

Multi-Temporal Sentinel-1 SAR-Based Assessment of Flood Inundation Expansion in the Kosi–Ganga Confluence Zone, Bihar, India

Braj Kishor Dwivedi*, Prof. Azizur Rahman Siddiqui, Vikas Singh

Department of Geography, University of Allahabad, Prayagraj 211002 Uttar Pradesh India.

*Corresponding Author

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ABSTRACT

Flood inundation is a recurrent hazard in the alluvial plains of Bihar, particularly within the interconnected Kosi–Ganga river system. This study assesses the spatial expansion of flood inundation in the Kosi–Ganga confluence zone of eastern Bihar during August–September 2026 using multi-temporal Sentinel-1 Synthetic Aperture Radar (SAR) imagery. SAR observations acquired on 19 August 2026 and 12 September 2026 were used to derive water masks and identify changes in surface-water extent between the reference and flood-period conditions. The results reveal a substantial expansion of mapped water/flood area from 358.090 km² to 749.516 km², representing an increase of 391.425 km² (109.31%). The Ganga-associated area increased from 264.156 to 501.616 km² (89.89%), while the Kosi-associated area increased from 93.935 to 247.900 km² (163.88%). Digital Elevation Model based analysis indicates that extensive inundation occurred across relatively low-lying floodplain surfaces particularly in Diara land. Subsequent Government of Bihar observations during 17–19 September 2026 recorded water levels above danger levels at selected Kosi and Ganga gauge stations, providing supporting hydrological context for continued elevated river conditions. The findings demonstrate the effectiveness of multi-temporal Sentinel-1 SAR for rapid flood-inundation assessment and provide a spatial baseline for subsequent flood exposure and risk studies in the Kosi–Ganga confluence zone.

Keywords - Flood Inundation, Kosi–Ganga Confluence Zone, Flood Area, Topographic Setting, Digital Elevation Model.

INTRODUCTION

Floods are among the most recurrent and damaging hydro-meteorological hazards in the alluvial plains of Bihar (Bhatt et al., 2026; Das et al., 2021; Senapati, 2022), where low-gradient terrain, large river systems and extensive floodplains create favourable conditions for the lateral spreading of floodwater (Bhatt et al., 2021; Das et al., 2021; Kaur et al., 2019; Shetty T et al., 2026). Bihar is particularly susceptible because of its dense network of Himalayan and Ganga-associated rivers, extensive low-lying alluvial plains and recurrent changes in river–floodplain connectivity. Previous studies have demonstrated that flood hazard in North Bihar is spatially heterogeneous and strongly influenced by topography, drainage characteristics, river dynamics and the distribution of exposed populations and agricultural land (Mishra & Sinha, 2020; Sahana & Patel, 2019; Tripathi et al., 2022). Historical assessments have further shown that major flood events in Bihar can produce extensive inundation and substantial socio-economic consequences, including damage to houses, crops and livelihoods (Kaur et al., 2019; Senapati, 2022).

The Kosi River represents one of the most dynamically evolving fluvial systems in North Bihar. Its highly mobile channel network, historical avulsion behaviour and complex channel–floodplain connectivity have important implications for flood propagation and spatial exposure. Sinha et al. (2013) demonstrated that the channel-connectivity structure of the Kosi avulsion belt has direct implications for flood-risk assessment, while Sinha et al. (2014) linked the planform dynamics and avulsion behaviour of the river with its geomorphic setting. The lower Kosi floodplain has consequently been recognised as a region of substantial flood susceptibility (Sahana

& Patel, 2019). More recent studies have continued to identify significant flood-risk conditions within the Kosi Basin using remote sensing and integrated risk-assessment approaches (Kumar et al., 2025; Shetty et al., 2026). At the same time, the Ganga floodplain in Bihar is also subject to extensive inundation and dynamic channel responses. These studies establish the Kosi and Ganga as important components of the regional flood system, but their interconnected confluence zone represents a distinct geomorphic and hydrological setting in which floodwater can spread across connected low-lying surfaces.

Remote sensing has become an important approach for rapidly delineating flood extent, particularly in regions where flood observations are spatially discontinuous. Optical satellite imagery can be constrained by cloud cover during flood events, whereas Synthetic Aperture Radar (SAR) provides observations independent of cloud and daylight conditions. Multi-temporal Sentinel-1 SAR imagery has therefore been widely applied for flood-water extraction using backscatter characteristics, thresholding and change-detection techniques (Clement et al., 2018; Vekaria et al., 2022). In the Indian context, Pinheiro et al. (2024) and Sajid et al. (2025) demonstrated the application of multi-temporal SAR and change detection specifically for inundation mapping along the Kosi River.

Despite these studies, much of the existing research in Bihar has concentrated either on historical flood-frequency and risk assessment, individual river basins such as the Kosi, or larger regional flood events. Studies of the Kosi have particularly emphasized long-term channel dynamics, flood susceptibility and basin-scale risk (Shetty T et al., 2026; Sinha et al., 2013, 2014) whereas investigations of the Ganga have examined flood extent and channel responses during individual events (Bhatt et al., 2021; Khan et al., 2022). Recent work has also demonstrated that flood timing and persistence across Bihar may vary spatially in relation to the Ganga and Kosi river systems, with river-proximal areas potentially experiencing prolonged inundation associated with river discharge and backwater processes (Srivastava, 2025). However, an event-specific assessment focused on the Kosi–Ganga confluence zone, integrating multi-date SAR-derived water extent with topographic and hydrological context, remains comparatively limited. This is particularly relevant for rapidly assessing the spatial expansion of floodwater during an ongoing flood episode.

Therefore, the present study investigates the September 2026 flood inundation in the Kosi–Ganga confluence zone of eastern Bihar using multi-date Sentinel-1 SAR observations. The study compares the mapped water extent between 19 August 2026 and 12 September 2026 to quantify the spatial and temporal expansion of inundated water surfaces and separately evaluates the contributions of the Ganga and Kosi corridors. The satellite-derived inundation is further interpreted in relation to the spatial distribution of elevation and subsequent river-stage observations from selected hydrological stations. The study particularly aims to determine the magnitude and spatial pattern of floodwater expansion within the interconnected river–floodplain system and to examine how low-lying terrain and elevated river stages provide context for the observed inundation. By combining satellite-based flood mapping with geomorphological and hydrological information, the study provides an event-specific spatial assessment of the September 2026 flood and establishes a baseline for subsequent flood exposure and risk investigations in the Kosi–Ganga confluence region.

Study Area

The study focuses on the Kosi–Ganga confluence zone in eastern Bihar, India, extending approximately between 25°12'–25°30' N and 86°54'–87°18' E (Fig. 1). The study region encompasses the adjoining floodplain of the Kosi and Ganga rivers and covers parts of Madhepura, Purnia, Katihar and Bhagalpur districts. Administratively, the selected region includes Uda Kishanganj tehsil of Madhepura, Dhamdaha tehsil of Purnia, Katihar tehsil of Katihar, and Naugachhia, Bhagalpur and Kahalgaon tehsils of Bhagalpur.

The Kosi is a major Himalayan River whose catchment extends across Nepal, Tibet and northern India. After traversing the plains of Bihar, the Kosi flows eastward and joins the Ganga near Kursela in Katihar district, forming the principal hydrological setting of the study region. The lower Kosi floodplain is characterised by a relatively low-gradient terrain and numerous former and active channel courses, while the Ganga forms the major east–west river corridor along the southern part of the study area.

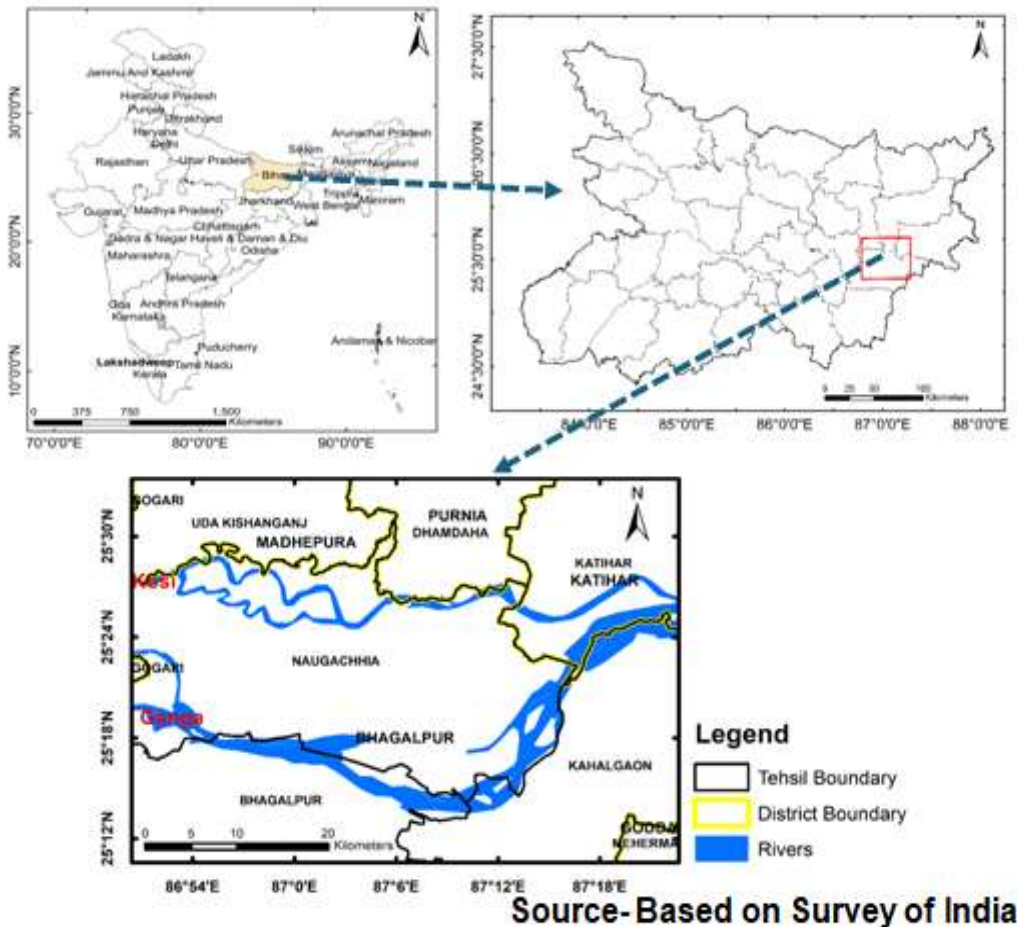


Figure 1. Location map of the Kosi–Ganga confluence study area in eastern Bihar (Prepared by Authors).

The selection of the Kosi–Ganga confluence zone provides a spatial framework for examining the 2026 flood inundation associated with the two interconnected river systems. The region also contains important hydrological monitoring locations, including Vijay Ghat Bridge and Kursela on the Kosi and Bhagalpur and Kahalgaon on the Ganga, which provide supporting hydrological context for interpreting the satellite-derived flood extent.

DATABASE AND RESEARCH METHODOLOGY

The study utilized Sentinel-1 SAR imagery for two observation dates: 19 August 2026 (pre-flood) and 12 September 2026 (flood-period). The SAR datasets were used to derive comparable pre-flood (W_1) and flood-period (W_2) water masks. The two water masks were subsequently compared to identify changes in surface-water extent. DEM was additionally used to examine the topographic context of flood inundation. Hydrological observations from selected Kosi and Ganga gauge stations were used as supporting contextual data.

The study employed a two-date Sentinel-1 Synthetic Aperture Radar (SAR)-based change-detection approach to assess flood inundation in the Kosi–Ganga confluence zone of Bihar. Sentinel-1 SAR imagery acquired on 19 August 2026 was used to represent the pre-flood condition, while imagery acquired on 12 September 2026 represented the flood-period condition. The methodological workflow consisted of satellite image acquisition, flood-water extraction, generation of water masks, and flood inundation change detection (Fig. 2).

Satellite Data and Image Processing

Two Sentinel-1 SAR images covering the study area were acquired for the selected dates. The images were processed using a consistent workflow to obtain comparable surface-water information for both periods. SAR-based imagery was used for water delineation, allowing the identification of water-covered areas from the radar backscatter characteristics of the two observations (Clement et al., 2018) .

Flood-Water Extraction

Flood-water extraction was performed separately for the two dates. The 19 August 2026 image was used to derive the pre-flood water mask (W_1), representing the surface-water extent before the flood period (Tiwari et al., 2020; Vekaria et al., 2022). The 12 September 2026 image was used to derive the flood-period water mask (W_2), representing the water extent during the flood period.

Flood Inundation Change Detection

The two water masks were compared spatially to identify changes in surface-water extent between the pre-flood and flood-period conditions. Areas classified as water in the flood-period image but not in the pre-flood image were identified as newly inundated areas. The flood inundation change was therefore expressed as:

$$\text{"Flood Inundation Change"} = W_2 - W_1$$

where W_1 denotes the pre-flood water mask and W_2 denotes the flood-period water mask. The resulting change-detection layer was used to delineate and quantify the spatial extent of flood inundation within the study area.

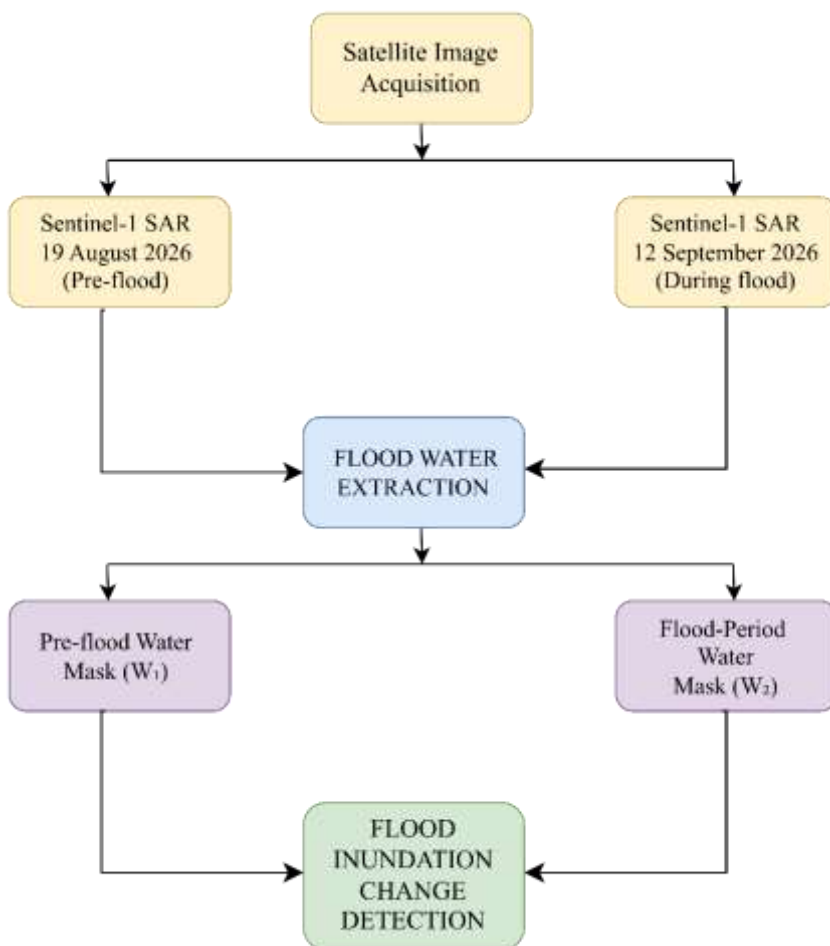


Figure 2. Research methodology for Sentinel-1 SAR-based flood inundation change detection.

RESULTS AND DISCUSSION

Spatial and temporal variation in flood inundation

The Sentinel-1-derived water/flood maps show a clear expansion of inundated area between the pre-flood and flood-period conditions (Fig. 3 and Fig.4). In the pre-flood condition, mapped water was largely confined to the active channels of the Ganga and Kosi and their associated water bodies. During the flood period, the water extent expanded laterally beyond the active channels into adjoining floodplain surfaces, particularly along the Kosi corridor in the northern part of the study region and along the Ganga corridor in the southern part.

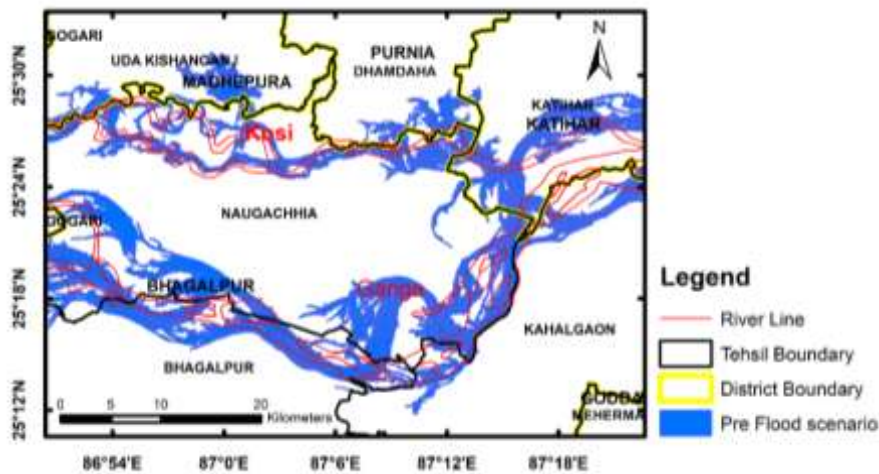


Figure – 3 Map of Pre-flood condition in Ganga and Kosi confluence zone (Prepared by Authors)

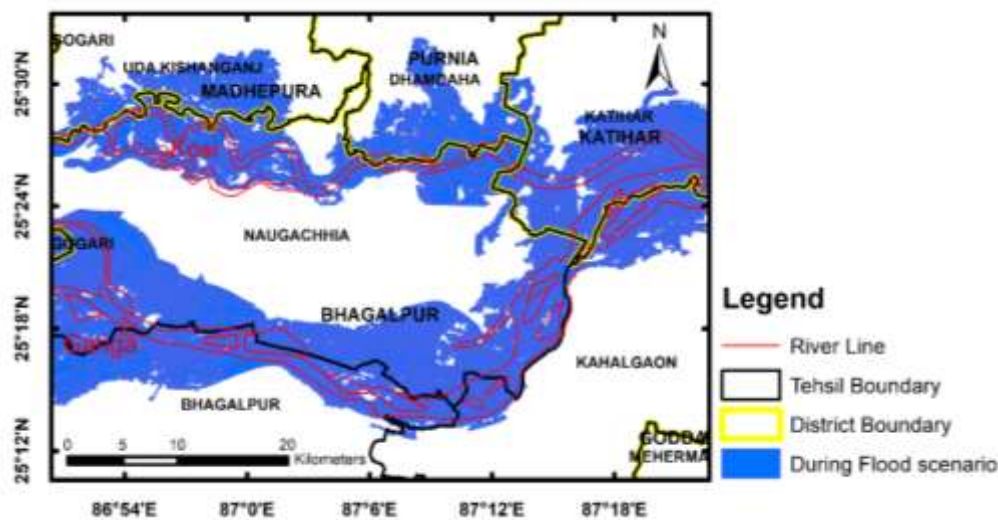


Figure – 4 Map of During flood condition in Ganga-Kosi confluence zone (Prepared by Authors)

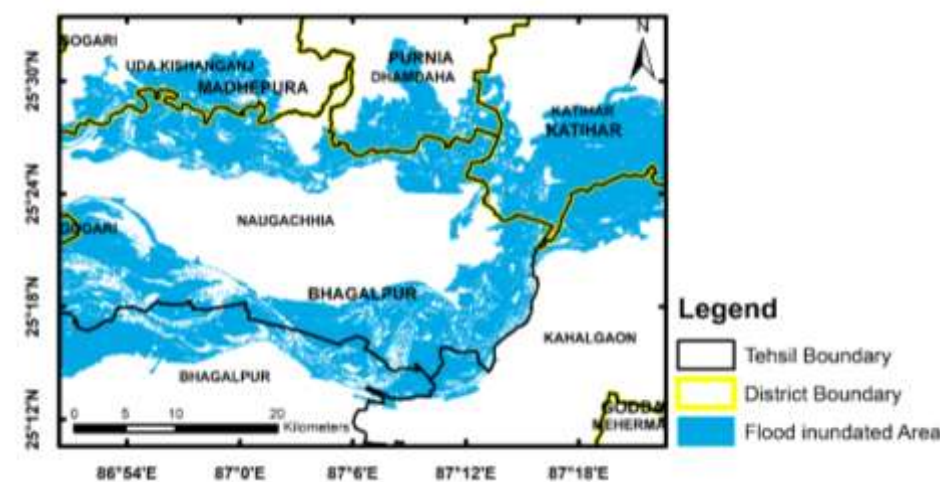


Figure – 5 Map of Flood Inundated area in Ganga and Kosi confluence Zone on 12 Sept. 2026 (Prepared by Authors).

The flood-period map therefore indicates a substantial spatial enlargement of surface-water coverage across the interconnected Kosi–Ganga floodplain. This pattern demonstrates the capability of Sentinel-1 SAR-based change detection to capture the spatial expansion of water during flood conditions, consistent with previous applications of Sentinel-1 for flood-inundation mapping in India (Sajid et al., 2025; Tiwari et al., 2020; Tripathi

et al., 2020). The mapped spatial patterns in the pre-flood and flood-period observations are also evident in the corresponding water masks.

The quantitative results further demonstrate the magnitude of this temporal expansion (Tables 1 and 2). The total mapped water/flood area increased from 358.090 km² on 19 August 2026 to 749.516 km² on 12 September 2026, representing an absolute increase of 391.425 km² (109.31%). The Ganga-associated mapped area increased from 264.156 to 501.616 km², corresponding to an increase of 237.460 km² (89.89%). In comparison, the Kosi-associated area increased from 93.935 to 247.900 km², an absolute increase of 153.965 km² (163.88%). Thus, although the Ganga accounted for the larger absolute area in both observations, the relative expansion was substantially greater in the Kosi system. The contribution of the Kosi to the total mapped area consequently increased from approximately 26.23% to 33.07%, while the Ganga contribution declined from approximately 73.77% to 66.93%. The results indicate that flood expansion occurred in both river systems, but the proportional increase was more pronounced within the Kosi corridor. Comparable spatially differentiated flood behaviour has been documented for Bihar, where proximity to the Ganga and Kosi has been associated with differences in the timing and persistence of inundation (Srivastava, 2025).

Table 1. Spatial extent of mapped water/flood area

Date	Total Area (km ²)	Ganga (km ²)	Kosi (km ²)
19-Aug-26	358.09	264.16	93.935
12-Sep-26	749.52	501.62	247.9

Table 2. Temporal change in mapped water/flood area

Parameter	19-Aug-26	12-Sep-26	Absolute Change (km ²)	Percentage Change (%)
Total Area	358.09	749.516	391.43	109.31
Ganga	264.156	501.616	237.46	89.89
Kosi	93.935	247.9	153.97	163.88

Topographic control and spatial distribution of inundation

The DEM provides an important topographic context for interpreting the observed inundation pattern. Elevation within the mapped study region ranges from approximately 8 to 174 m, with the lowest elevations concentrated along the Ganga and Kosi corridors and their adjoining floodplain surfaces. Comparatively higher terrain occurs mainly toward the southern and peripheral portions of the study region, particularly around the Bhagalpur–Kahalgau sector. The flood-inundation map shows a strong spatial correspondence between the broad low-lying riverine surfaces and the mapped floodwater, with extensive inundation occurring along the Kosi floodplain in the north and across the Ganga floodplain in the south. Moreover, the spatial distribution of inundation along the Ganga floodplain, particularly in the Bhagalpur–Kahalgau region, can also be interpreted in the context of the region's Diara landforms (Fig.6). V. Kumar et al. (2013) described the Diara lands of Bhagalpur as alluvial landscapes shaped by river meandering, channel shifting, erosion and sediment deposition, with the presence of dead and disconnected channels. These geomorphological characteristics reflect the complex organization of the Ganga floodplain and may facilitate the temporary storage and lateral redistribution of floodwater beyond the active channel.

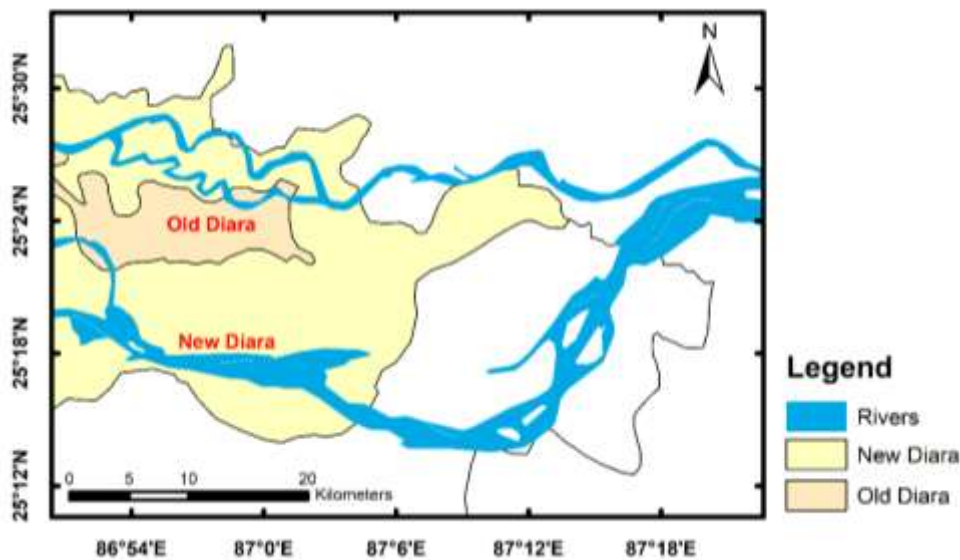


Figure – 6; Extent of Diara land in study area after V. Kumar et al. (2013).

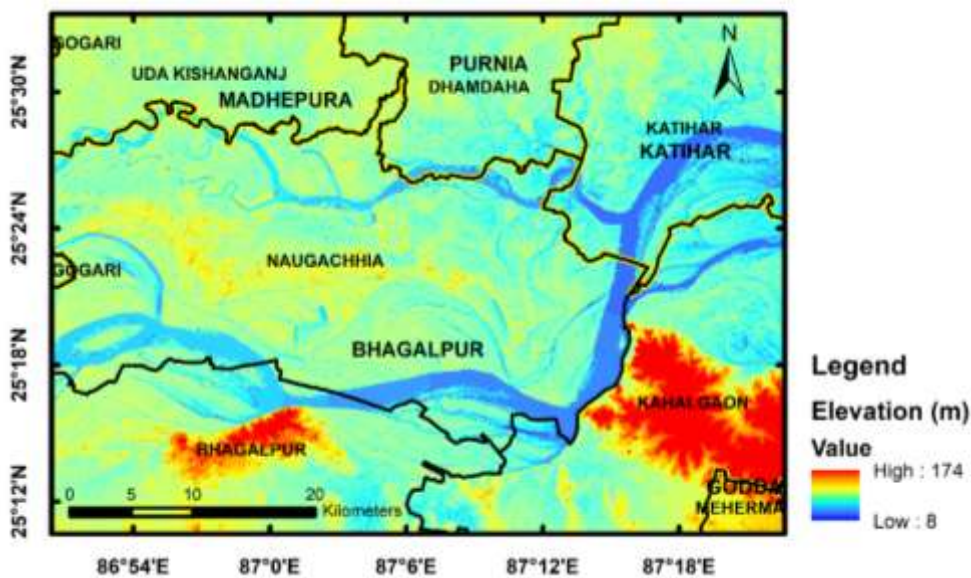


Figure – 7; Elevation map of study area (Prepared by Authors)

The correspondence indicates that local relief and floodplain morphology provide favourable topographic conditions for the lateral spreading and temporary retention of floodwater. This interpretation is consistent with several studies, which reported that the generally gentle to nearly flat terrain of North Bihar contributes to flood susceptibility and waterlogging (Bhatt et al., 2026; S. Kumar et al., 2025; Sinha et al., 2014; Tripathi et al., 2022). However, the DEM represents topographic conditions rather than the hydrological causes of the 2026 event; therefore, the observed relationship should be interpreted as a spatial association between low elevation and greater inundation susceptibility, rather than direct evidence of causation (Aryal et al., 2026; Pinheiro et al., 2024).

The spatial pattern is also consistent with the hydrological setting of the Kosi–Ganga confluence. The inundation extends beyond the present channels into broad floodplain areas, suggesting that floodwater occupied topographically connected low-lying surfaces during the event. Previous Sentinel-1-based analysis of Bihar has similarly demonstrated that floodwater can progressively expand across low-lying areas and that areas near the Ganga may experience later or more prolonged inundation during major flood episodes (Sajid et al., 2025; Tripathi et al., 2020). The present findings therefore provide spatial evidence that the September 2026 flood was not restricted to channel overflow zones but involved substantial floodplain inundation within the interconnected Kosi–Ganga system.

Hydrological context and implications of the 2026 inundation

The satellite-derived spatial expansion is supported by the available hydrological observations from the Government of Bihar. On 17 September 2026, the observed water levels at the Vijay Ghat Bridge and Kursela stations on the Kosi, and at Bhagalpur and Kahalgaon on the Ganga, were reported above their respective danger levels, with decreasing trends indicated for the first 24 hours. This hydrological information provides supporting evidence that elevated river stages persisted in both river systems around the flood-period observation. The concurrence of expanded satellite-derived water extent and elevated river stages highlights the interconnected nature of flood dynamics within the Kosi–Ganga confluence zone. Similar importance of river proximity and river discharge in determining the spatial and temporal behaviour of Bihar floods has been analysed by Srivastava (2025) while Sajid et al. (2025) demonstrated the utility of Sentinel-1 time-series observations for monitoring flood progression in the Lower Ganges Basin.

Overall, the results demonstrate a more than twofold expansion of mapped water/flood area between the two observation dates, with substantial inundation extending across the floodplain of both river systems. The larger relative increase in the Kosi-associated area indicates pronounced spatial expansion within the Kosi floodplain, whereas the Ganga remained the dominant contributor to the total mapped water extent. The combined interpretation of the flood maps, quantitative area statistics, DEM and hydrological observations indicates that the September 2026 event produced extensive floodplain inundation within the Kosi–Ganga confluence region. These findings reinforce the usefulness of multi-date Sentinel-1 observations for rapid spatial assessment of flood dynamics in riverine environments where cloud cover can limit optical satellite observations. Previous studies have similarly demonstrated the effectiveness of Sentinel-1 SAR for rapid flood delineation and temporal monitoring in India (Sajid et al., 2025; Vekaria et al., 2022)

Subsequent hydrological observations provide additional context for the persistence of elevated river conditions following the satellite observation period. The official water-level and flood forecast data issued by the Government of Bihar for 17–19 September 2026 indicate that water levels remained above the respective danger levels at all four monitoring stations considered in the study: Vijay Ghat Bridge and Kursela on the Kosi, and Bhagalpur and Kahalgaon on the Ganga. On 17 September, the observed water levels were 31.73 m at Vijay Ghat Bridge, 31.02 m at Kursela, 33.91 m at Bhagalpur and 32.21 m at Kahalgaon, compared with respective danger levels of 31.00, 30.00, 33.68 and 31.09 m (Table 3). The forecast data for 18 and 19 September also retained the stations above their respective danger levels, although a decreasing trend was indicated. Because these gauge observations post-date the 12 September satellite observation, they are not used to validate the mapped inundation extent; rather, they provide independent hydrological context indicating that elevated river stages persisted after the analysed flood-period image.

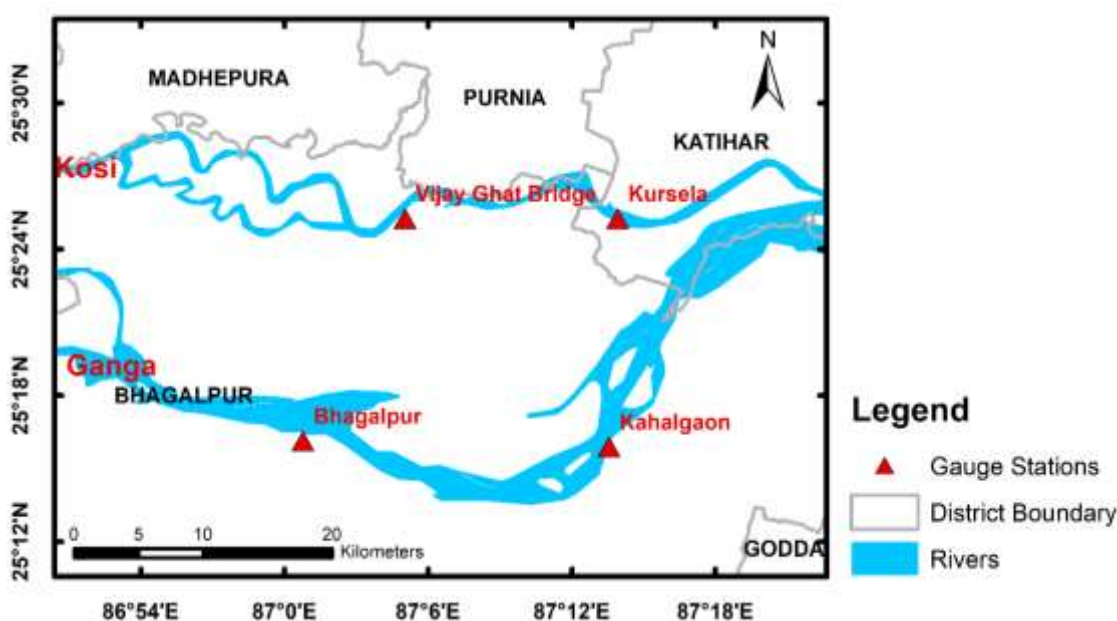


Figure -8 Location of Gauge stations in study area

Table 3 Water level data at different gauge stations

Sl. No.	River	Site/Station	District	Danger Level (m)	H.F.L. (m)/Year	Today's Observed WL at 8:00 AM (m)	Forecast 17-09-2026 (m)	Forecast 18-09-2026 (m)	Forecast 19-09-2026 (m)	Trend	Remarks
1	Kosi	Vijay Ghat Bridge	Bhagalpur	31	33.50/NA*	31.73	31.73	31.69	31.65	D	Above DL
	Kosi	Kursela	Katihar	30	32.10/82	31.02	31	30.94	30.89	D	Above DL
2	Ganga	Bhagalpur	Bhagalpur	33.68	34.86/2021	33.91	33.91	33.85	33.81	D	Above DL
	Ganga	Kahalgaoon	Bhagalpur	31.09	32.87/2003	32.21	32.21	32.16	32.11	D	Above DL

Note: Observed water levels were recorded at 8:00 AM on 17 September 2026, while forecasts cover 17–19 September 2026. “Above DL” indicates levels exceeding the danger level, and “D” denotes a decreasing trend. Gauge data provide subsequent hydrological context and do not directly validate the inundation mapped on 12 September 2026.

CONCLUSION

The present study demonstrates a substantial spatial and temporal expansion of flood-related surface water within the Kosi–Ganga confluence zone of eastern Bihar during August–September 2026. Sentinel-1 SAR-based analysis indicates that the mapped water/flood area increased from 358.090 km² on 19 August 2026 to 749.516 km² on 12 September 2026, representing an increase of 391.425 km² (109.31%). The Ganga-associated area increased by 89.89%, whereas the Kosi-associated area increased by 163.88%, indicating a considerably greater proportional expansion along the Kosi floodplain. Spatially, the floodwater extended beyond the active river channels into adjoining low-lying floodplain surfaces, particularly along the Kosi corridor and the Ganga floodplain. The DEM further indicates that these inundated areas are predominantly associated with relatively low-elevation terrain and diara land, highlighting the importance of floodplain topography in controlling the spatial distribution and lateral spread of floodwater.

The observed inundation pattern is likely to reflect the combined influence of elevated river stages, low-gradient floodplain morphology, and the hydrological connectivity of the Kosi–Ganga system. The available Government of Bihar observations subsequently recorded water levels above the danger levels at Vijay Ghat Bridge and Kursela on the Kosi and Bhagalpur and Kahalgaoon on the Ganga during 17–19 September 2026, providing supporting evidence of sustained elevated river conditions after the satellite observation period. However, these later gauge observations cannot be considered direct validation of the 12 September inundation extent. Previous studies have similarly highlighted the susceptibility of the low-relief floodplains of North Bihar to inundation and the importance of the Ganga–Kosi river system in shaping flood dynamics. The present study therefore identifies topographic setting and river-stage conditions as important contributing factors, while the relative contributions of rainfall, upstream discharge, channel capacity, backwater effects and other hydrological processes require higher-frequency rainfall, discharge and water-level observations for definitive attribution. Overall, the study demonstrates the utility of multi-date Sentinel-1 SAR observations for rapid assessment of flood expansion in the Kosi–Ganga confluence zone and provides a spatial baseline for subsequent flood-risk, exposure and vulnerability assessment.

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