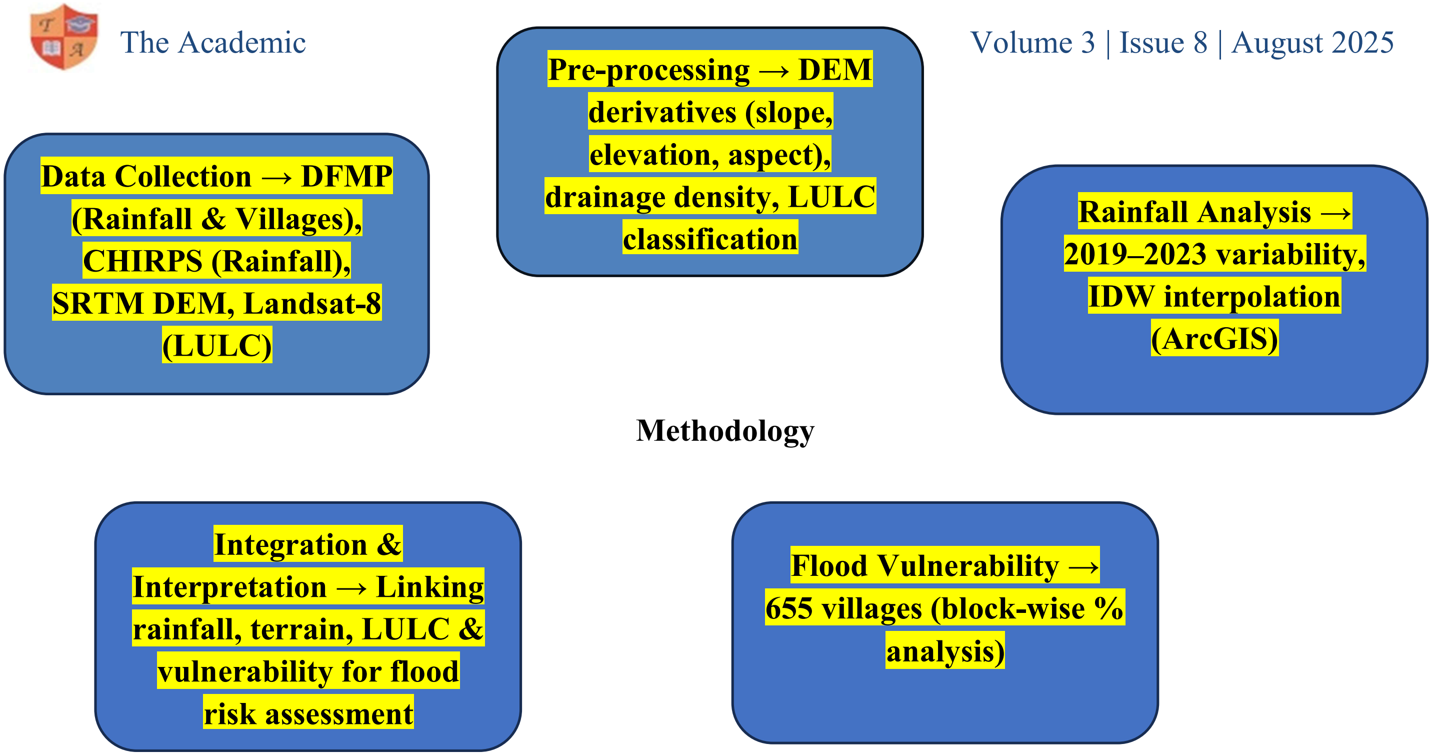

Figure2: Methodology Flowchart

Result and Discussion:

Table1: Flood-Prone villages in Prayagraj District

Tehsil/Block	Major Rivers	No. of Flood-Prone Villages
Soraon	Ganga, Yamuna	45
Phulpur	Ganga	32
Karchana	Ganga, Yamuna	38
Meja	Ganga	41
Handia	Ganga, Yamuna	35
Bara	Yamuna	28
Koraon	Tons	21
City (Prayagraj Urban)	Ganga, Yamuna, Sangam	17

Source: *District Flood Management Plan – Prayagraj (2024-2025)*

In Prayagraj district, around 257 villages have been identified as flood-prone in the 2024–25 flood management plan. Most of these habitations lie along the Ganga, Yamuna, and Tons rivers, where the low-lying terrain is highly exposed to seasonal flooding. The areas most affected are Meja, Karchana, and Soraon tehsils, where recurring floods submerge villages such as Kakrahni, Dankar Mau, Jalupur, and Bijora. Other clusters of vulnerable settlements are found in Handia, Bara, and Koraon, while even the urban neighborhoods of Jhusi, Daraganj, Salori, and Jhalwa are at risk because of their closeness to the river confluence (Sangam).These villages represent the district's repeated flood hotspots, shaped not only by the shifting nature of river channels and silt accumulation but also by human activities like unregulated construction and pressure on floodplains. This situation points to the need for a comprehensive flood management strategy, which should combine engineering measures such as embankments and improved drainage with community-based solutions like disaster preparedness and effective early warning system.

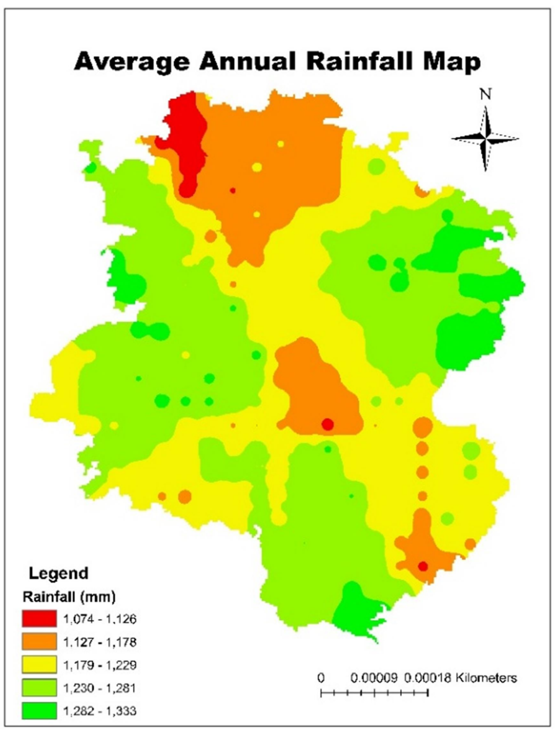

Figure 3. Average annual rainfall distribution in Prayagraj district (2019–2023).

The map shows spatial variability of rainfall derived from CHIRPS data. Higher rainfall zones are concentrated in the southern and western parts, whereas deficits are observed in central plains, indicating localized variability that influences flood intensity

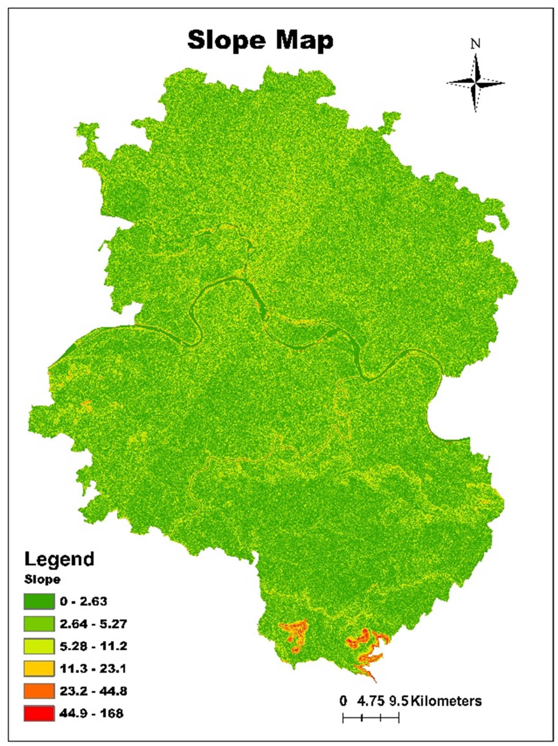

Figure 4. Slope map of Prayagraj district.

Low slope values (0–5°) dominate the floodplains of the Ganga and Yamuna, making them prone to water stagnation, while steeper slopes in the south (Meja, Koraon) reduce flood risk.

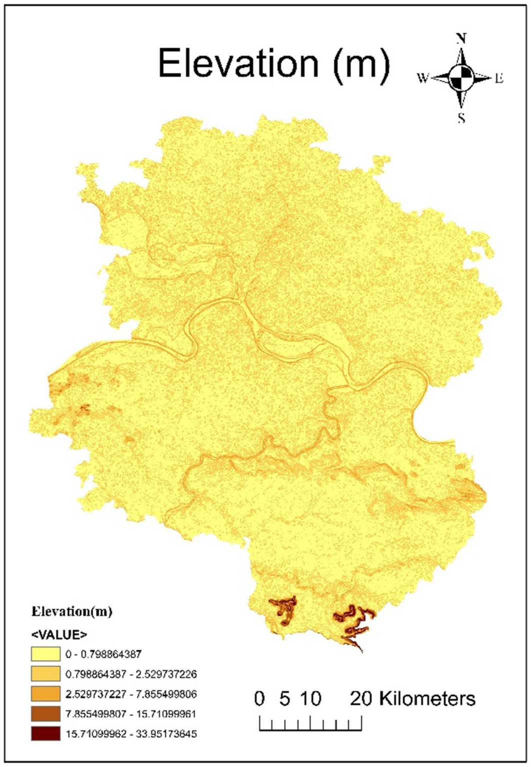

Figure 5. Elevation map of Prayagraj district.

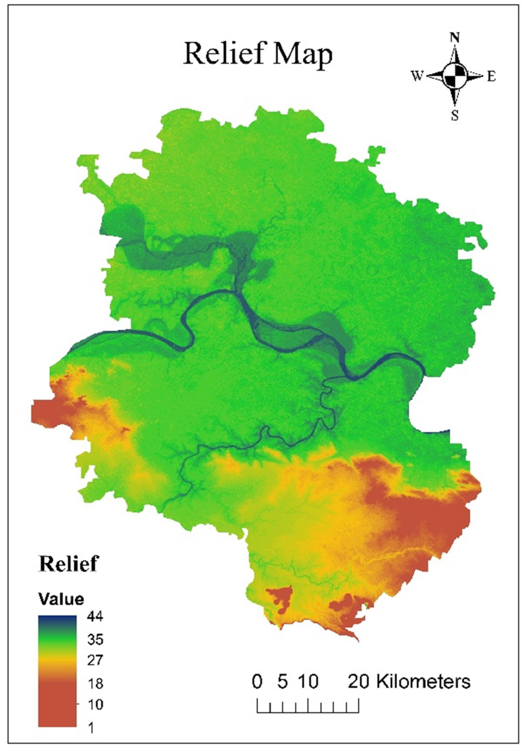

Figure 6. Relief map of Prayagraj district.

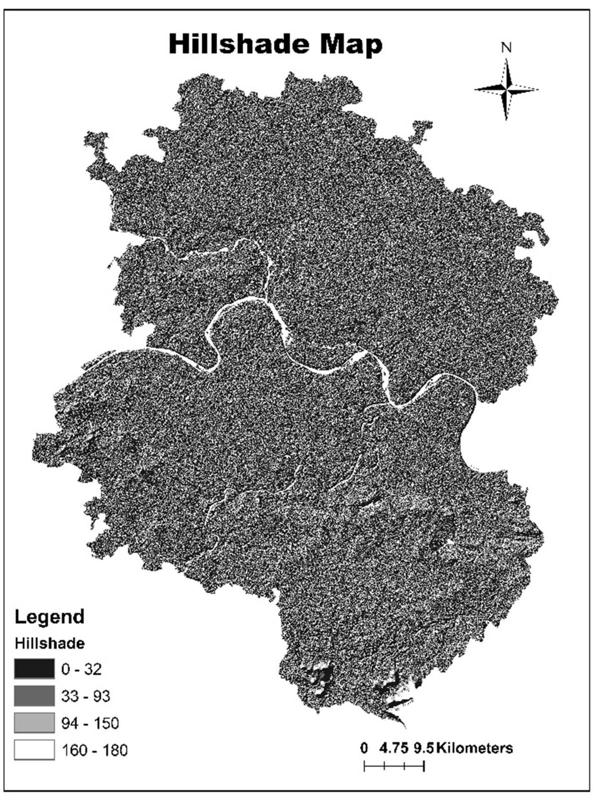

Figure 7: Hillshade map of Prayagraj district.

The hillshade enhances topographic variation and emphasizes the sharp gradient between the alluvial plains and southern uplands

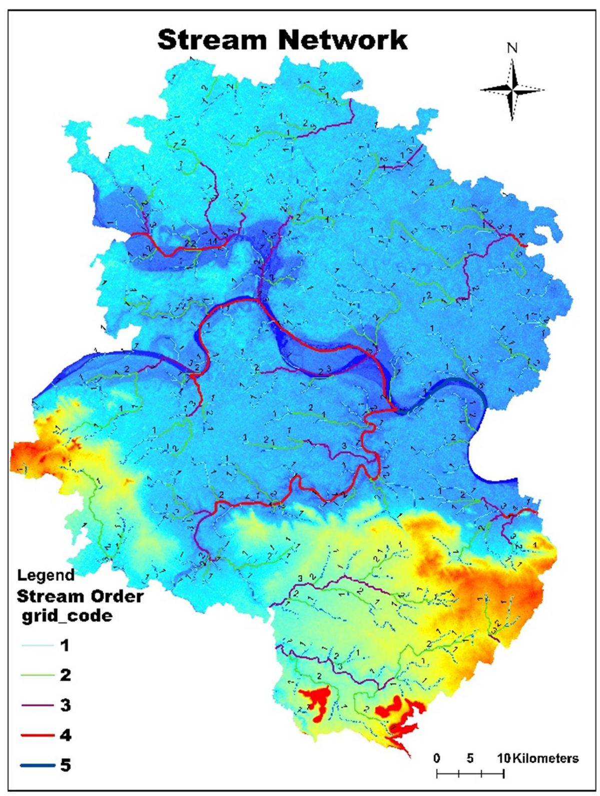

Figure 8. Stream network of Prayagraj district.

The network shows tributaries converging into the Ganga and Yamuna, intensifying flood hazard in the confluence zone.

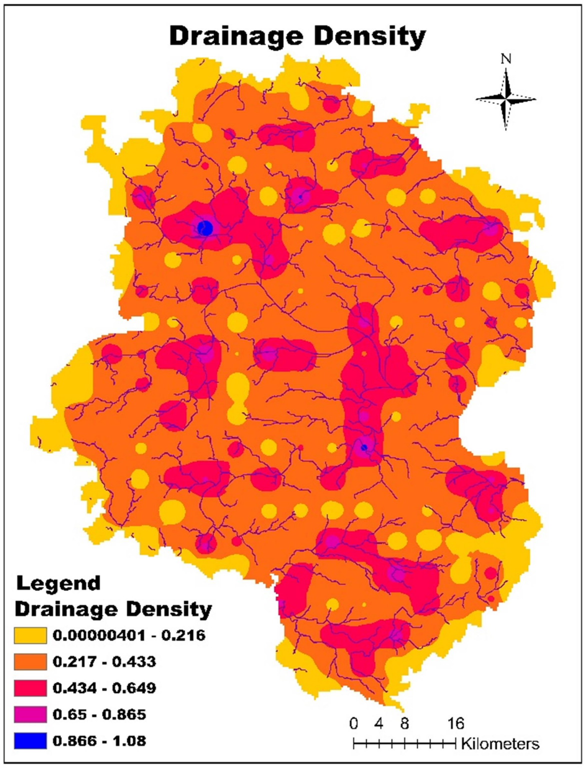

Figure 9. Drainage density map of Prayagraj district.

Areas with high drainage density experience rapid runoff accumulation, leading to flash flooding, particularly in Phulpur and Soraon blocks.

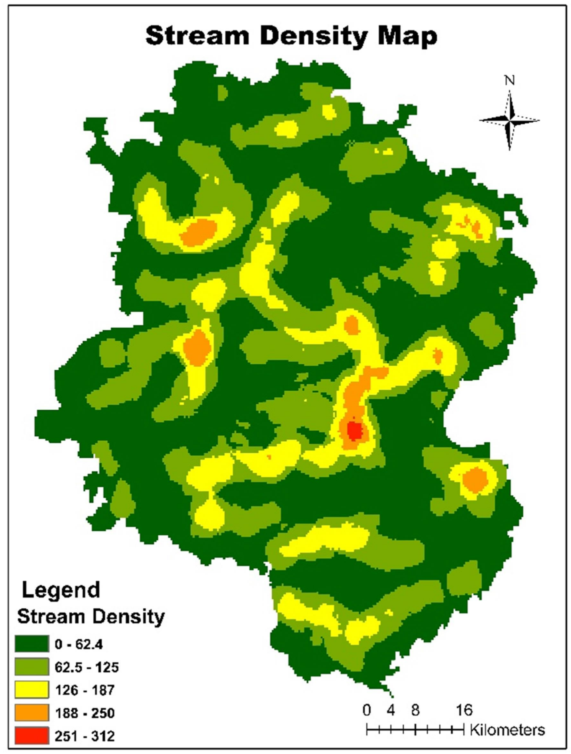

Figure 10. Stream density map of Prayagraj district.

High stream density zones overlap with low-lying floodplains, confirming their susceptibility to frequent inundation

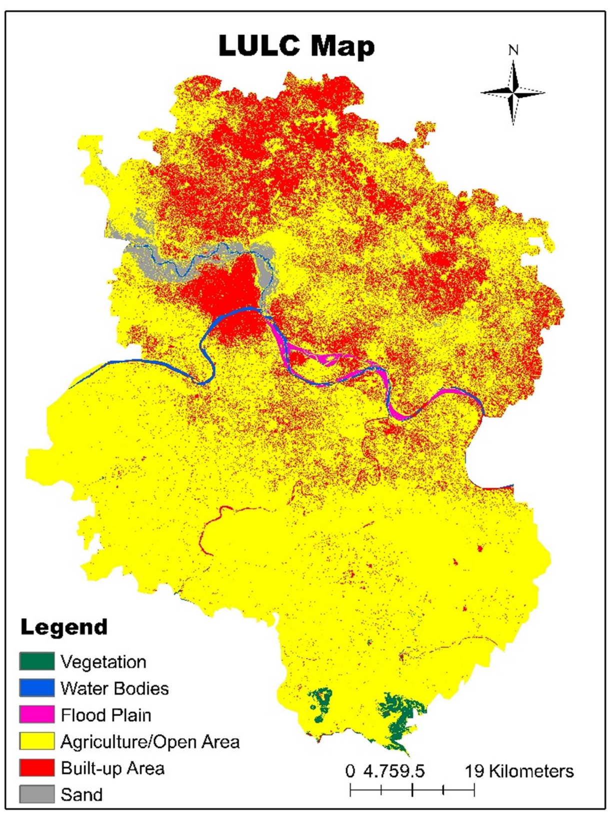

Figure 11. Land Use and Land Cover (LULC) map of Prayagraj district.

Agricultural land and built-up areas dominate flood-prone regions, while limited vegetation cover reduces natural flood absorption capacity. Croplands and settlements located along riverbanks face the highest

The spatial analysis demonstrates that rainfall, topography, drainage, and land use collectively govern flood vulnerability in Prayagraj district. The average annual rainfall map (Fig. 3) indicates considerable spatial variability, with higher rainfall recorded in southern and western pockets, aligning with CHIRPS-based IDW outputs. Years of extreme rainfall, such as 2022, coincided with severe flood events, confirming the role of precipitation anomalies in triggering large-scale inundation.

Terrain analysis derived from DEM (Figs. 5) reveals that the northern and central floodplains are characterized by low slope values (0–5°) and low relief, making them highly susceptible to prolonged waterlogging. In contrast, the southern tracts of Meja and Koraon display higher slope and relief, which allow faster runoff and reduce flood risk. The elevation gradient highlights that most flood-affected villages are situated in low-lying zones along the Ganga and Yamuna, validating DFMP (2024–25) records.

Hydrological analysis of drainage patterns (Figs. 8) shows that areas with high drainage and stream density experience rapid runoff accumulation, leading to flash floods, particularly in Phulpur and Soraon blocks. Conversely, low drainage density zones in the plains are more prone to stagnant flooding. The stream network further illustrates the role of tributaries converging into the Ganga and Yamuna, intensifying flood hazard at confluence zones.

The LULC map (Fig. 11) highlights that agricultural land and built-up areas dominate the flood-prone regions. Large tracts of croplands situated along the riverbanks are regularly inundated during high flood years, causing severe agricultural losses. Expanding built-up areas in low-lying floodplains, especially around Prayagraj city and Naini, increase exposure to urban flooding. Limited vegetation cover reduces the district's natural capacity to buffer floods, compounding the vulnerability.

Overall, the integration of rainfall variability, terrain, drainage density, and land use patterns demonstrates that flood vulnerability in Prayagraj is a product of both natural physiography and anthropogenic pressures. Blocks such as Phulpur, Soraon, and Handia emerge as the most vulnerable, while Koraon and Meja remain relatively safe due to their upland physiography. These results are consistent with historical flood records and recent studies in the Ganga–Yamuna basin, which emphasize the combined influence of rainfall extremes, topographic setting, and land use on flood hazards (Roy & Blaschke, 2020; Mishra et al., 2021; Kumar et al., 2023).

The combined evaluation of rainfall variability, topographic features, drainage characteristics, and land use demonstrates that flood vulnerability in Prayagraj emerges from the interaction of both natural and anthropogenic drivers. Rainfall distribution patterns (Fig. 3) and terrain conditions, including slope and elevation (Figs. 4–6), align closely with the spatial distribution of flood-affected villages documented in the DFMP (2024–25). Similarly, drainage density maps (Figs. 8–10) reveal that areas with denser networks of streams experience rapid runoff accumulation, which magnifies flood risk. Land use analysis (Fig. 11) further indicates that agricultural land and expanding built-up areas in floodplains are the most exposed, intensifying both rural and urban vulnerabilities. These observations are consistent with previous findings across the Ganga–Yamuna basin, where land use change, rainfall extremes, and floodplain settlement have been shown to exacerbate flood hazards (Roy & Blaschke, 2020; Mishra et al., 2021; Ali et al., 2023)

Conclusion:

This study applied a multi-source GIS-based approach to evaluate flood vulnerability in Prayagraj district. The results reveal that inter-annual rainfall variability between 2019 and 2023 strongly influenced the occurrence of floods, with 2022 representing a year of extreme precipitation and severe inundation. Terrain analysis confirmed that low-lying floodplains with gentle slopes and high drainage density are particularly prone to prolonged waterlogging and flash flooding, while southern upland tracts remain comparatively safe. The LULC classification further highlights that agricultural fields and built-up areas, which dominate the floodplains, are highly exposed to inundation. The DFMP data confirmed that 655 villages, especially in Phulpur, Soraon, and Meja blocks, face recurrent flood risks, indicating a strong overlap of rainfall extremes, topographic vulnerability, and human settlement patterns.

Overall, the findings underscore that flood hazard in Prayagraj is not solely a climatic phenomenon but a product of coupled climatic, geomorphological, and anthropogenic factors. Strengthening floodplain zoning, regulating construction in high-risk areas, developing resilient cropping systems, and improving community-based early warning mechanisms are necessary to minimize future impacts.

Reference:

1. Ali, S., Khan, M., & Ahmad, R. (2023). Impact of land use change on flood vulnerability in Ganga–Yamuna floodplain regions of India. Journal of Flood Risk Management, 16(2), e13245. https://doi.org/10.1111/jfr3.13245
2. Climate Hazards Group. (2023). CHIRPS v2.0: Climate Hazards Group InfraRed Precipitation with Station data (1981–present). University of California, Santa Barbara. https://data.chc.ucsb.edu/products/CHIRPS-2.0/
3. Government of Uttar Pradesh, Department of Revenue. (2024–2025). District Flood Management Plan: Prayagraj. Lucknow: Author.
4. Ghosh, S., Kumar, R., & Singh, A. (2020). Rainfall anomalies and their role in flood frequency across the Ganga basin. Natural Hazards, 104(3), 2985–3003. https://doi.org/10.1007/s11069-020-04200-9
5. Gupta, A., & Mishra, S. (2021). Changing flood dynamics in the Middle Ganga Basin: Causes and consequences. International Journal of Disaster Risk Reduction, 62, 102391. https://doi.org/10.1016/j.ijdrr.2021.102391
6. Gupta, A., & Nair, P. (2021). Urban flood risk and drainage congestion in Indian cities. Environmental Development, 37, 100613. https://doi.org/10.1016/j.envdev.2020.100613
7. Gupta, R., Sharma, K., & Srivastava, P. (2021). Flood risk in Uttar Pradesh: A state-level perspective. Journal of Environmental Geography, 14(2), 1–15. https://doi.org/10.2478/jengeo-2021-0001
8. Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., & Kanae, S. (2013). Global flood risk under climate change. Nature Climate Change, 3(9), 816–821. https://doi.org/10.1038/nclimate1911
9. Kumar, A., Singh, S., & Verma, P. (2021). Hydro-geomorphological controls on flood vulnerability in the Ganga Basin. Geocarto International, 36(12), 1338–1354. https://doi.org/10.1080/10106049.2019.1700867
10. Kumar, S., Mishra, S., & Yadav, R. (2023). Hydro-climatic variability and its impact on floods in Uttar Pradesh. Water Resources Management, 37, 421–438. https://doi.org/10.1007/s11269-022-03256-3
11. Mishra, V., Singh, R., & Shukla, A. (2021). Anthropogenic pressures and flood hazards in North India Environmental Hazards, 20(3), 287–303. https://doi.org/10.1080/17477891.2020.1865567
12. Mishra, V., Yadav, M., & Shukla, R. (2022). Increasing frequency of floods in South Asia under climate variability. Climatic Change, 170(3–4), 12–29. https://doi.org/10.1007/s10584-022-03418-1

13. National Disaster Management Authority. (2022). Guidelines for flood management in India. Government of India.
14. NASA Jet Propulsion Laboratory. (2013). NASA Shuttle Radar Topography Mission (SRTM) Global 30m DEM (Version 3). NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC). https://doi.org/10.5067/MEaSUREs/SRTM/SRTMGL1.003
15. Prakash, S., & Singh, R. (2022). Flood vulnerability assessment in the Middle Ganga Basin using rainfall variability. Natural Hazards Research, 2(4), 45–57. https://doi.org/10.1016/j.nhres.2022.08.004
16. Rahmati, O., Zeinivand, H., & Besharat, M. (2016). Flood hazard zoning using GIS and multi-criteria decision analysis (MCDA): A case study in Iran. Water, 8(1), 11. https://doi.org/10.3390/w8010011
17. Roy, P., & Blaschke, T. (2020). Land use dynamics and flood hazard in alluvial floodplains of India. Science of the Total Environment, 732, 139222. https://doi.org/10.1016/j.scitotenv.2020.139222
18. Sharma, A., & Patel, R. (2021). GIS-based flood risk mapping in the Ganga–Yamuna basin. Journal of Hydrology: Regional Studies, 37, 100915. https://doi.org/10.1016/j.ejrh.2021.100915
19. Shukla, R., Pandey, P., & Singh, A. (2019). Urbanization and flood risk in Indian cities. Sustainable Cities and Society, 48, 101487. https://doi.org/10.1016/j.scs.2019.101487