

Land Area Reclamation & Expansion In Mahakumbh-2025, India: A Case Study

Sujeet Kumar Singh¹. Upendra Singh². Anil Garg³. Anurag Yadav^{4*}. Raj Mohan Singh⁵

¹Executive Engineer Barrage, Mechanical Maintenance, Division, Varanasi, Uttar Pradesh, India; Email: ee.barragemechvaranasi@gmail.com

²Chief Engineer, E&MM Lucknow, Uttar Pradesh, India; Email: upendraupid@gmail.com

³Principal Secretary, Irrigation Department, Uttar Pradesh, India; Email: garganil1971@gmail.com

⁴Research Scholar, Civil Engineering Deptt., MNNIT Allahabad, Prayagraj, Uttar Pradesh, India, 211004; Email: anuragyadava123@yahoo.com (*Corresponding Author)

⁵Professor, Civil Engineering Deptt., MNNIT Allahabad, Prayagraj, Uttar Pradesh, India; Email: rajm@mnit.ac.in

Abstract

Mahakumbh-2025, held in Prayagraj Sangam, India, is the world's largest religious gathering. Millions of devotees took a holy dip at Sangam, the confluence of the Ganga, Yamuna, and Saraswati rivers. The highest concentration of pilgrims is expected at Sangam Nose, the precise meeting point of the rivers. To ensure adequate space for movement and proper water depth for rituals, geospatial technology was employed to analyze the Ganga's approach to the Sangam Nose. Satellite imagery using ArcGIS showed that during Ardhkumbh-2019, the Ganga bifurcated into three streams upstream, shifting towards the right bank and widening by 200–500 meters. This reduces circulation space, impacting the bathing area. To counter this, the authorities developed a Digital Elevation Model (DEM) to assess contours and elevation for dredging and material disposal for reclamation and expansion of the area. Utilizing information of dredging and dumping, the three bifurcated streams were merged into a single channel, improving water depth for dipping and reclaiming 32 hectares of circulation space near Sangam Nose. For Mahakumbh-2025, a total area of 4,000 hectares will be used to accommodate 650 million devotees, as per the state government of Uttar Pradesh, India. This strategic intervention not only enhances space for pilgrims but also serves as a model for flow channelization projects worldwide.

Keywords: *Triveni Sangam, Mahakumbh-2025, Satellite Imagery, Dredging, Area Expansion*

1. INTRODUCTION

The Maha Kumbh Mela is the most significant religious event and a grander form of the Kumbh Mela, celebrated once every 144 years—equivalent to 12 cycles of the 12-year Kumbh Mela cycle—coinciding with a unique celestial alignment [1]. The Maha Kumbh Mela, a festival rooted in Hindu mythology, is the world's largest gathering and a profound act of faith, where saints, sadhus, sadhvis, kalpvasis, and pilgrims from all around the world come to take a holy dip at Sangam Triveni in Prayagraj, India.

Fluvial remote sensing is an emerging discipline that integrates river science, remote sensing, and geospatial technologies, offering significant potential to reconstruct fluvial dynamics across various temporal and spatial scales, supported by the growing availability of remotely sensed environmental data [2-4]. Temporal analysis of fluvial path aids in understanding past changes, assessing process rates, and guiding sustainable river management and restoration [5]. In a study ArcGIS and Google Earth Engine are used to analyze Landsat satellite imageries (1999–2023), extracting river flow path and improving water body detection accuracy [6]. The Vietnamese Mekong Delta has undergone significant morphological changes over the past 30 years, with severe riverbank erosion and islet accretion causing major agricultural losses and economic damage, highlighting the vital role of satellite imagery and GIS in sustainable river management [7]. The flow path changing of the Ganges River in Bangladesh was analyzed by a study using satellite images from 1973 to 2009, which showed significant bankline movement, with the left bank being prone to accretion and the right bank to erosion, largely due to the erodibility of riverbank materials. Over time, the river's width and island area were fluctuated, ultimately being increased due to net erosion, with a high erosion rate being influenced by seasonal discharge variations [8]. A procedure to analyze the temporal evolution of river morphology is presented using remote sensing and satellite imagery data. Measurements of surface classifications, channel widths, centerline lengths and sinuosity indices were derived from LANDSAT, CORONA, Sentinel-2, aerial photos and DEM for three dynamic Albanian rivers. The results with minimal deviation from expert reference data, highlight the method's potential for monitoring river changes and for the development of automatic tracking systems for future studies [9]. Better understanding is required for the management of long-term river morphology

changes caused by human activities natural processes. A 58-year dataset of Tedor River, Japan, was analyzed in a study, and 5-phases of vertical adjustment influenced by sediment extraction and dam construction were revealed, with alternating aggradation and degradation phases shown by the results, incision linked to narrowing and deposition to widening, while a braided pattern was exhibited by the river from 1950–2000 [10]. The sequential flow path dynamics of Brahmaputra rivers are reported by a study using Landsat images from 1976 and 1987–2016 in ArcGIS environment, in which dominant geomorphic agents such as distributary activities, meandering, breaches, avulsions, and confluence migrations are revealed by the analysis, with the upper stretch (Simen, Gai, Jiadhal) being identified as the most active. A crucial foundation for riverine management in this water-troubled region is provided by the findings [11]. Natural and human activities cause morphological changes in channels, requiring both planform and vertical assessments. A study investigated Dry Creek's morphology using high-resolution remote sensing, revealing a southwest channel shift of up to 478 m and net deposition of 3.4–3.6 cm from 2018 to 2022 [12].

Land reclamation has historically supported agriculture, urbanization, and industrialization, with recent globalization driving coastal projects [13]. In a study leveraged remote sensing and machine learning used to evaluate wetland restoration near the Mississippi River's Southwest Pass, showing a 30 km² land recovery with 85% classification accuracy. The findings highlight the effectiveness of dredged material use and advocate for continuous innovation in coastal restoration efforts [14]. Large, low-lying rivers serve various societal purposes but face numerous disturbances. The Apalachicola River in Florida saw significant sand bar enlargement due to dredging, followed by passive recovery as vegetation regrew. To accelerate restoration, willow stakes were planted, showing synergies between natural recovery and active intervention, offering insights for future river restoration projects [15]. A study evaluates eco-friendly dredging using nature-based solutions to improve fish habitat quality while achieving flood control. Results highlight habitat defects and suggest tailored dredging methods to enhance river continuity and reduce flood risk [16]. Navigation channels are crucial for inland transport, requiring sediment excavation to enable navigation in braided rivers. A study assesses the feasibility of dredging mid-sand bars in the Brahmaputra River, analyzing heavy metal contamination at 42 locations over 600 km [17]. Deltaic channels are crucial pathways linking rivers and the ocean, influencing estuarine stability and material transport. In the anthropocene, these channels have undergone dramatic changes due to reduced sediment supply, dredging, and storm-induced filling. Analysis of North Passage (NP) in the Changjiang Estuary (1979–2020) reveals distinct morphodynamical stages, long-term channel deepening, periodic volume fluctuations, and the influence of engineering works on erosion and deposition patterns [18]. A study examines the impacts of dredging and land reclamation in Pengerang, Malaysia, revealing that affected villagers experienced negative consequences from a petroleum hub project, emphasizing the need for improved monitoring and management [19].

The literature related to river morphology assessment and the importance of dredging in river and coastal regions illustrates that it has a wide scope in land reclamation and the expansion of wetlands for better utilization. This study presents a novel case study on the morphological changes of the Ganga River, focusing on dredging work undertaken to shift the river's path and expand the circulation area for the Maha Kumbh 2025 in Prayagraj, India. The selection of dredging and material dumping sites was based on area expansion regions and the lowest and lower elevation areas identified from a contour map generated using DEM. River channelization through dredging was carried out along a path length of 2,600 meters. In a 1,600-meter section, a width of 150 to 200 meters was maintained, while in a 1,000-meter section, a width of 30 meters was preserved. Four heavy dredgers were deployed for this work. The dredged material was disposed of through discharge pipes at distances ranging from 250 to 500 meters, depending on requirements. The Ganga River had naturally shifted its course, splitting into three streams between Shastri Bridge and Sangam Nose, which posed a challenge in organizing the Maha Kumbh 2025. Through dredging, the three streams of the Ganga River were successfully merged into a single unified channel, ensuring better flow and circulation.

2. Method & Materials

2.1 Study Area

The study site is located in the Sangam region of Prayagraj district, Uttar Pradesh, India. It extends from the downstream of Shastri Bridge to Sangam Nose and continues 1,400 meters further downstream from Sangam Nose. The geographic coordinates of the study area range from longitude 81°51'30" E to 81°55'30" E and latitude 25°25'00" N to 25°27'00" N, as shown in Fig. 1.

The Ganga River holds immense religious significance in Hinduism and is considered a tirtha—a sacred crossing between heaven and earth. It is deeply revered and believed to possess the power to purify both the body and soul. Flowing approximately 2,525 km eastward through India and Bangladesh, the river ultimately empties into the Bay of Bengal. The Ganga is joined by several major tributaries, including the Yamuna, Ramganga, Ghaghara, Gandak, Kosi, Mahananda, and Sone. Its basin is one of the most densely populated regions in the world. At Prayagraj, the Yamuna and the invisible Saraswati converge with the Ganga at a sacred confluence known as Sangam. At the study site, the Ganga River flows with a steep gradient from Shastri Bridge to Sangam Nose, resulting in a high-velocity water current. Following Ardh Kumbh 2019, the river deviated from its natural course, shifting towards the right side. This shift reduced the circulating area and bathing space while also eroding the existing Sangam Nose from 2019, posing a significant challenge for organizing Mahakumbh 2025. This deviation was the primary reason for selecting the site for the study. The study area is located in the Sangam region of Prayagraj, which is a crucial location for hosting Mahakumbh 2025.

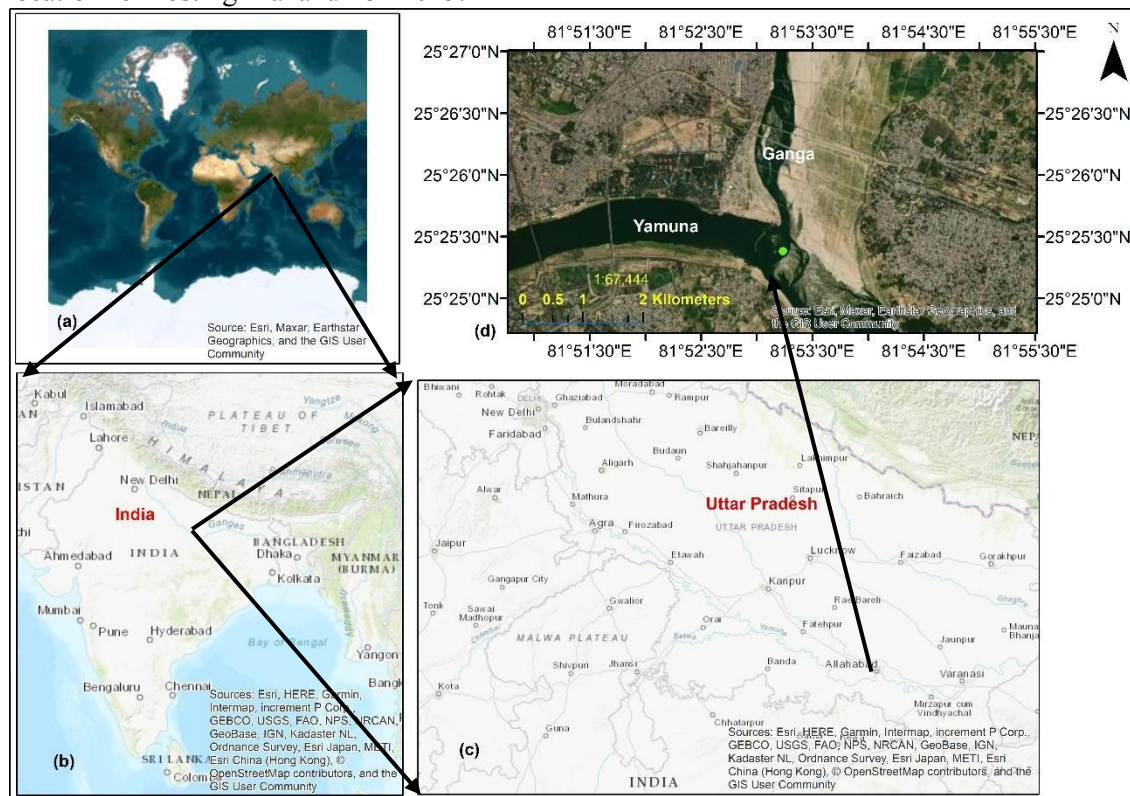


Fig.1 Ganga, Yamuna and Invisible Saraswati River confluence Sangam Region map: (a) World; (b) India; (c) Uttar Pradesh (UP) a state of India; (d) Sangam at Prayagraj UP

2.2 Data Requirement

The flow path changes in the River Ganga at the Triveni Sangam area from 2019 to 2024 are by this study. Necessary thematic maps and riverbank change maps are included. The analysis is begun with a detailed assessment of the river's morphology as it is flowed through the Sangam nose area, with a particular focus on riverbank migration. The morphological characteristics of the river were analyzed through the preparation and examination of a series of satellite-based thematic maps. Satellite imagery of 2019, 2020, 2021, 2022, 2023 and 2024 of sangam area were analyzed to observe changes in river flow path. Relevant data was obtained and interpreted using GIS and remote sensing tools. A detailed assessment of the river's dynamics and transformations over time was provided by this approach, enhancing the understanding of its behavior and supporting the development of effective riverbank protection strategies. The Multispectral Instrument (MSI), which captures high-resolution images across a broad range of spectral bands, is equipped on the Sentinel-2 satellite, which is part of the European Space Agency's Copernicus program. Imagery with spatial resolutions of 10 m, 20 m, and 60 m is provided, depending on the spectral band, enabling detailed observation and analysis of land and water surfaces.

The process of bathymetry measuring and mapping the underwater topography of a study area to generate

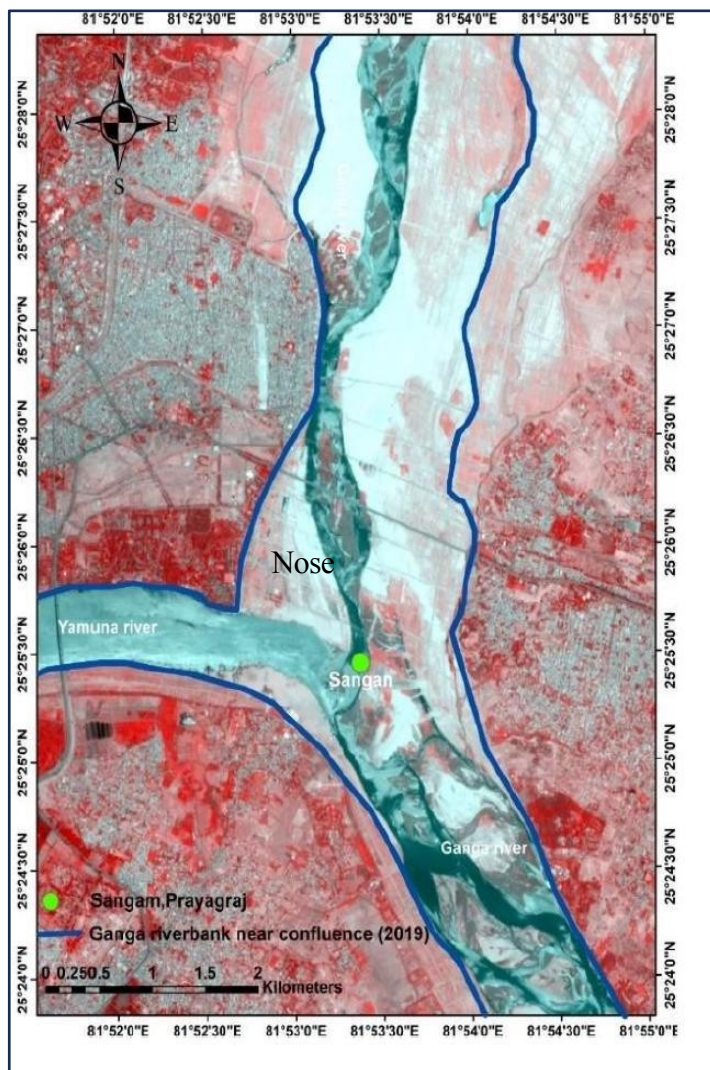
a DEM. Detailed analysis of depth and contours of the riverbed are provided by this method. In this study, bathymetric data was obtained through hydrographic and LiDAR surveys conducted by the Mela authority. High-precision elevation data is captured by these surveys, which is crucial for understanding the underwater terrain and for planning and designing effective river management and training projects. The elevation differences are revealed by the DEM of the Sangam area, and a contour map of the study area can be generated using it. Suitable locations for dredging and dumping may be identified with the assistance of this map. Once dredging path and dumping site finalized the dredging work using four dredgers has been started.

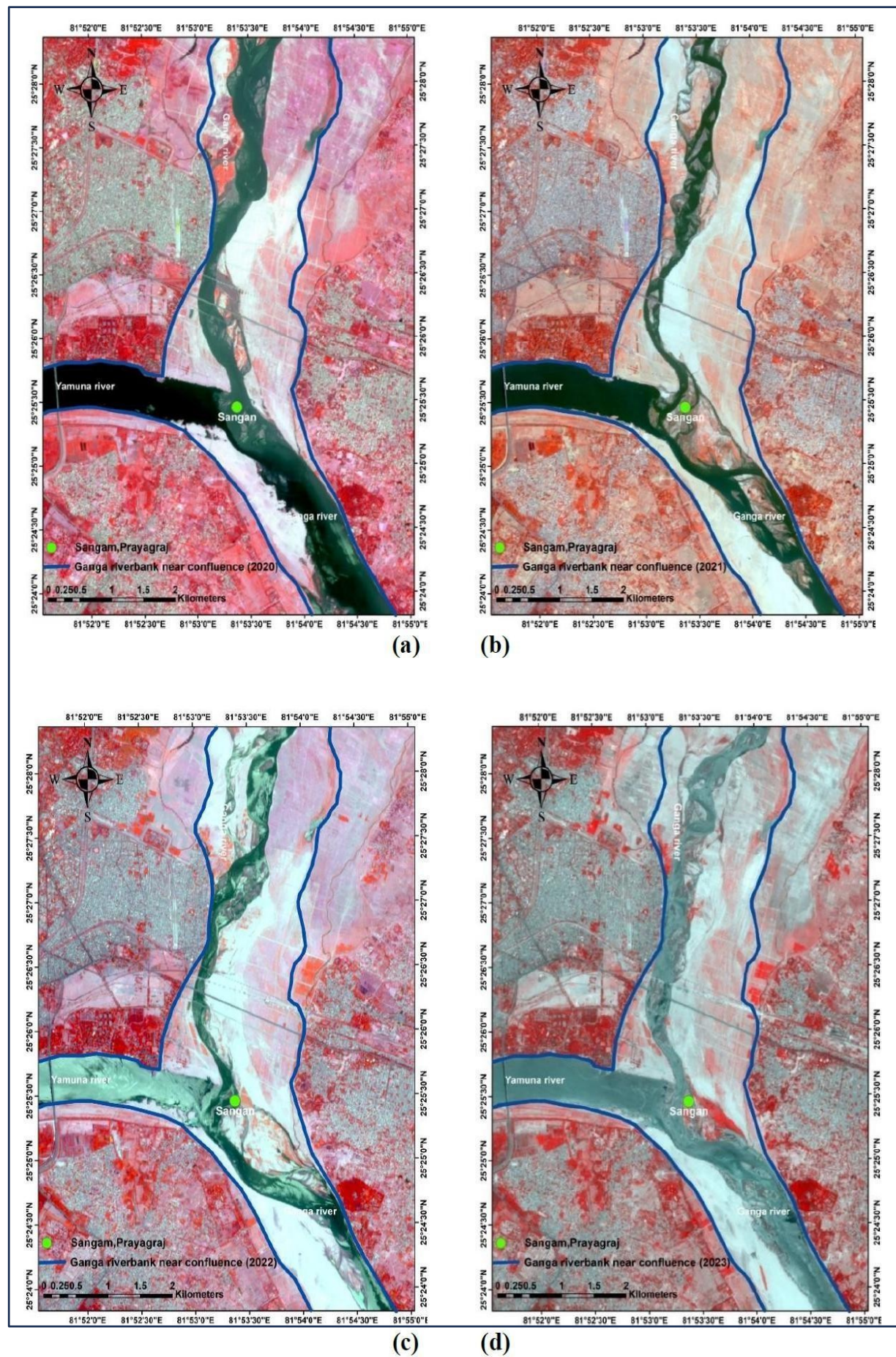
3. RESULT AND DISCUSSION

In this study, the variation in the flow path of the Ganga River from 2019 to 2024 has been analyzed. A contour map has been created to understand the elevation profiles, aiding in the finalization of the dredging path and the formation of a nose at Triveni Sangam. The study utilized satellite imagery collected over a five-year period from 2019 to 2024, specifically focusing on January, when floodwaters usually subside. Triveni Sangam from 2019 to 2024 is presented in Fig. 2 and Fig. 3 (a-e).

The 2019 image served as the reference for georeferencing subsequent images, ensuring spatial consistency. GIS software was utilized for classification and segmentation, focusing on isolating the riverbanks and the Sangam Nose area. This study explores the temporal evolution of erosion dynamics and quantifies the extent of land loss in the Sangam Nose region.

Fig. 2 River Bankline near Sangam in 2019





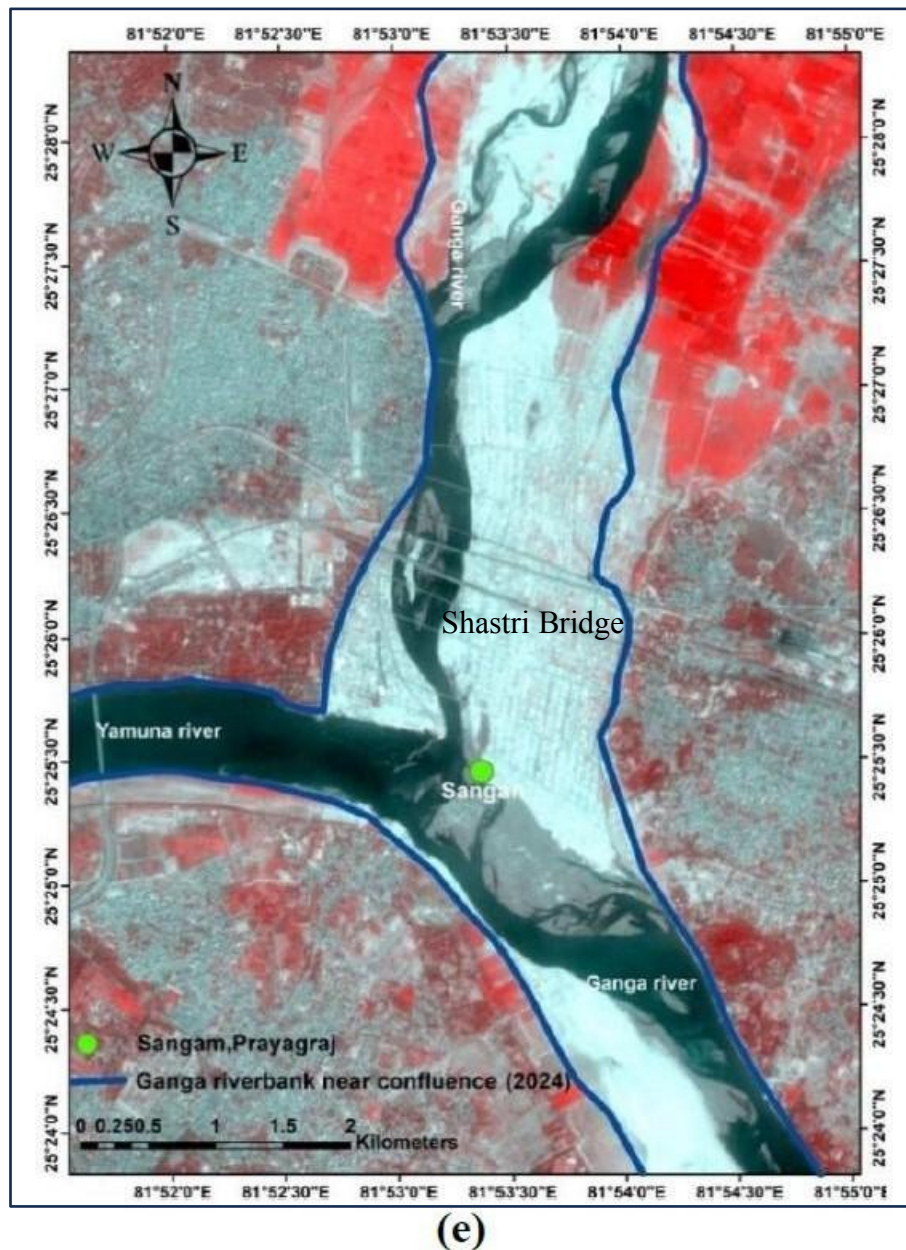


Fig. 3 River Bankline delineation near Sangam: (a) 2020; (b) 2021; (c) 2022; (d) 2023; (e) 2024

The nose area highlighted in Fig. 2 is consistently present in all figures, which were analyzed in GIS to assess changes in area and river path. The Table 1 reveals a substantial reduction in the size of the Sangam Nose area from 2019 to 2024, with an estimated loss of approximately 30% of its original area. This concerning trend emphasizes the Sangam nose area's susceptibility to fluvial processes and underscores the urgent need for mitigation measures.

Table 1. Quantitative analysis of Sangam Nose area changes from 2019 to 2024

Sr. No.	1	2	3	4	5	6
Year	2019	2020	2021	2022	2023	2024
Nose Area (Ha)	102.2	86.6	86.2	74.3	71.5	71.2
% Area lost from 2019		15%	16%	27%	30%	30%

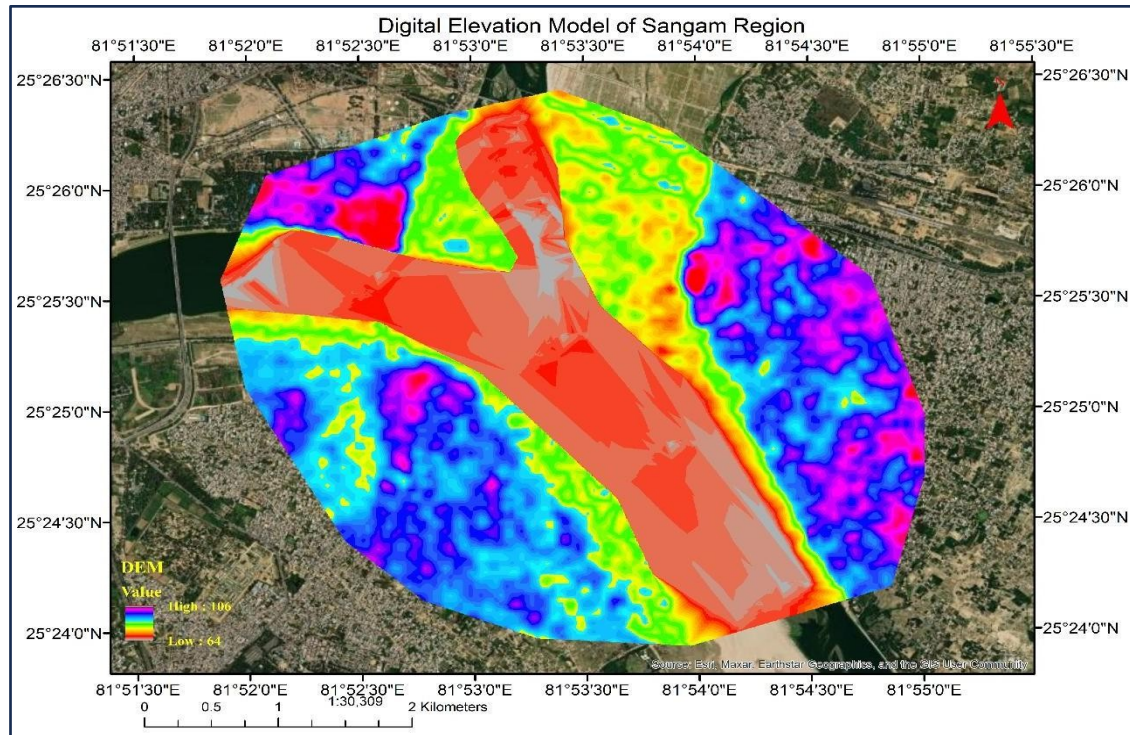


Fig. 4 Digital Elevation Model of Sangam Region

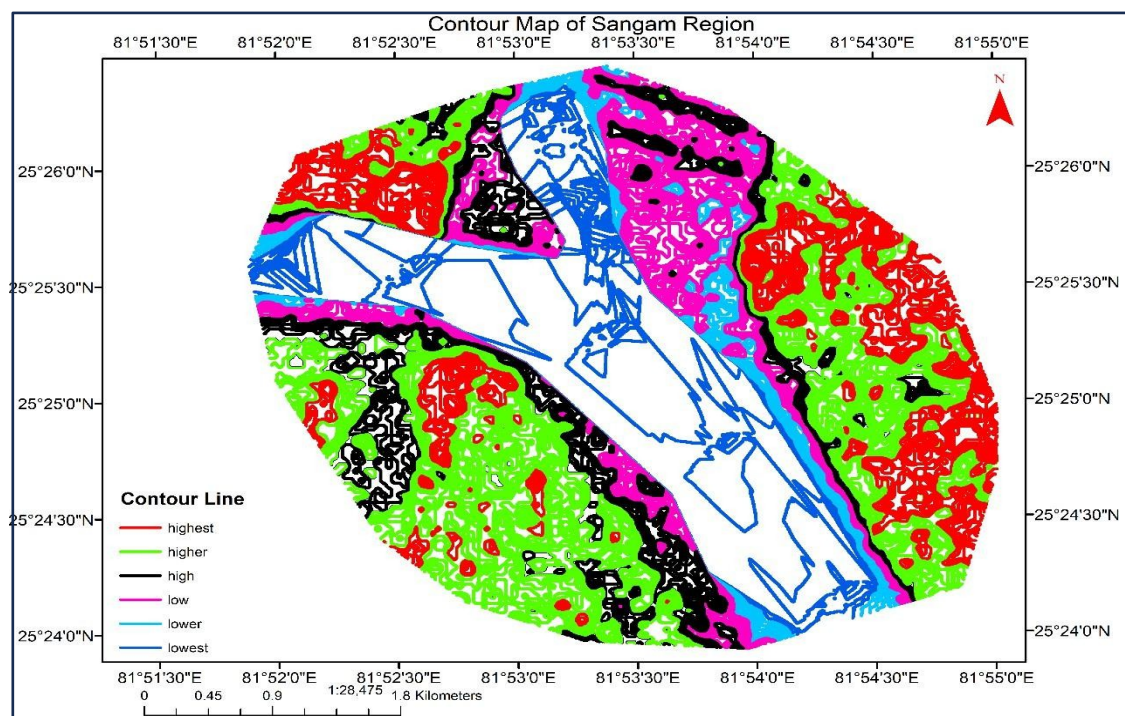


Fig. 5 Classified Contour lines of Sangam Region

To determine the lowest point of the river, an elevation map is essential. Since the river's path changes from year to year, freely available DEM data is not highly useful for this study, especially given that the best available resolution is 12.5×12.5 m. Therefore, to accurately analyze the elevation of the region, a DEM was constructed using LiDAR technology. The DEM used in this study has a resolution of 4×4 m, with elevation values ranging from 64 m to 106 m, as shown in Fig. 4. A contour map of the study area was created using the Spatial Analyst tool in the ArcGIS platform. The contour lines were classified into six elevation categories: lowest (64–70 m), lower (71–76 m), low (77–82 m), high (83–88 m), higher (89–94 m), and highest (95–106 m), as shown in Fig. 5.

Based on the classification of the contour map, the lowest elevation of the area has been identified, and the exact elevation profile has been analysed. From the 2024 imagery, as shown in Fig. 3(e), it is evident

that near Shastri Bridge, the river has three bifurcations, occupying a large area. This needs to be reduced to a single channel with the appropriate depth, which will help manage crowd movement and provide sufficient water for the holy bath. By identifying the lowest point from the contour map, a suitable starting point for dredging has been determined. This will allow the water to follow the lowest path naturally, while the dredged material can be used for land reclamation and the extension of the circulation area. Based on the imagery, contour map, and requirement the dredging path and Sangam nose has been decided, as shown in Fig. 6. Further dredging and dumping operations have been carried out using dredgers, and the river depth has been maintained and checked using echosounder as shown in Fig. 7. The Sangam nose area of 2 hectares is also constructed using dredged material as shown in Fig.6. Sangam nose periphery around east west north and south expanded by using huge dredger machine by the process of dredging. Sangam nose expanded 2 hectare which significantly increases bathing area with all facility. Sangam nose having high spiritual value, after expansion 2 lakh devotees to bath at a time compared to the 50000 devotees who could bath in 2019. The depth of the right-side stream, which had to be blocked, was measured using an echosounder and found depth range from an average of 3.0 meters to 7.0 meters.



Fig. 6 Dredging path and Nose preparation



Fig. 7 Depth of River using Echosounder

The dredged material is carried away a distance of 250 to 500 meters towards the right side. As a result, the right-side has silted due to the dredged material. From Shastri Bridge to Sangam Nose, spanning 1,400 meters with an average width of 200 meters, the right-side area has been reclaimed.

The right bank was reinforced by depositing dredged material to improve the circulation area, while the river was redirected towards the left bank through dredging, unifying it into a single stream, as illustrated in Fig. 8. The average depth was measured using an echosounder.

There are limitations to this study, as future flooding events may alter the current conditions, potentially requiring similar efforts to be repeated. As an example, the Johor River Estuary has undergone significant environmental degradation from 1973 to 2017 due to extensive construction land sprawl and reclamation driven by dredging or human activities, emphasizing the need for improved coastal planning and management [20].



Fig. 8 Drone view of before and after dredging of Ganga River from upstream shastri bridge

4. CONCLUSIONS

In this study, geospatial technology was utilized alongside dredging and channelization work to ensure a uniform stream depth, enabling greater land reclamation and an expanded circulation area for Mahakumbh-2025. Satellite imagery from Ardhkumbh-2019 to 2024, spanning six years, was thoroughly analyzed to assess riverbank changes. The analysis revealed that the river had been shifting towards the right bank, resulting in an approximate 30% reduction in the circulation area near Sangam Nose. A Digital Elevation Model (DEM) of the region indicated an elevation variation of 42 meters, which was classified into six categories. The lowest elevation areas were identified as priority zones for starting of dredging. Additionally, the three bifurcations of the Ganga near Shastri Bridge were unified, and the central depth was maintained at approximately 5.0 m to ensure proper water flow and stability. As a result of these efforts, 32 hectares of land were successfully reclaimed and extended to enhance circulation for devotees. Sangam nose is also created which enhances two hectares of land for holy bath. Furthermore, a total of 4,000 hectares in the Sangam area was allocated to accommodate the large influx of pilgrims during the holy dip at Mahakumbh-2025. This study provides valuable insights into managing low-lying areas for temporary settlements and ensuring sustainable planning for large-scale religious gatherings.

Declaration

Compliance with Ethical Standards	The authors were compliant with the ethical standards.
Funding	Not Applicable
Conflict of Interest	The authors declare that they have no conflict of interest.
Ethical Approval	Not applicable
Informed Consent	Not applicable.
Data Availability	Data will share on request

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