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IPSA-Kumbh: Mapping Impact of Floating Population on Sewerage during Maha Kumbh 2025

National Mission for Clean Ganga (NMCG)
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This report, “IPSA-Kumbh: Mapping the Impact of Floating Population on Sewerage during Maha Kumbh 2025”, presents the findings of a study on water quality during the world’s largest religious congregation, held at the confluence of the rivers Ganga, Yamuna, and Saraswati. It provides a comprehensive assessment of water quality and modelling for the Ganga and Yamuna, along with an analysis of flow behavior and pollution load under different discharge scenarios, with a particular focus on the Prayagraj region. In addition, the study includes infrastructure assessment, remote sensing analysis, DPSIR framework development, and socio-cultural aspects related to Water, Sanitation and Hygiene (WaSH) services of Kumbh.

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Executive Summary

Kumbh is one of the largest Sanatani Hindu religious celebrations that attract large numbers of devotees and visitors from across the world. Managing this massive influx of pilgrims and their ritual activities, while ensuring that river water quality remains suitable for bathing and other rituals, poses a major challenge for the Kumbh Mela authorities. IPSA-Kumbh project (*Mapping the Impact of Floating Population on Sewerage during Maha Kumbh 2025*) focuses on the following objectives:

1- Mapping Kumbh Mela infrastructure related to floating population contributing to sewerage, using 2D and 3D GIS-based mapping.
2- Measuring and mapping river water quality parameters using field measurements and remote sensing algorithms, pre-, during-, and post-Kumbh.
3- Detecting sewerage hotspots by spatially modelling the impact of sewerage infrastructure, and stakeholder awareness on the river water quality through the WaSH approach and develop a K-WaSH framework.
4- Developing a GIS-dashboard for hotspot mapping to mitigate the impact of the floating population on water quality.

In line with these objectives, the chapter plan of this report is as follows. Chapter 1: Introduction, rationale of the study, and methodology; Chapter 2: Mapping the impact of floating population on river water quality; Chapter 3: Geospatial data for Infrastructure mapping; Chapter 4: River water quality monitoring using remote sensing and in-situ measurements; Chapter 5: Hydrodynamic and water quality modelling using HEC-RAS; Chapter 6: Socio-cultural aspects of Kumbh and development of K-WaSH framework.

Workflow and Findings:

Chapter 1: Introduction, rationale of the study, and methodology:

1- This report examines how the Maha Kumbh 2025 at Prayagraj affected the sewerage system and river water quality of the Ganga and Yamuna. The 45-day event (13 January–26 February) drew an estimated 660 million pilgrims, placing very high operational demand on both permanent and temporary arrangements for water supply, sanitation and wastewater management, with systems functioning close to their designed capacity during peak periods, aggravating long-standing pollution challenges in the Ganga basin.
2- The IPSA-Kumbh project addresses this challenge through an integrated, spatial approach. It maps Kumbh-related infrastructure (tents, toilets, roads, pontoon bridges, ghats, parking

areas etc.) using very high-resolution satellite data and deep-learning based algorithms. The study monitors river water quality before, during, and after the event, and identifies sewerage "hotspots" where infrastructure stress and water quality deterioration are most severe. In parallel, a K-WaSH (Kumbh–Water, Sanitation and Hygiene) framework is developed based on stakeholder surveys to capture practices, perceptions and service gaps. The outcomes include a GIS-based dashboard to guide future planning and policy for Maha Kumbh and similar large religious gatherings.

Chapter 2: Mapping the impact of floating population on river water quality:

1- In this study, water samples were collected 29 times across three phases: Pre-Kumbh, During Kumbh, and Post-Kumbh between 16th December 2024 and 24th March 2025. The samples were collected from sixteen (16) sampling sites (SP 1 to SP 16), covering upstream control points, major bathing ghats, and downstream stretches. Ten (10) physicochemical parameters were analysed: Water Surface temperature (WST), pH, Turbidity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Nitrate, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Chlorophyll-a.

2- Based on the spatial and temporal variation of these parameters, derived from the heat maps and interpolated geospatial maps, during the sampling period, it was found that pH, BOD, and COD showed a modest increase on major bathing days during Kumbh at SP 9 (Sangam region), with cumulative downstream effects observed at SP15 and SP16. Sector-wise population density corresponded with expected short-term fluctuations in water quality indicators during peak days. DO was negatively correlated with BOD, COD, and temperature, while remaining above the minimum level required for outdoor bathing and river health. Nitrate levels were continuously high in the Yamuna River, indicating a post-organic degradation process. The Sangam area showed a temporary increase in nutrient indicators during peak activity periods, which gradually dispersed downstream. Chlorophyll a showed a positive relationship with indicators of organic pollution and hence can be linked with organic waste generated during ritual offerings. The data also showed that the self-cleaning processes require more time to fully restore river conditions after the sudden surge in mass gatherings. In addition, larger volumes of water discharge are needed to dilute pollution during the major bathing days to maintain the water quality.

3- The findings highlight that, while the river demonstrates an inherent capacity for partial recovery post-event, the scale of pollutant loading during the Kumbh poses a considerable

challenge to its assimilative capacity. The study underscores the urgent need for proactive measures, including enhanced sewage treatment infrastructure, regulated discharge management, timely flow augmentation from upstream barrages, and sector-wise monitoring strategies. Implementation of such measures can mitigate peak-event water quality deterioration, protect aquatic biota, and safeguard public health.

4- A higher number of temporary wastewater treatment setups (eg, STPs and Geo-tubes), along with nature-based treatment approaches (constructed wetlands), were used to treat a high volume of domestic wastewater. More accurate predictions of the floating population can support freshwater discharge planning to maintain water quality for outdoor bathing and other ritual activities. Further, adequate sanitation facilities and sufficient volunteers (Safai Mitras and Ganga Sewa Dost) are essential for collecting worship waste, including biodegradable organic debris (such as flowers, garlands, and food items) and non-biodegradable materials (such as plastic wrappers and bottles) left by pilgrims. Continuous, real-time water quality monitoring can provide immediate assurance of safety for pilgrims and issue timely alerts to water management authorities.

Chapter 3: Geospatial data for Infrastructure mapping:

1- A geospatial and AI-enabled farmwork has been developed to map infrastructure and LULC change relevant to the temporary city created for Maha Kumbh 2025. A detailed geospatial database of tents, toilets, roads, pontoon bridges, ghats, parking areas and administrative sectors over roughly 4,000 hectares of the Kumbh area has been constructed using very high-resolution World View Legion imagery (30 cm panchromatic, 8 multispectral bands).

2- A deep learning method using YOLO11-OBB (oriented bounding box) was applied to automatically detect infrastructure. The model achieved a strong performance (precision 90%, recall 80%, F1 0.86, MAP@05 to 0.80) indicating high reliability for large-scale mapping. At the same time, manual digitization in QGIS was undertaken to capture sector boundaries, temporary bridges, population hotspots, and other infrastructural features, including any objects missed by the YOLO11-OBB model. This exercise provided a comprehensive and quality infrastructure database. Overall, the model demonstrates that combining satellite data with advanced AI based object detection system and GIS provides a precise and effective monitoring system for infrastructure for such kind of mega event.

3- Furthermore, Land Use-Land Cover (LULC) change analysis was conducted for the Prayagraj between 2019 (Ardh Kumbh) and 2025 (Maha kumbh) using remote sensing satellite imagery. The results show an expansion of built-up area (75%) and barren land

(87%) and reduction in waterbodies (24%), agriculture (16%) and forest (38%). These changes reflect the change in riverine landscape.

Chapter 4: River water quality monitoring using remote sensing and in-situ measurements

1- To integrate in-situ measurements with remote sensing algorithms and capture spatio-temporal variations in water quality parameters pre-, during-, and post-Kumbh, the following research questions were addressed- (i) How do water quality indices vary across the three temporal phases of the Kumbh? (ii) To what extent do remote sensing indices correlate with in-situ measurements? (iii) Where are the pollution hotspots, and how are they linked to the event infrastructure?

2- Water quality was monitored using different spectral indices. NDWI to delineate water coverage area, NDCI to approximate chlorophyll-a and nutrient enrichment, and NDTI to capture turbidity and suspended sediments. Time-series Sentinel-2 MSI Level-1C scenes from December 2024 (pre-Kumbh), January–February 2025 (during Kumbh) and March–April 2025 (post-Kumbh) was processed using Google Earth Engine (GEE). In-situ based water quality parameters were matched with satellite scene acquisition between December 2024 and March 2025 and complemented with parameters from CPCB monitoring stations.

3- The findings show intensified water quality degradation, particularly at the Sangam confluence and upper Ganga ghats, where crowd density and ritual activities were highest on major bathing dates such as 22 January 2025. The NDWI comparisons indicate higher water coverage in December 2024 relative to 2023, reflecting better water conditions on 18 December 2024 (pre-Kumbh) than during the same period in 2023, suggesting that additional measures were taken to ensure higher flows during the Kumbh. However, during peak bathing days (22 January 2025 and 06 February 2025), infrastructure was overloaded alongside the riverbanks, leading to spikes in chlorophyll-a (NDCI) due to nutrient enrichment and increase in turbidity (NDTI) linked to sediment resuspension and runoff. The proximity of ghats, drains, and STPs at Sangam made this zone highly sensitive during the Kumbh phase (e.g., 03 February 2025), amplifying spatio-temporal variations in water quality indices. Spatial autocorrelation analysis (Moran's I) detected crowd hotspots concentrated around Sangam, validating the use of geospatial tools for hotspot identification. Overall, the results demonstrate the value of integrating remote sensing indices (e.g., NDTI) with ground-based datasets for large-scale, event-driven water quality monitoring.

Chapter 5: Hydrodynamic and water quality modelling using HEC-RAS

1- Systematic monitoring and a comprehensive understanding of water quality indicators are crucial for effective water resources management and macro-level decision-making. In this context, the present study focuses on the simulation of three (3) key parameters, such as Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), and pH, along an 18 km reach of the Ganga River at Prayagraj, including three CPCB monitoring stations, namely Lord Curzon Bridge, Pontoon Bridge No. 15, and Sangam. The simulation integrates a coupled hydrodynamic water quality approach using HEC-RAS and QUAL2Kw models. The HEC-RAS model effectively simulated flow dynamics of the Ganga and Yamuna during the Kumbh period, showing reliable performance.

2- In the upstream Ganga reach near Nagvasuki Temple, the reduction of the cross-sectional area causes flow contraction, resulting in high velocities (2.5–5.5 m/s). These higher velocities limit bathing activities and reduce pollutant accumulation, contributing to relatively better water quality. On the other hand, the Yamuna river revealed lower velocities (0.5–1.5 m/s) and smoother channel geometry, with a consistent width of 500 m to 650 m from upstream to Sangam. The Ganga River, however, shows significant variability in channel geometry, with widths ranging from 100 to 400 m in the middle reach. This variability directly influences flow velocity and pollutant transport, making the Ganga reach more prone to localized stagnation and accumulation. Overall, the velocity distribution and channel geometry govern these hydraulic differences, influencing bathing patterns and water quality near the Sangam region.

3- Results indicate that on all major bathing dates, BOD concentrations were reduced by approximately 20% between STP 4 and STP 5 as compared to the upstream location, primarily due to the dilution effect of the river. However, BOD levels increased by about 10% after CPCB Station 2, largely due to the organic load generated from mass bathing activities during the Kumbh. The DO levels remained within the CPCB permissible limits for bathing (≥5 mg/L) throughout the study period, which can be attributed to sanitation measures implemented by the government and the natural self-cleansing capacity of the Ganga river. Additionally, this study analyzes three (3) different discharge scenarios corresponding to dilution effects, and the results highlight a significant increase in BOD levels from the Sangam to the downstream region of the river. This rise is primarily attributed to reduced discharge, which decreases the river dilution capacity and intensifies the impact of anthropogenic activities such as mass bathing. The Root Mean Square Errors

(RMSE) for BOD, DO, and pH were 1.695 mg/L, 0.876 mg/L, and 0.346, respectively. The corresponding mean absolute errors (MAE) were 1.032 mg/L, 0.654 mg/L, and 0.245, while the percentage bias coefficients (PBIAS) were 24.96%, 0.81%, and 0.16%. These results indicate that the model demonstrated reliable accuracy and applicability for simulating water quality parameters.

4- Hence, the HEC-RAS and QUAL2Kw models confirm that in the stretch between STP 4 and STP 5, where flow velocity is relatively high, the water quality is better. This is also the region with lower bathing activity, and thus, the natural self-cleansing capacity of the river was more effective. However, beyond STP 5, near the Nagvasuki temple and approaching the Sangam, bathing activities increase significantly as pilgrims gather to take the holy dip. In this stretch, flow velocity decreases, and water quality begins to deteriorate. After the Sangam, the inflow from with the Yamuna river, three major STPs and a drain, further contributes to the decline in water quality of the Ganga River. This study demonstrates the applicability of HEC-RAS and QUAL2Kw in simulating water quality dynamics during large-scale religious events and provides useful insights for the prevention and management of river pollution in mega events such as the Maha Kumbh 2025.

Chapter 6: Socio-cultural aspects of Kumbh and development of K-WaSH framework

1- Through this study we explored the Status and Impacts of WaSH services (Water, Sanitation and Hygiene) at Mahah Kumbh Mela 2025 and introduces an in-depth assessment and framework i.e. K-WaSH framework to understand how WaSH services perform under the pressure of 66 million floating population at such mega event. K-WaSH is built on the DPSIR (Driver–Pressure–State–Impact–Response) framework to organize complex human–environment relationships. It defines four “State” dimensions: equitable service accessibility; infrastructure and technology; operations/management and risk aversion; and psychosocial factors. These are connected to three groups of “Drivers” (psychosocial, institutional/governance, infrastructure/technology), four types of “Impacts” (environmental, economic, health, and justice/social), and a set of emergent “Pressures” (operational, behavioural, financial, and infrastructure-related).

2- The framework was tested empirically across 25 sectors of the Kumbh area over three phases—pre (Dec 2024–early Jan 2025), during (13 Jan–26 Feb 2025) and post (27 Feb–31 Mar 2025. It involves a mixed-methods design i.e. 3,350 bilingual surveys of floating and local population; 52 stakeholder and focus group discussions; over 2,000 geotagged photographs; and consultations with a wide network of government agencies, NGOs,

religious organisations, academics and vendors. Qualitative data were coded in ATLAS.ti using K-WaSH themes, while survey data were analysed in Excel and Python (descriptive statistics and correlations).

3- It was found that the influx population was highly dynamic across phases. In the pre-Mela phase, pilgrims were largely local, middle-aged, educated, higher-income professionals, shifting during the Mela to a more nationally diverse crowd with more young people and a strong male bias (rural women being under-represented in surveys). In the post-Mela phase, the profile shifted again towards more economically vulnerable, less educated groups. The local pilgrims appeared to time their visits before the peak period to avoid congestion. Although observational insights indicated a substantial presence of women from rural backgrounds during Kumbh Mela, their representation within the survey sample remained limited, due to their reluctance to answer the survey.

4- Overall, people were satisfied with the WaSH services during the Mela. They also understood there would be some gaps because the crowd was so large. Stakeholders told us that some natural factors cannot be controlled, which makes it hard to plan WaSH services. For example, setting up WaSH systems depends a lot on how long the monsoon lasts and the water level at Prayagraj. Since the Mela takes place on the banks of the Ganga and Yamuna, the flow of the rivers affects how and when these services can be set up. This year's Maha Kumbh Mela was also affected by these issues, which slowed down the work and service delivery

5- During the Mela, WaSH facilities and sanitation workers were under heavy pressure, especially on main Snan days, showing the need to improve public behaviour. New systems like private sanitation services and tech-based checks helped manage and monitor WaSH services. However, problems like limited pictorial and multilanguage signboards made it hard for pilgrims to find nearby WaSH facilities.

6- In the post-phase, WaSH service facilities were dismantled as per the guidelines of PMA, which used disinfection and proper waste disposal to mitigate spread of infection from the Mela site that has been contaminated over the period of 45 days. Activities like cleanliness drives initiated by eminent organizations, such as NMCG, ensured the post recovery of Ganga Yamuna floodplains.

7- Our overall observation indicates that for a successful WaSH service, beyond the deployment of infrastructure, the floating population visiting the site needs to be imbued with WaSH practices and knowledge. This can be effectively undertaken in the pre-phase of the Mela, across the country as it attracts population from all places of India, where we

induce certain WaSH practices and knowledge through social media and campaigns. This would help in reducing pressure both on the facilities and cleaning staff during the Mela. Secondly, both observations and stakeholder consultation in our study suggest that religious and spiritual leaders can play a crucial role in changing the behaviour of the floating populations especially through their sermons. Finally, we think that there is a scope of further developing private partnerships to share the burden of service delivery in the purview of WaSH services. Our consultation with PMA officials shows that are open to the idea and if possible, they might try in the next edition of Kumbh Mela at Prayagraj.

8- Since the framework was developed parallelly to the Maha Kumbh Mela, this posed both pros and cons for us. As pros, we were able to minutely capture and modify the framework as per the needs and requirements which the research team learnt from the field, however, the cons were in uniformly capturing data across the three phases. As DPSIR based frameworks and models are heavily dependent on the availability of reliable and disaggregated data for each component, in mass gatherings, population estimates, and facility usage data are often uncertain, leading to potential biases in assessing state and impacts, especially when focusing on indicators.

9- The K-WASH framework using DPSIR has strong potential to become a data-based system for tracking and reporting WaSH services. As the first framework for religious mega events, it should be tested again in future Kumbh Melas in other cities to improve it. With AI, the framework could collect and report real-time data on drivers, pressures, state, impacts and responses, helping PMA and other groups take quick actions to keep WaSH services running well. Future research can focus on adding these features and creating an easy-to-use app or dashboard.

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Chapter 1: IPSA-Kumbh Introduction, Rationale of study and Methodology

1.1 Project Introduction

Ganga-ji or the Ganga holds immense cultural, spiritual, ecological, and economic significance in India. The Ganga River, stretching for about 2,500 km, supports about 600 million people across its vast river basin through the urban centres, rural communities, economic activities and livelihoods, as well as religious rituals and ceremonies. Recognizing this vital role, the Government of India and state governments have undertaken extensive programs and investments to restore and protect the Ganga, including improving sewage treatment, regulating industrial discharge, and strengthening waste management systems. Such sustained efforts have begun to yield positive changes in the water quality at several stretches of the river. However, rapid urbanization and the sheer scale of faith-based gatherings such as the Kumbh Mela, the largest human gathering on Earth, which draws millions of floating populations of pilgrims and tourists to the riverbanks; continue to place immense pressure on existing and temporary infrastructure and management systems specially established for the Maha Kumbh 2025. Due to such large gatherings, a marked deterioration of water quality parameters was recorded by past research and field-campaigns by the Central Pollution Control Board (CPCB) suggesting the stress caused by the floating population on the sewerage infrastructure.

Therefore, to implement sustainable solutions to protect this vital lifeline of Indian civilization, it is essential to understand the relationship between water pollution in the Ganga and the Kumbh Mela through the impact of the floating populations on the sewerage infrastructure. Incorporation of remote sensing and GIS techniques has been proposed as effective tools for managing Maha Kumbh Mela (Saha and Khare, 2015). The 45-day Maha Kumbh 2025 (January 14 to February 26) in Prayagraj presents a need to monitor and manage the sewerage infrastructure to safeguard the river's sanctity.

Through this project, “IPSA-Kumbh: Mapping the Impact of Floating Population on Sewerage during Maha Kumbh 2025”, we propose the use of advanced spatial mapping and monitoring of sewerage infrastructure and relating it to the quality of river water. In this project, “Sewerage” refers to the entire system for the collection, conveyance, treatment (STPs), and safe disposal of wastewater and faecal sludge generated from permanent and temporary settlements in the Maha Kumbh area. It includes all physical infrastructure and operational arrangements handling such flows. In the IPSA-Kumbh project, baseline maps of infrastructure

catering to the floating population and having a bearing on the sewerage systems, such as registered hotels, toilets, tents and ghat, and others need to be mapped and annotated using high resolution imagery. During the Kumbh Mela, water quality parameters and used water discharge rate collected along the riverbank as well as at drains are useful in understanding the spatio-temporal variation of pollutants. Furthermore, by using a spatial model, the correlation, and impact of the sewerage infrastructure on the water quality needs to be investigated, to establish the type and location of infrastructure most stressed by the floating population. Finally, through the social surveys of the various stakeholders like floating populations, religious heads & sheers, local populations, academicians and researchers, service providers, government officials and NGOs, participating in Maha Kumbh, their perspectives and awareness can be assessed under the framework of K-WASH (Kumbh- Water, Sanitation, and Hygiene).

1.1.1 Major Attributes of the River Ganga and Yamuna

India is endowed with abundant water resources, with approximately 45,000 km of riverine systems traversing the length and breadth of the country. The river systems are classified into 12 major basins, 46 medium basins, and 14 minor and desert basins. Among these, the Ganga River Basin is the largest. The Ganga is a transboundary river, flowing through India and Bangladesh. Originating from the western Himalayas in Uttarakhand, the river travels a length of about 2,525 km through the Gangetic plains of northern India, passing through Uttar Pradesh, Bihar, Jharkhand, and West Bengal, before ultimately draining into the Bay of Bengal. The river has an average annual discharge of about 493,400 million cubic meters. Its major tributaries include the Yamuna, Ramganga, Gomti, Ghaghara, Gandak, Damodar, Kosi, and Kali-East, while significant sub-tributaries are the Chambal, Sindh, Betwa, Ken, Tons (beyond five states), Sone, and Kasia-Haldi (CPCB, 2019).

The Yamuna River originates from the Yamunotri Glacier situated in the Bandarpunch range of the Himalayas in Uttarakhand. From its source, the river flows southward through the Himalayan foothills of Uttarakhand before entering the Indo-Gangetic Plains. The Yamuna traverses a course of approximately 1,376 km, passing through the states of Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh, before ultimately confluencing with the River Ganga at Prayagraj (CPCB, 2021; Rajan & Nandimandalam, 2024). Encompassing the largest catchment in the nation, it fulfills the freshwater needs of millions of people for domestic, agricultural, commercial, and industrial purposes. Consequently, the Ganga and Yamuna have consistently

remained a focal point for administrative authorities, institutions, academicians, and researchers, particularly regarding their water quality challenges (Matta et al., 2022).

1.1.2 About the Maha Kumbh Mela

The Kumbh Mela is a mass bathing festival of huge religious and cultural significance, held at six-year intervals (Ardh-Kumbh) and every twelve years (Maha Kumbh) along the banks of sacred rivers in India. The festival is celebrated at four major locations, such as Prayagraj (at the Triveni Sangam, the confluence of the Ganga, Yamuna, and the legendary Saraswati rivers), Haridwar (on the banks of the Ganga), Nasik (on the banks of the Godavari), and Ujjain (on the banks of the Kshipra). The Kumbh Mela attracts a vast congregation of participants, including Naga Sadhus, ascetics from various Akhadas, their disciples, devotees with deep religious faith, as well as pilgrims and visitors from across India and around the world. The Maha Kumbh 2025 was organized at Prayagraj, Uttar Pradesh, from 13 January to 26 February 2025. The major bathing dates included Paush Purnima (13 January), Makar Sankranti (14 January), Mauni Amavasya (29 January), Basant Panchami (3 February), Maghi Purnima (12 February), and Maha Shivratri (26 February). The 45-day event attracted nearly 660 million people as per ministry of information and broadcasting, Government of India: making it the largest recorded gathering worldwide in the history of the Kumbh.

1.1.3 Need of the Present Study

The Ganga River, affectionately known as Ganga-ji, holds a sacred place in the hearts and minds of millions of Indians, embodied in cultural, spiritual, ecological, and economic significance. Spanning over 2,500 km and sustaining a vast river basin, the Ganga supports approximately 600 million people in urban centers, rural communities, economic activities, and religious ceremonies. However, despite its revered status, the Ganga faces a daunting challenge in the form of water pollution, resulting from industrial discharge, urbanization, and inadequate waste management practices. This environmental degradation becomes starkly evident during events such as the Maha Kumbh, the largest human gathering on Earth, which draws a floating population of pilgrims, tourists, and visitors to the banks of the Ganga.

The Maha Kumbh Mela, celebrated once every 12 years, represents a convergence of spirituality, culture, and tradition, attracting millions to the sacred city of Prayagraj (formerly Allahabad). As the magnitude of the Maha Kumbh unfolds, so does the strain on existing infrastructure, particularly in sanitation and wastewater management. The needs of the floating population, which is estimated to be millions of people, are met through a combination of

existing and temporary infrastructure erected specifically for the event, including tents, toilets, and other facilities. However, this influx of people and the accompanying surge in activities have been accompanied by a marked deterioration in water quality parameters, as documented by previous research and field campaigns conducted by the Central Pollution Control Board. These studies underscore the stress exerted on sewerage infrastructure due to the presence of the floating population during the Maha Kumbh. In light of these challenges, there is an urgent imperative to implement sustainable solutions to protect the lifeline of Indian civilization, the Ganga River. Understanding the intricate relationship between water pollution in the Ganga and the Maha Kumbh is paramount, with remote sensing and Geographic Information System (GIS) technologies emerging as promising tools for effective management of such mega-events.

Further, Mass religious gathering events, like Maha Kumbh, pose complex challenges in managing WaSH (Water, Sanitation, and Hygiene) services while catering to the needs of pilgrims (Almehmadi & Alqahtani, 2023). These gatherings are considered vulnerable areas which pose risks to public health safety, such as the transmission of travel-related infectious diseases, personal hygiene and the dignity of the pilgrims (Sphere Handbook, 2018). As the influx of piligrims/floating population cannot be restricted or easily controlled in the Maha Kumbh Mela, WaSH related problems may occur from infrastructural, governance and management failure, and practices influences by the people's religious sentiments/beliefs and personal behaviour. The Maha Kumbh 2025 presents a critical juncture to monitor and manage sewerage infrastructure to safeguard the sanctity of the river.

In response to this imperative, our project, "IPSA-Kumbh: Mapping Impact of Floating Population on Sewerage during Maha Kumbh 2025," implemented the use of advanced spatial mapping and monitoring techniques to understand and mitigate the impact of the floating population on sewerage infrastructure and water quality through a systematic approach that includes baseline mapping, water quality assessment, spatial modelling, stakeholder engagement (for WaSh purpose), and policy integration. The project aims to provide actionable insights and recommendations for sustainable water management practices for upcoming Maha Kumbh. By leveraging technology, science, and community engagement, we strive to contribute to the preservation and rejuvenation of the Ganga River, ensuring its continued vitality for generations to come.

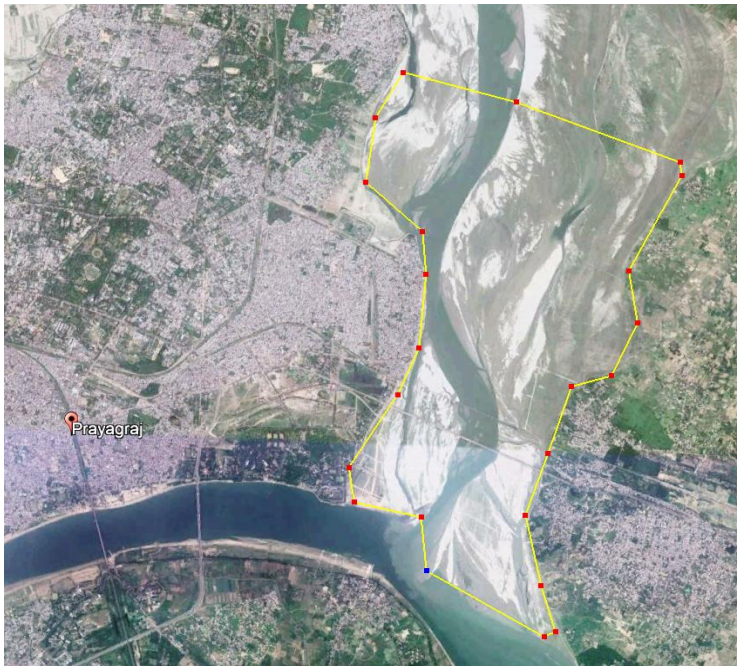
1.4.1 Rationale for selecting Maha Kumbh in Prayagraj as a case study

1.4.1.1 Untreated water discharge

Prayagraj, like many urban centers in India, faces challenges related to water pollution, particularly from the discharge of untreated sewage into the Ganga river and its tributaries. To address this, the Government of India and state governments have undertaken extensive programs and investments to improve sewerage infrastructure treatment to restore and protect the Ganga. However, the high population density during the event like Maha Kumbh might contribute to the contamination of water bodies, posing risks to public health, ecosystem integrity, and the cultural significance of the Ganga River.

1.1.4.2 Floating population pressure

Being one of the four sites for Maha Kumbh, the Mela in Prayagraj is characterized by a massive floating population that converges on the banks of the Ganga River and its confluence with the Yamuna and mythical Saraswati rivers. The influx of millions of pilgrims and tourists during the Maha Kumbh event exerts significant pressure on existing infrastructure and services, including sanitation, waste management, and water supply. As per the previous satellite mapping shown in figure 1.1(a) and 1.1(b), the load of infrastructure in the vicinity to the Sangam area is quite evident.



(a) Pre-Kumbh, October 2012



(b) during Kumbh, February 2013

Figure 1.1. High resolution satellite data of previous Maha kumbha acquired on (a) October-2012 and (b) February 2013

1.2 Project objectives

Figure. 1.2 shows an overview of our current research study, which is achieved through the following objectives.

1. Mapping Kumbh Mela infrastructure related to floating population contributing to sewerage, using 2D and 3D GIS-based mapping.
2. Measuring and mapping river water quality parameters using field measurements and remote sensing algorithms, pre-, during-, post-Kumbh.
3. Detecting sewerage hotspots by spatially modelling the impact of sewerage infrastructure, and stakeholder awareness on the river water quality through the WaSH approach and develop a K-WaSH framework.
4. Developing a GIS-dashboard for hotspot mapping to help mitigate the impact of the floating population on water quality.

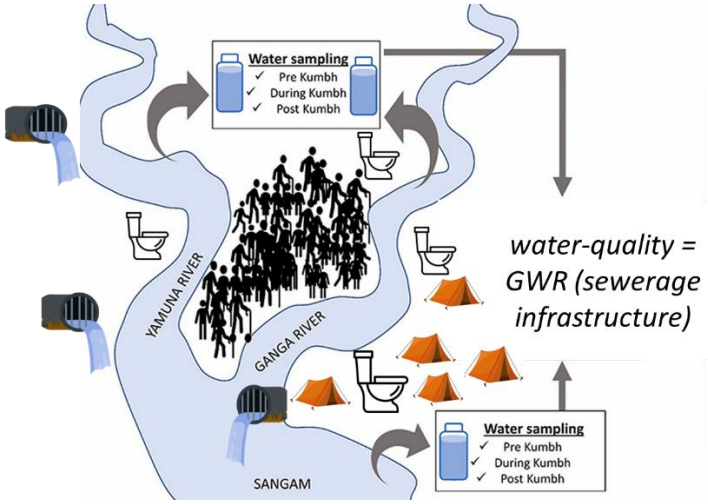


Figure 1.2. Graphical abstract of the project (modified from Varma et al. 2022)

1.3 Project Methodology

A comprehensive review of existing literature, research studies, and data related to water pollution, sewerage infrastructure, and Maha Kumbh events was conducted. Secondary data from government reports, academic publications, and relevant databases to understand the context, challenges, and opportunities associated with the project were collected. Fig. 1.3a illustrates the methodology pertaining to remote sensing and GIS mapping and in-situ observations; whereas. Fig 1.3b shows the methodology used to develop K-WaSH framework.

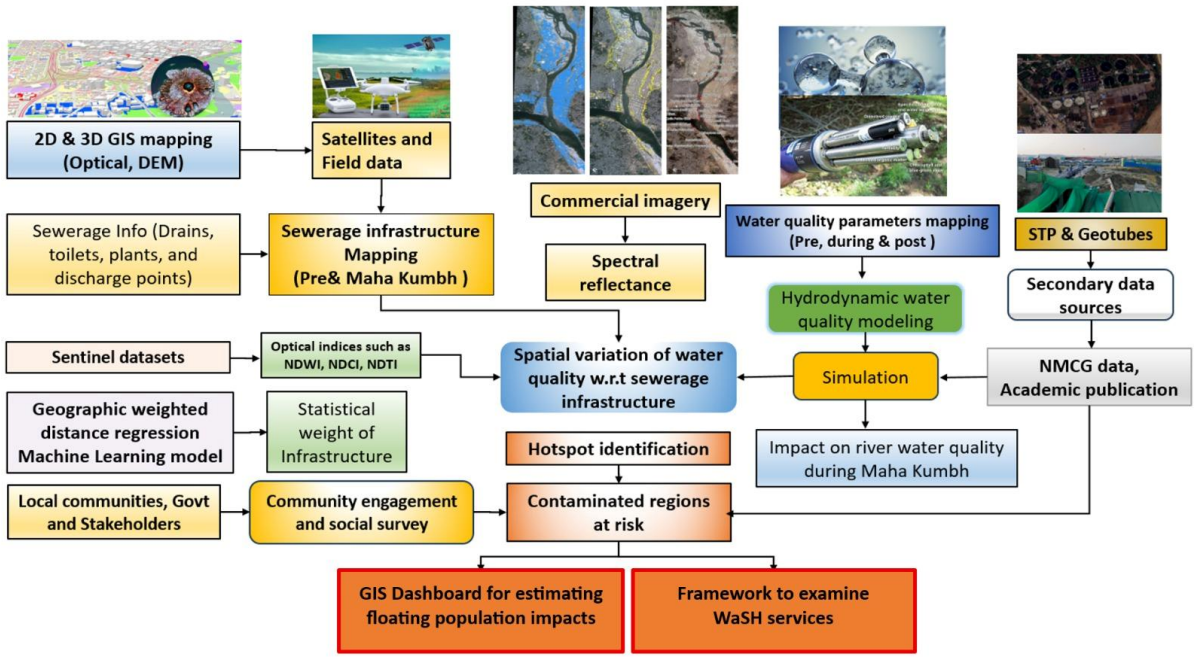


Figure 1.3(a). Methodology (Mapping Impact of Floating Population on Sewerage infrastructure for Maha Kumbh 2025)

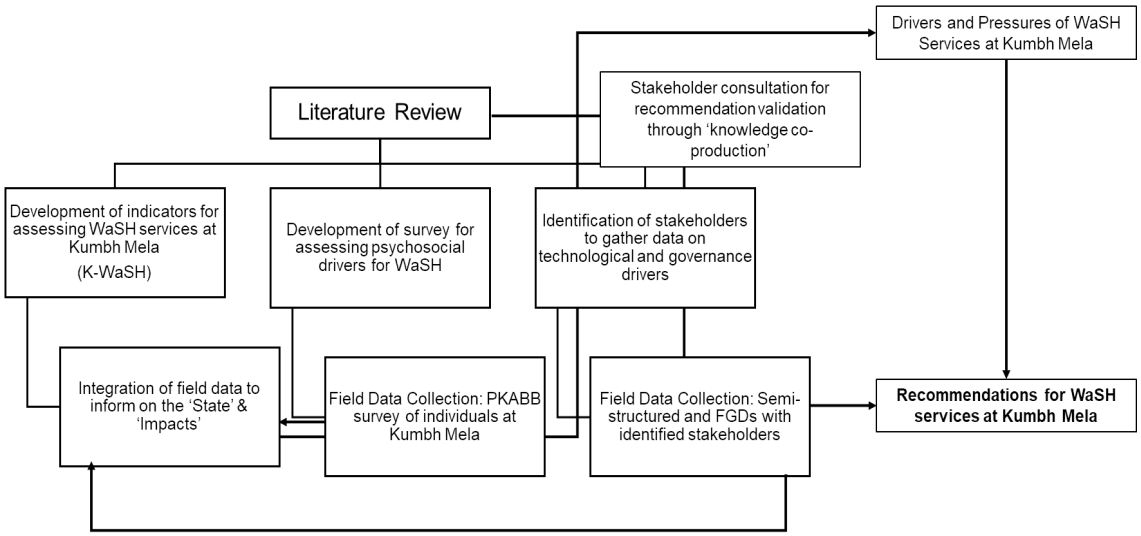


Figure 1.3 (b). Methodology (K-WaSH framework development for improved WaSH services for Maha Kumbh 2025).

Chapter 2: Mapping Impact of Floating Population on River Water Quality

2.1 Introduction

Rivers have been the centre of civilisation for decades. In a spiritual country like India, they hold a primary significance in its religious texts and rituals. Pilgrims bathe in these rivers, believing that it will provide them with salvation from their sins and offer them peace. However, in doing so, it often leads to deterioration in the water quality of the same river. Gathering like the Kumbh, which takes place in Prayagraj at Sangam (confluence of River Ganga and River Yamuna), is one of the largest known religious events in the world. An effective monitoring and management system is needed to keep the water quality pristine enough so that the pilgrims can have a safe and blissful experience. Mass Bathing events like the Kumbh Mela significantly affect the river water quality due to the addition of various ritual offerings and the use of personal care products, soaps, and oils on riverbanks. This raises nutrient levels in water, promoting algal blooms and eutrophication, which further depletes oxygen and affects aquatic life, and thus are of major concern (Tyagi et al., 2013; Dwivedi et al., 2020). Furthermore, these organic wastes increase the Biological Oxygen Demand (BOD), thereby reducing Dissolved Oxygen (DO) levels. Additionally, offerings contaminate sediments, posing long-term ecological threats. Key water quality parameters that were analysed in this study included Water Surface Temperature (WST), pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), turbidity, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Chlorophyll-a, and Nitrate. Table 2.1 illustrates the health significance of water quality parameters and the impact on those parameters due to mass bathing.

Table 2.1. Health significance and impact of mass bathing on water quality parameters.

Parameter	**Health Significance**	**Impact from Mass Bathing**
Temperature	Affects aquatic life; high temperatures increase pathogen survival.	A slight rise can stress aquatic organisms and promote pathogen growth.
pH	Optimal range (6.5-8.5) supports life; extremes harm fish and infrastructure.	Soaps and personal care products may temporarily alter pH, affecting ecosystems.

EC	High levels may cause skin irritation and taste issues.	Increased by soaps and salts from bathing.
TDS	It can affect taste and be harmful to those with kidney issues.	Organic/inorganic matter increases TDS, reducing clarity and altering taste.
Turbidity	High levels promote microbial growth, making water unsafe.	Sediment disturbance reduces sunlight penetration, affecting aquatic life.
DO	Essential for aquatic life; low levels cause fish kills.	Increased organic waste lowers DO, leading to hypoxia.
Chlorophyll-a (Chl-a)	High levels indicate eutrophication and toxic algae risks.	Nutrients from bathing promote algal blooms, reducing oxygen.
BOD	High BOD signals organic pollution and oxygen depletion.	Organic waste raises BOD, harming aquatic ecosystems.
COD	High levels indicate chemical pollution.	Synthetic products increase COD, straining oxygen availability.
Nitrate	Excess leads to algal blooms.	Increase eutrophication risks.

There exists a considerable amount of literature that studies the impact of mass bathing practices on water bodies. Sood et al. (2008) have reported that significant pollution in the lower stretches of the River Ganga and its tributaries is primarily due to intense human activities driven by religious beliefs. Such rituals frequently result in elevated levels of BOD, creating health risks not only for individuals participating in these rituals but also for downstream ecosystems. Kulshrestha & Sharma (2006) have assessed the river water quality during the *Ardh* Kumbh Mela, 2004 at Haridwar (Uttarakhand), and found that the mass bathing has made the water unfit for bathing. After the holy dip by the pilgrims, BOD and COD were also found to spike during bathing; however, DO remained under a safe limit. Decreased transmittance also signified increased accumulation of soluble and suspended matter in the water. A similar study was undertaken at *Brahmasarovar* in Kurukshetra, Haryana, by Bhatnagar & Sangwan (2008), and it was found that organic pollution load increased in the *sarovar* after mass bathing in 2007, which was signified by spiked values of BOD, total solids, alkalinity, chlorides, among others. In addition, the use of soaps and detergents by pilgrims resulted in increased phosphate levels. Additionally, the high organic matter and pollution due

to animal origin, like bathing, adding ashes, and urination in water, also increased the chloride and ammonia contents of water. Research was also conducted for Maha-Kumbh 2010 at Haridwar (Sharma et al., 2012; Tyagi et al., 2013), and similar results were obtained, i.e., increased values of BOD, COD, total coliforms, ammoniacal nitrogen, and others.

For Prayagraj, several studies have assessed the impact of mass bathing practices on river water quality during the Kumbh mela. Dwivedi et al. (2020) collected samples for microbial studies, physico-chemical parameters, and bacteriophage studies before, during, and after Maha Kumbh 2013. During the event, the values of BOD increased to as much as five (5) times the bathing limit. There were insignificant changes in TDS; however pH, hardness, nitrate, and phosphate concentration increased significantly. Discarding items like soaps, shampoos, detergents, polythene, discarded clothes, as well as food, flowers, leaves, milk, curd, ghee, coins, and others, further deteriorates the water quality. Srivastava et al. (2013) also evaluated the water quality during the same period using the fuzzy environmental model for physico-chemical parameters of river water. Varma et al. (2022) further used multivariate statistical techniques and the Water Quality Index (WQI) for the assessment of water quality during Kumbh 2019 from Prayagraj, India. They too found similar results of increased TDS, COD, BOD, and MPN count of coliforms. The observed Water Quality Index (WQI) values ranged from 59 to 132, reflecting a notable decline in water quality, from very poor to unsuitable for drinking, throughout the event. Yadav & Bhatia (2020) reported that the water quality of Phaphamau site was significantly more inadequate than Sanga and Daraganj Ghat and rated the water under class ‘D’ as per CPCB norms. In addition, they also found that many epidemics of waterborne disease and other infectious cases occurred after the Kumbh, concluding that water quality was unfit for drinking and bathing. Water quality Index reported that water quality parameters such as colour, pH, DO, and BOD were within the permissible limit, except BOD during Kumbh, based on five different sampling sites of the river Ganga, Yamuna and confluence points (Kanauia & Tiwari, 2023). Notably, however, the DO of all sites was higher than the standard limit for outdoor bathing.

Conventional water sampling and analyses, although precise, are often site-specific and economically less feasible, which limits their applicability for large scales. Advanced geo-spatial tools like Geographical Information Systems (GIS) can prove to be handy aids in the spatial analysis and visualisation of such data. Additionally, satellite-based or Remote-Sensing measurements can provide data for inaccessible sites and their real-time measurements, if

needed. However, their direct measurements are often limited to optically active water quality parameters (Turbidity, Chlorophyll, etc.).

In this chapter, efforts are made to analyse field and lab-based findings using various GIS techniques like, interpolation, to understand the spatial distribution of water quality parameters in the river area during the three phases of Kumbh (Pre-Kumbh, During Kumbh, and Post-Kumbh). Additionally, heatmaps and correlation analysis help to understand the inter-relationships of these water quality parameters and their behavior during Maha-Kumbh. Finally, population density (Date-wise and Sector-wise) has been estimated using Remote Sensing data with the derived outputs subsequently validated with official records provided by the government authorities.

2.2 Objectives

The present study focused on the river water quality of the Ganga and Yamuna rivers and their confluence point (sangam) using conventional sampling and geospatial analysis approaches. Additionally, the study aimed to understand how mass gatherings and other factors impact river water quality and to ultimately develop a holistic approach for river water quality assessment. Key objectives of the study are given below:

- Impact of the Maha-Kumbh 2025 on river water quality through a phase-wise approach encompassing Pre-Kumbh, During-Kumbh, and Post-Kumbh.
- Physicochemical analysis of collected water samples from various sampling locations.
- Generation of spatiotemporal representations of water quality variations using heatmaps and GIS-based spatial distribution maps for identifying pollution hotspots.
- Statistical analysis for understanding interdependencies of parameters, pollution linkages, and ecosystem response under varying anthropogenic pressures.
- Estimation of population density using remote sensing and comparing geospatial estimates with authority-reported data for assessing human pressure distribution.
- Recommendations for improved water quality management, mitigation strategies, and post-event recovery planning for future mass gatherings.

2.3 Methodology

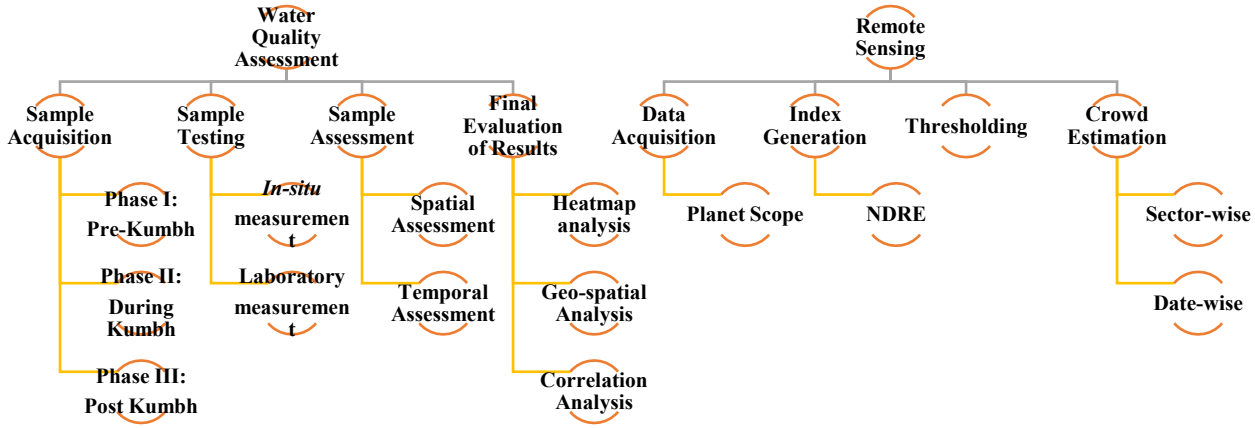


Figure 2.1. Flowchart of methodology

An overall work plan is depicted in Figure 2.1. It highlights the methodology that extends from water sample acquisition to testing, analysis, and interpretation. Further, it also highlights the steps taken for population estimation from Remote Sensing data using the indices approach. While identifying points for water sampling, the following points were considered: major bathing sites, accessibility, and locations of upstream and downstream point sources like STP discharge points or the inflow of major wastewater drains into the rivers. Table 2.1 and Figure 2.2 depict the details and location of the sampling sites finalized for the study. Various control points were considered that were free from any major influence, (e.g., bathing), and these acted as a reference for water quality measurements. These control points were - SP1 in the upstream of River Ganga, SP14 in the upstream of River Yamuna, and SP16 in the downstream of River Ganga after the confluence. Each sampling location was further validated from the GPS coordinates. The water quality assessment spanned three operational phases of the Kumbh—Pre-Kumbh, During Kumbh, and Post-Kumbh thereby enabling a comparative understanding of peak bathing events impacts and residual impact influenced by pilgrimage activities. Further, water quality parameters, sampling sites, days and frequency were strategically planned to obtain representative data during the peak period of Amrit Snan (refer to Annexure A and B).

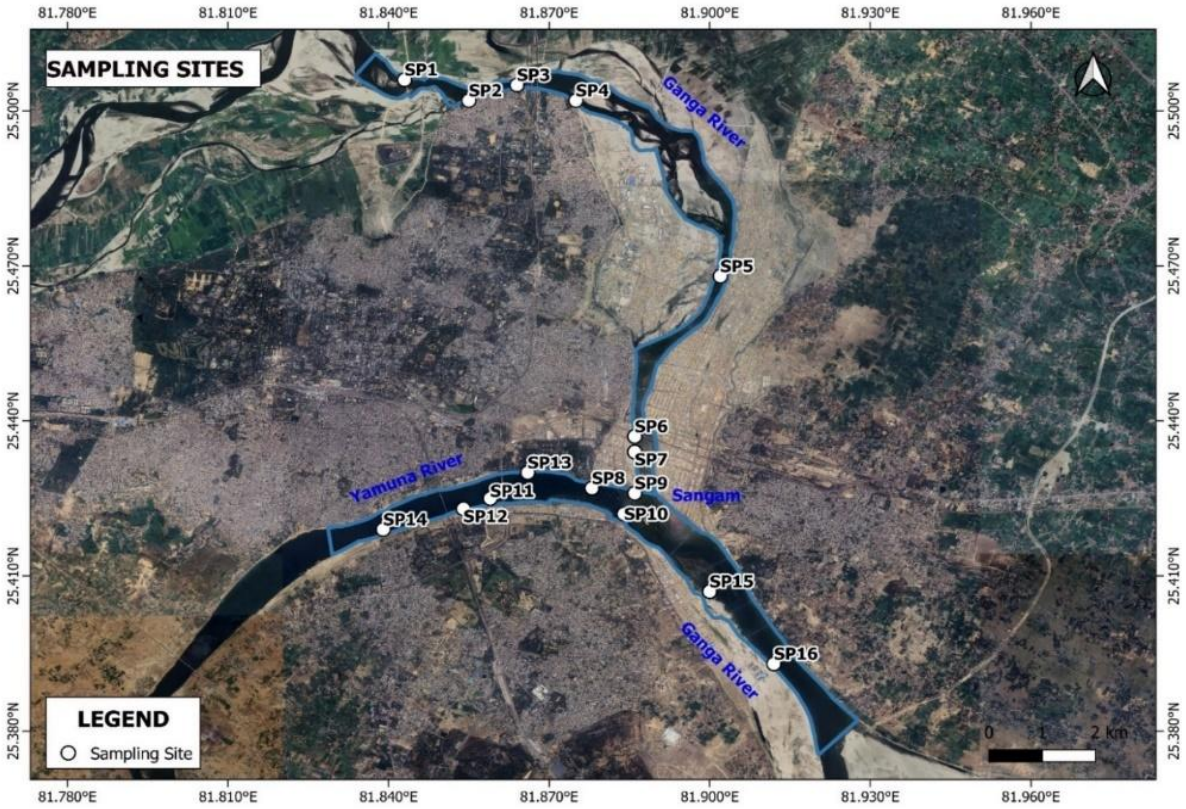


Figure 2.2. Sampling locations in the Study Area.

Table 2.2. Details of location of water quality sampling points, Maha Kumb 2025.

Sampling site	Longitude (X)	Latitude (Y)	Details		
SP1	81.847	25.502	New Ganga bridge	u/s to Rajapur STP	Ganga u/s Control
SP2	81.855	25.503	Rasulabad Ghat	d/s to Rajapur STP	
SP3	81.866	25.508	Phaphamau		
SP4	81.881	25.490	Salori	u/s to Salori STP	
SP5	81.886	25.460	Shri Nagavasuki temple	d/s to Salori STP	
SP6	81.886	25.437	Shastri bridge		
SP7	81.887	25.429	Ganga, Near Sangam		
SP8	81.878	25.427	Sangam/Fort		
SP9	81.884	25.426	At Sangam nose	At confluence	
SP10	81.882	25.423	Arail Ghat		
SP11	81.859	25.425	Naini bridge	d/s to Naini STP	

SP12	81.854	25.423	Old bridge	u/s to Naini STP	
SP13	81.866	25.430	Shri Mankameshwar Mahadev Temple	Saraswati Ghat	
SP14	81.839	25.419	Mahewa Ghat		Yamuna u/s Control
SP15	81.901	25.409	Peepa Pul No. 28	Arail Uparhar	
SP16	81.914	25.394	Peepa Pul No. 30	Dewrakh Uparhar	Ganga d/s Control

2.3.1 Water quality analysis

Water sample acquisition and analysis were performed following the standard guidelines as mentioned in the American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater, 2017 (23rd Edition). Further, the same guideline is followed in analysing samples for various water quality parameters (pH, TDS, EC, Turbidity, Temperature, DO, Nitrate, BOD, COD, and Chl-a). These water quality measurements were done *in-situ* and *ex-situ* using various instruments and analytical techniques (Table 2.3).

Table 2.3. Standard procedure for various parameter analysis.

Parameter	Method	Instrument	Analysis
pH	APHA 4500-H+ B. Electrometric Method	Multiparameter Meter with Available GPS, Logging Probe, Turbidity & Ion Measurements (HI9829)	In situ
EC	APHA 2510 B		
TDS	APHA 2540 B		
Turbidity	APHA 2130 B Nephelometric Method		
Temperature	APHA 2550 B		
DO	APHA 4500-O C Azide Modification	Advanced Dissolved Oxygen Benchtop Meter (HI6421)	In situ & In Lab
Nitrate	APHA 4500-N Nitrogen D. Conductimetric Determination of Inorganic Nitrogen	ISE Bench Meters and Nitrate Combination (HI5222 and HI4113)	In Lab

BOD	APHA 5210 Biochemical Oxygen Demand (BOD) B	NSW-152 B.O.D. Incubator	
COD	APHA 5220 Chemical Oxygen Demand (COD) C Close-Reflux Titrimetric Method	COD Reactor (HI5222)	
Chl-a	APHA 10200-H Colourimetric Method		

Geospatial and statistical analysis of laboratory results and field data were performed to differentiate temporal and spatial patterns in water quality. Finally, a few recommendations were suggested for improving water quality to make river water suitable for bathing and performing other ritual activities. Heatmap for the measured quality parameters illustrated the maximum, mean, and minimum values recorded during the Pre-Kumbh, During-Kumbh, and Post-Kumbh phases across all the sampling sites. Similarly, spatial maps were also generated in QGIS software by Inverse distance weighting (IDW) interpolation. Pearson correlation analysis was performed to find a correlation between different water quality parameters overall, pre, during, and post Kumbh.

2.3.2 Crowd Estimation using Remote Sensing

To estimate the crowd, the Normalized Difference Red Edge (NDRE) index was applied to the satellite imagery using the formula (B8 - B7) / (B8 + B7), where Band 8 corresponds to the Near-Infrared (NIR) spectrum and Band 7 represents the Red Edge band (Fig 2.3). A specific threshold value ranging from 0.11 to 0.19 was used to differentiate densely populated regions from the background and non-crowded areas. After applying the threshold, the values of the resultant image were 0 & 1, where 0 represents no crowded zone and 1 represents a crowded zone. In Planet scope 3 m spatial resolution data, approx. 7 people per square meter (Dave et al.) were considered in a single pixel of the satellite image (Dave et al.). This helped in deducing population density from the obtained image. Here, this method allowed effective detection and extraction of human presence based on spectral reflectance properties.

No of Total Headcount = Pixel count × No of Persons per Pixel

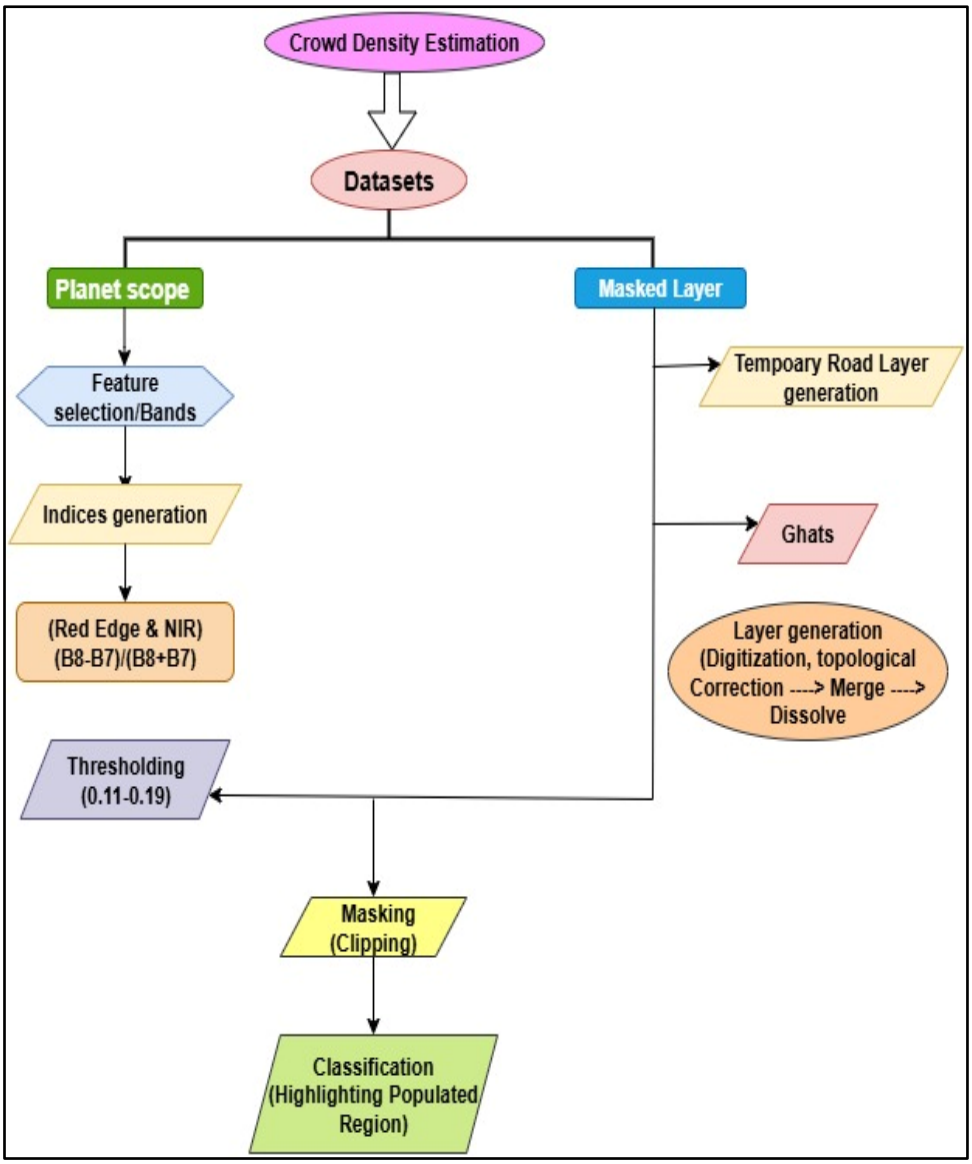


Figure 2.3. Methodology Flowchart for crowd Density Estimation

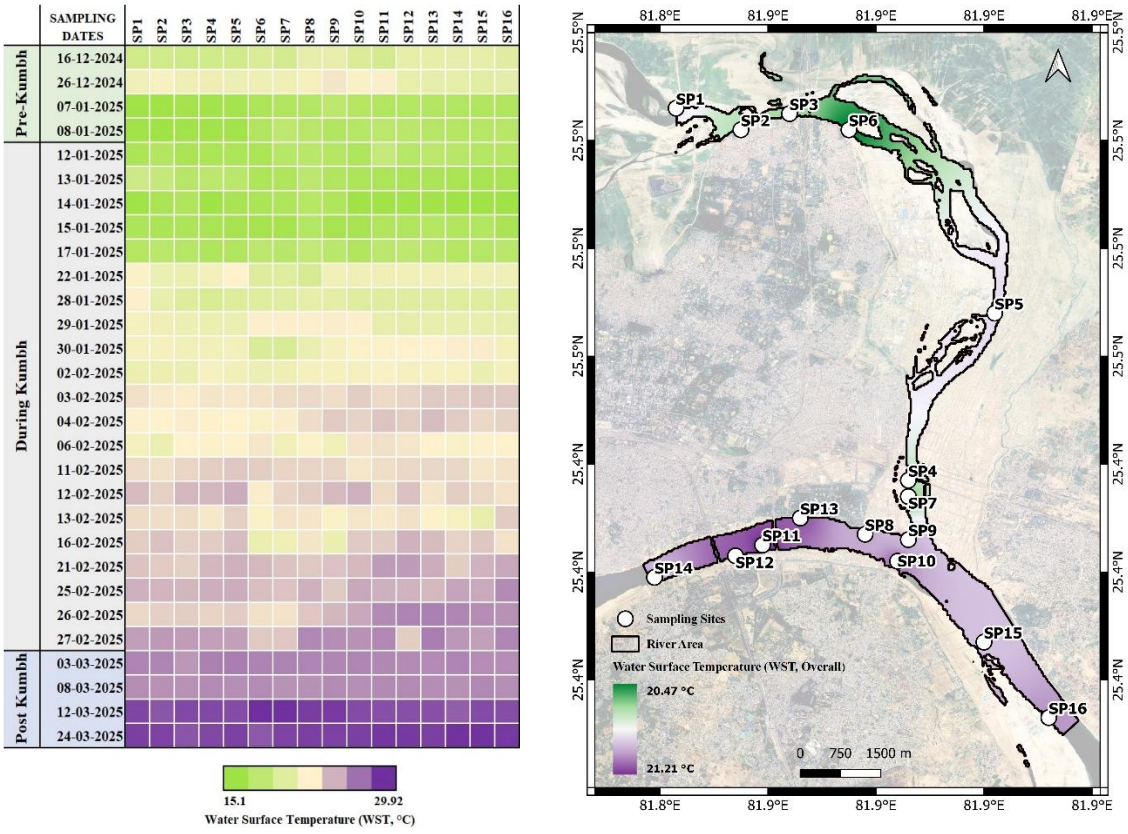
2.4 Results and Discussions

To understand the spatial and temporal variation of water quality parameters, analytical tools like heatmaps (which showed the range of values for each site on sampling dates) and spatially interpolated maps (by considering parameter values at each site as an overall average as well as during the Pre, During, and Post Kumbh phases) were utilized for each quality parameter was performed. Finally, to understand the inter-relationships between these parameters, Pearson's correlation analysis was done for each of the phases. The heatmap and mean geospatial maps are discussed in subsequent sections for each parameter, along with the probable causes of such variation. Annexure C depicts phase-wise spatial results for these parameters.

2.4.1 Water Quality Parameters

2.4.1.1 Water Surface Temperature (WST)

Water surface temperature of the river is one of the prime indicators for seasonal and diurnal changes. It also closely links with other water quality parameters and impacts on the aquatic life of the riverine ecosystem. Figure 2.4 (a and b) shows the seasonal and site-specific variation in water surface temperature (Annexure C) during sampling days in the form of a heatmap and mean spatial variation. Impact of mass bathing, ritual activities and uses of soaps and other personal care products on the sampling sites is evident especially during major bathing days of Kumbh. This may be due to the decrease in the velocity of river flow and increased heat exchange due to turbulence on surface and riverbed. Sampling Sites - SP5 to SP9, which are major bathing sites, show a slight rise in WST during main *snan* days which persists as Kumbh progresses. During post-Kumbh phase, this increase in temperature becomes more evident as days progress at most sites, which may directly be attributed to the seasonal temperature increase. Mean spatial variation for all sites shows that River Yamuna had higher WST than River Ganga. Major bathing sites like SP8, SP9, and SP10 depict pockets of higher mean WST values while upstream sites for River Ganga (SP1 to SP7) had lower mean WST values. This temperature gradient between the two rivers is carried on as higher means of WST values after the confluence in the River Ganga (SP15 and SP16).

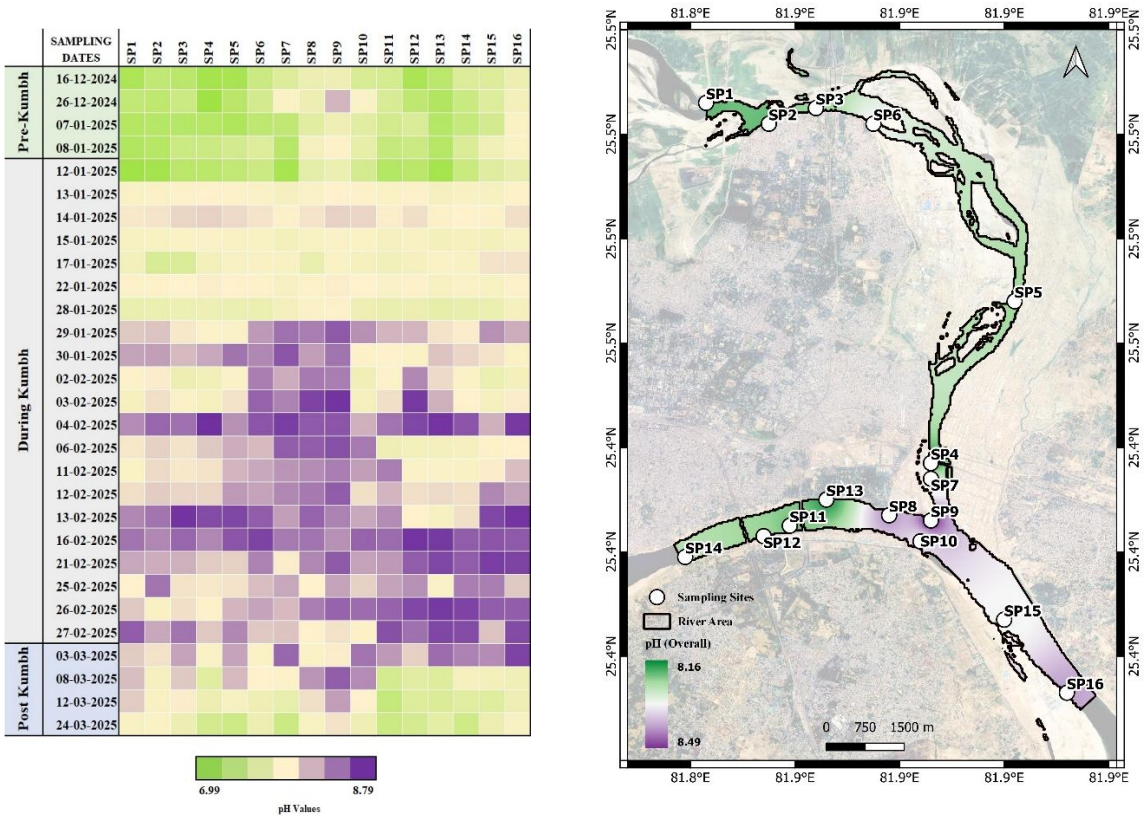


(a) (b)

Figure 2.4. Variation of Water Surface Temperature in °C, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.2 pH Values

CPCB recommends that water is suitable for 'organised outdoor bathing' if its pH lies between 6.5 to 8.5. This ensures protection to skin and delicate organs (e.g. nose, ears, eyes, etc.) which are exposed during bathing. pH was measured on-site using handheld HANNA multiparameter probe. The pH values of all sites were found to vary from 6.99 to 8.79 across sampling days (Figure 2.5a), with higher values (making water slightly alkaline) occurring majorly after *Mouni Amavasya snan* at Sangam sites. Pre-Kumbh phase saw almost neutral pH values while post-Kumbh showed a mixed trend, suggesting partial recovery of river system. Further, mean pH values for all sites as depicted in the spatial map showed hotspots in majorly two regions – around the confluence (*Sangam*), and at downstream of River Ganga (site SP16), suggesting that mass bathing and seasonal dynamics are the primary drivers of elevated pH levels (Figure 2.5b). Thus, pH levels showed a transition from neutral conditions (pre-Kumbh) to alkaline conditions (during Kumbh) to finally heterogenous conditions (post-Kumbh). It can also be observed that post event, pH recovery was much better in River Yamuna than River Ganga.



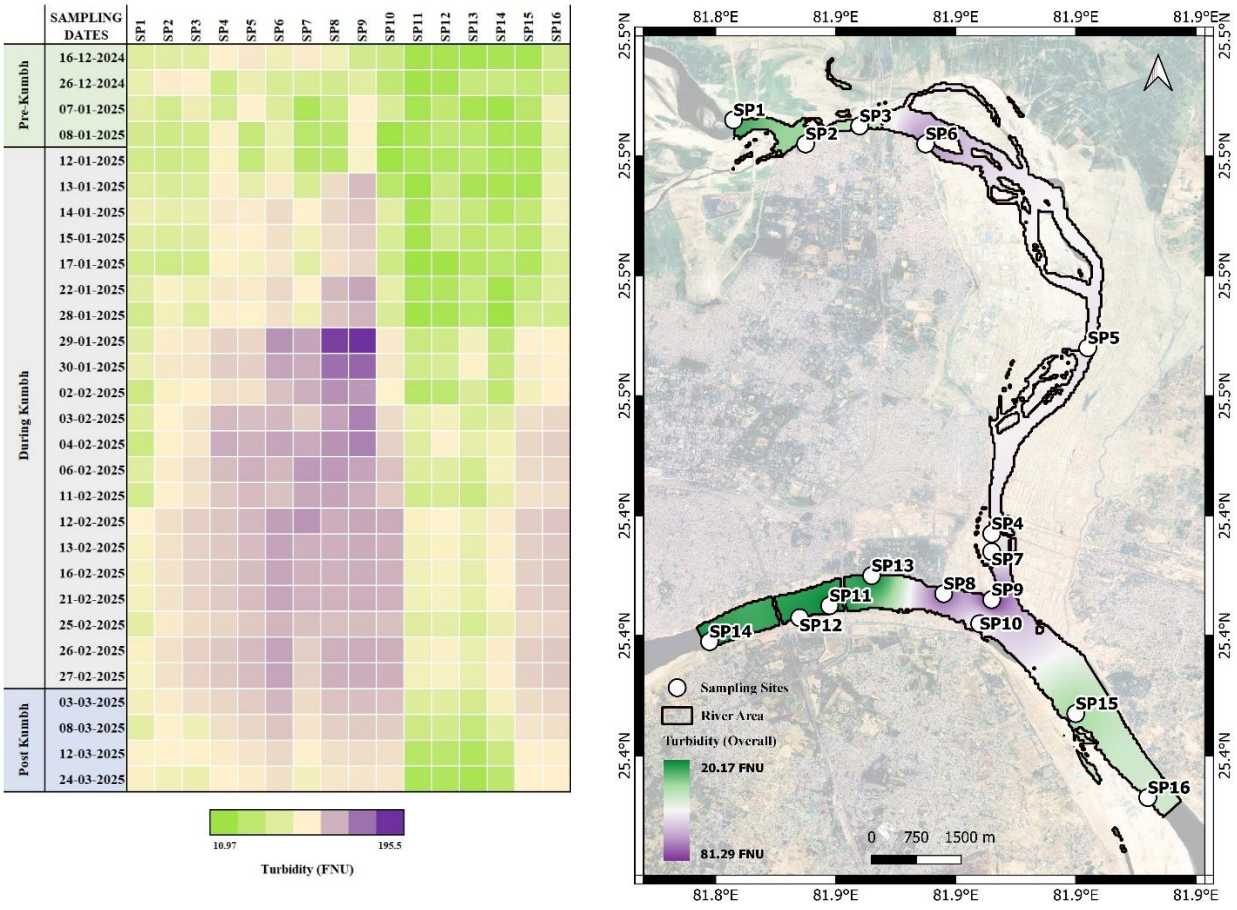
(a) (b)

Figure 2.5. Variation of pH values, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.3 Turbidity

Turbidity is another key parameter that measures the cloudiness or haziness of water. It is usually measured in terms of Nephelometric Turbidity Units (NTU) or Formazin Nephelometric Units (FNU). Regular monitoring of turbidity provides valuable information about sediment transport, pollution load, and the overall health of the water body. During mass bathing events like Kumbh mela, collective movement of thousands of devotees stirs up bottom sediments, resuspending fine particles and increasing turbidity levels significantly, especially in shallow or slow-moving stretches of the river. Additionally, soaps, oils, and ritualistic offerings add to the particulate load. Elevated turbidity levels, as a result, limits light penetration and potentially disrupts photosynthetic activity in aquatic plants and phyto-planktons. Turbidity was measured on-site using handheld HANNA multiparameter probe. Heatmap (Figure 2.6a) for these measured values showed that turbidity values ranged from 10.97 FNU to 195.5 FNU for all the sampling sites during the three phases of sampling. Similarly, spatial distribution (Figure 2.6b) shows variation in mean turbidity values in the study area. Two major inferences that can be made include: River Ganga is more turbid than

River Yamuna. During Kumbh, turbidity markedly increased at several sites, reflecting higher suspended solids and pollution load due to mass bathing and intensified human activity. In the post-Kumbh phase, turbidity showed partial decline but remained elevated at many locations compared to pre-event levels, suggesting persistent disturbance and slower recovery of water quality.



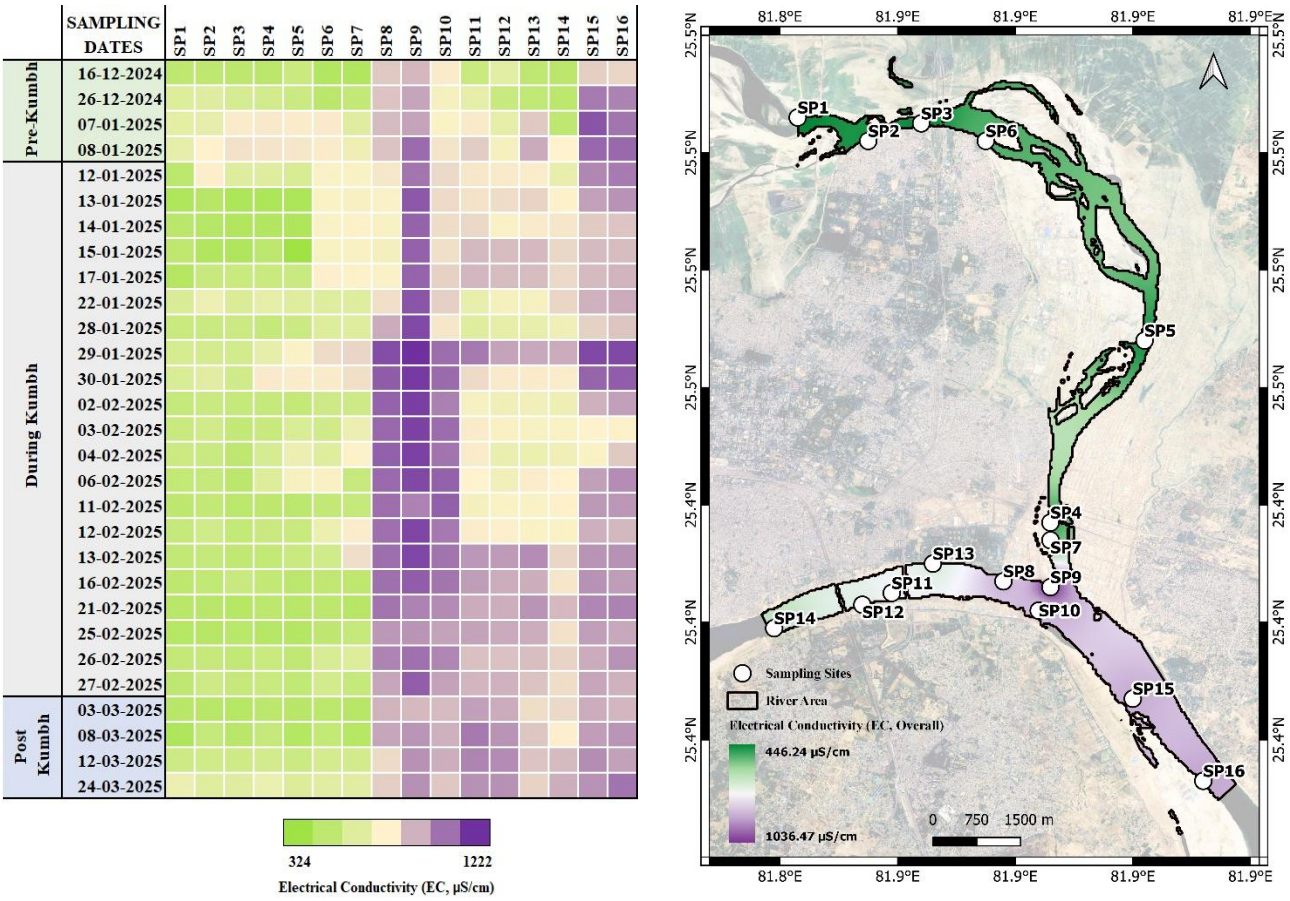
(a) (b)

Figure 2.6. Variation of Turbidity in FNU, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.4 Electrical Conductivity (EC)

Electrical Conductivity (EC) measures the ability of water to conduct an electric current and provides a quick estimate of its total ionic strength or salinity. Bathing, organic and inorganic offerings often elevate ion concentrations, leading to measurable fluctuations in EC. The heatmap and spatial map (Figure 2.7a and b) of sampling sites indicated variation in water conductivity, with elevated values observed particularly near high-activity bathing areas.EC was measured on-site using handheld HANNA multiparameter probe and HANNA pen-type probe. Heatmap (varying from 324 to 1222 µ/cm) showed higher EC at Sangam sampling site

(SP9) pre, during and post Kumbh that may be due to the organic waste and bathing and ritual activity turbulence. Further during Kumbh EC increased at SP8, SP9 and SP10 with downstream of Ganga SP15 and SP16 due to their cumulative effects (Fig. 2.7). Upper Ganga and Yamuna region sampling sites show stable EC values in pre and during Kumbh that suggest good dilution and buffering capacity of the river, whereas hotspots are found to occur in Sangam region and downstream of Ganga regions reflecting a higher concentration of dissolved ions, likely due to organic waste, human activities, and inflow of pollutants during mass gatherings.



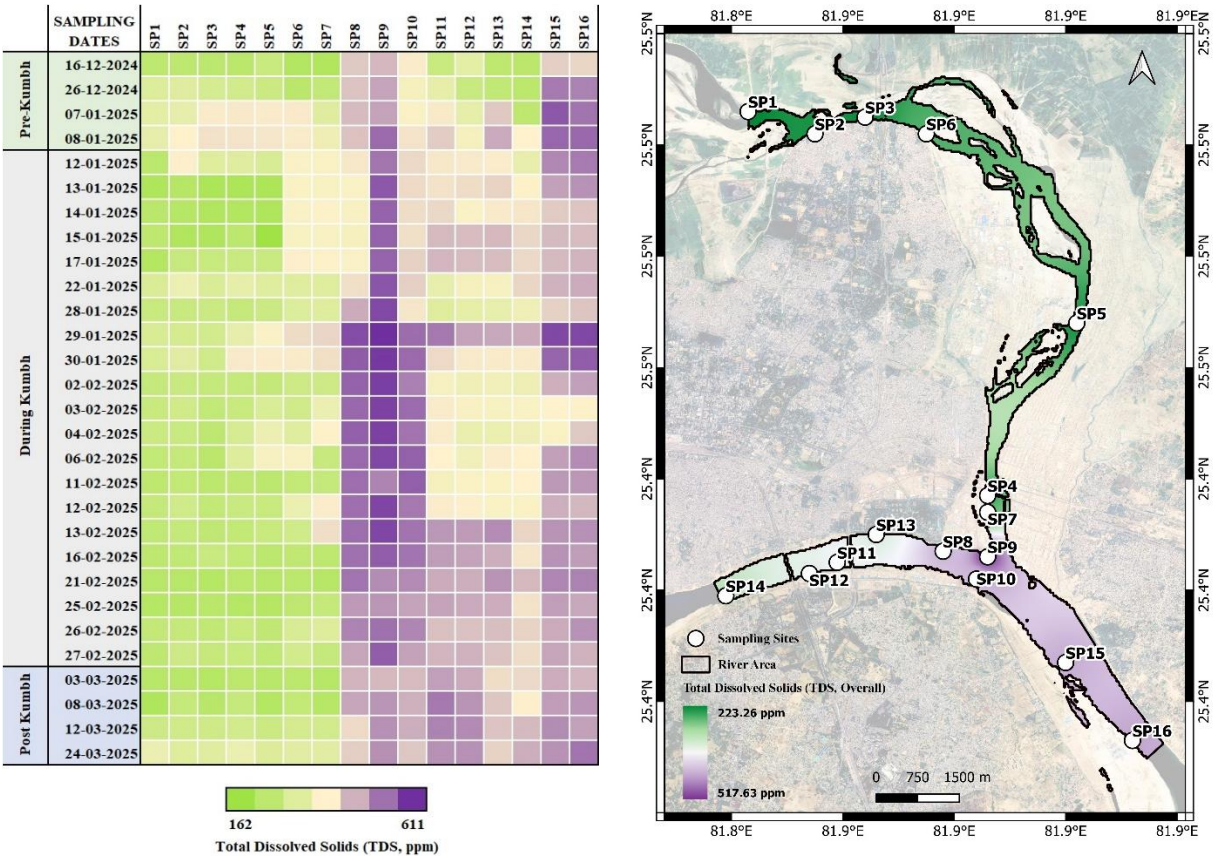
(a) (b)

Figure 2.7. Variation of EC in µS/cm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.5 Total Dissolved Solids (TDS)

Total concentrations of dissolved organic and inorganic solids in an aqueous system are called Total Dissolved Solids (TDS). It is generally expressed in milligrams per litre (mg/L) or parts per million (ppm), and it provides a direct measure of the salinity and mineral content of a water body. Due to being highly correlated, TDS follows almost similar trends to the EC for

the sampling sites. In the present study, TDS was measured on-site using handheld HANNA multiparameter probe and HANNA pen-type probe. TDS value ranges from 162 to 611 ppm and shows a higher value at major bathing sites and at Sangam region due to inputs from mass bathing, detergents, and organic/inorganic loadings. This is equally evident from the heatmap (higher values) as well as spatial map (hotspots) shown in Figure 2.8a and b. Also, upstream control sites free from any external influence during the event like SP1 and SP14 depicted lower values, but the downstream control site SP16 showed highest accumulated TDS concentration.



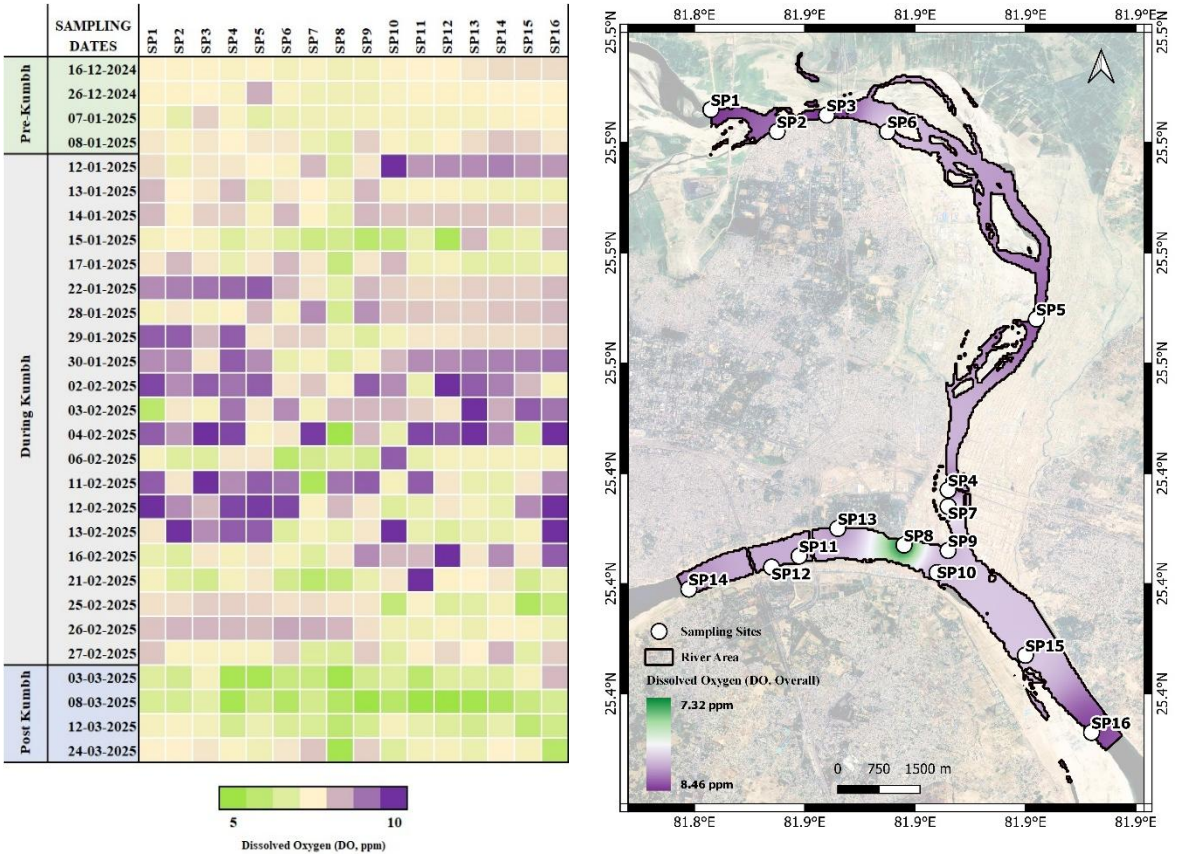
(a) (b)

Figure 2.8. Variation of TDS in ppm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean patial variation across all sites

2.4.1.6 Dissolved Oxygen (DO)

Dissolved oxygen represents the amount of oxygen present in water in its dissolved form. In water bodies, DO enters from atmosphere through diffusion and from the aquatic plants release during photosynthesis. Thus, monitoring of DO becomes one of the most essential parameters for assessing the health of aquatic ecosystems. CPCB recommends a minimum value of 5 ppm to prevent production of anaerobic gases from the sediments for outdoor bathing. During the

three phases of Kumbh, DO is found to vary from 5 to 10 ppm at all sampling sites (Figure 2.9a). However, mean values at all sites were found to range from 7.32 to 8.46 ppm (Figure 2.9b). Measured values (from heatmap) at all sites indicate that higher values are observed during Kumbh, which may be attributed to increased dilution and turbulence. However, spatial distribution suggests a lower DO at site SP8 in comparison to other sites, which had higher mean values. This may be because at site SP8 consistent lower values are observed with insignificant variation due to low mixing. Post Kumbh result shows that DO in all sampling sites decline but remain above the permissible limits showing the recovery instincts of the rivers.



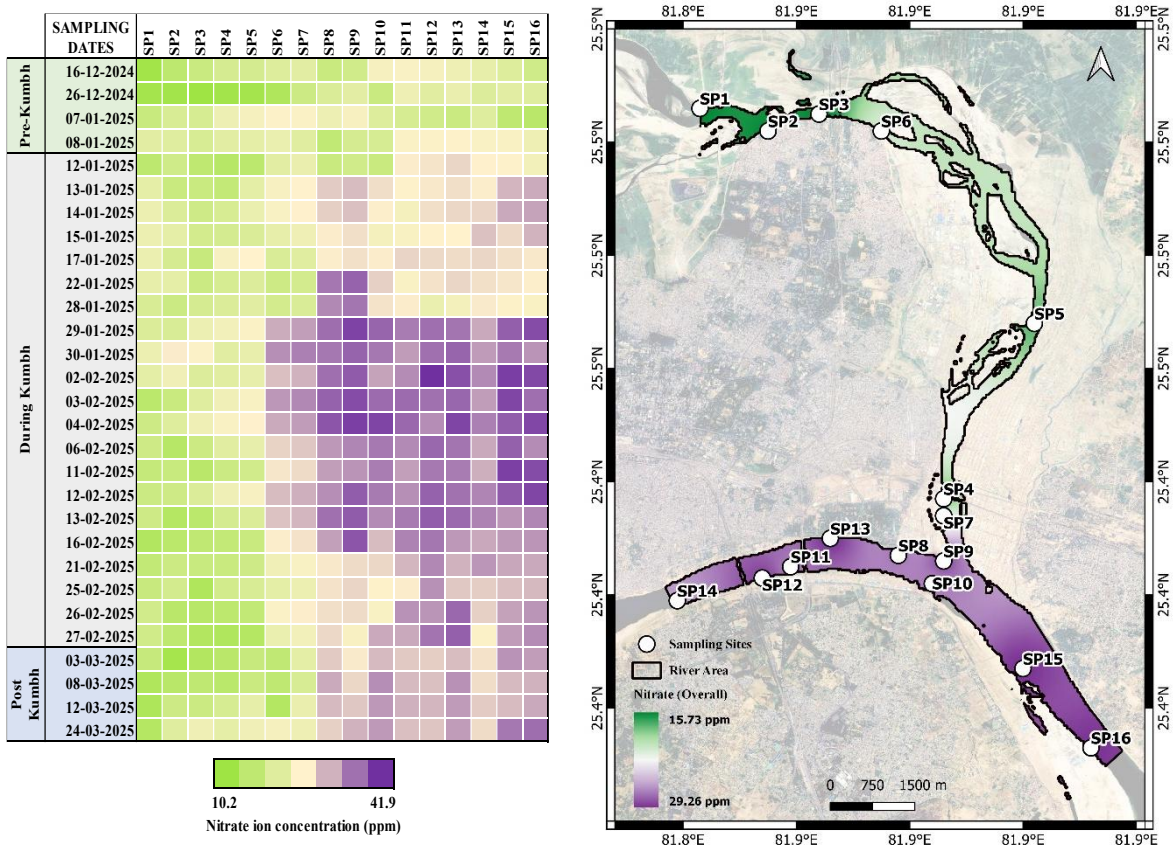
(a) (b)

Figure 2.9. Variation of DO in ppm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.7 Nitrate Concentration

Nitrate (NO_3^-) is a crucial nutrient for aquatic plants and phytoplankton growth but in excess it can lead to nutrient enrichment in the water body and eutrophication. However, elevated nitrate levels do not indicate presence of pollution directly, they may also indicate past pollution levels as nitrate appear in water after nitrogenous wastes are sufficiently oxidized to nitrate by

dissolved oxygen. Mass bathing often increases river nitrate concentration by introducing organic waste and sewage from pilgrims, which contains nitrogen-rich compounds that are converted to nitrates through nitrification. Heatmap and spatial distribution of all sixteen sampling sites shows Ganga upstream SP1 to SP7 having lower nitrate value as compared to River Yamuna (SP11-SP14), Sangam (SP8-SP9) and downstream sites of Ganga (SP15 and SP16) indicating river's natural assimilative capacity and recovery from the organic and ammoniacal nitrogenous loads (Fig 2.10a and b). Post-Kumbh, nitrate levels declined overall, with rapid recovery at upstream sites, partial reduction at major ghats, and persistently elevated concentrations downstream.



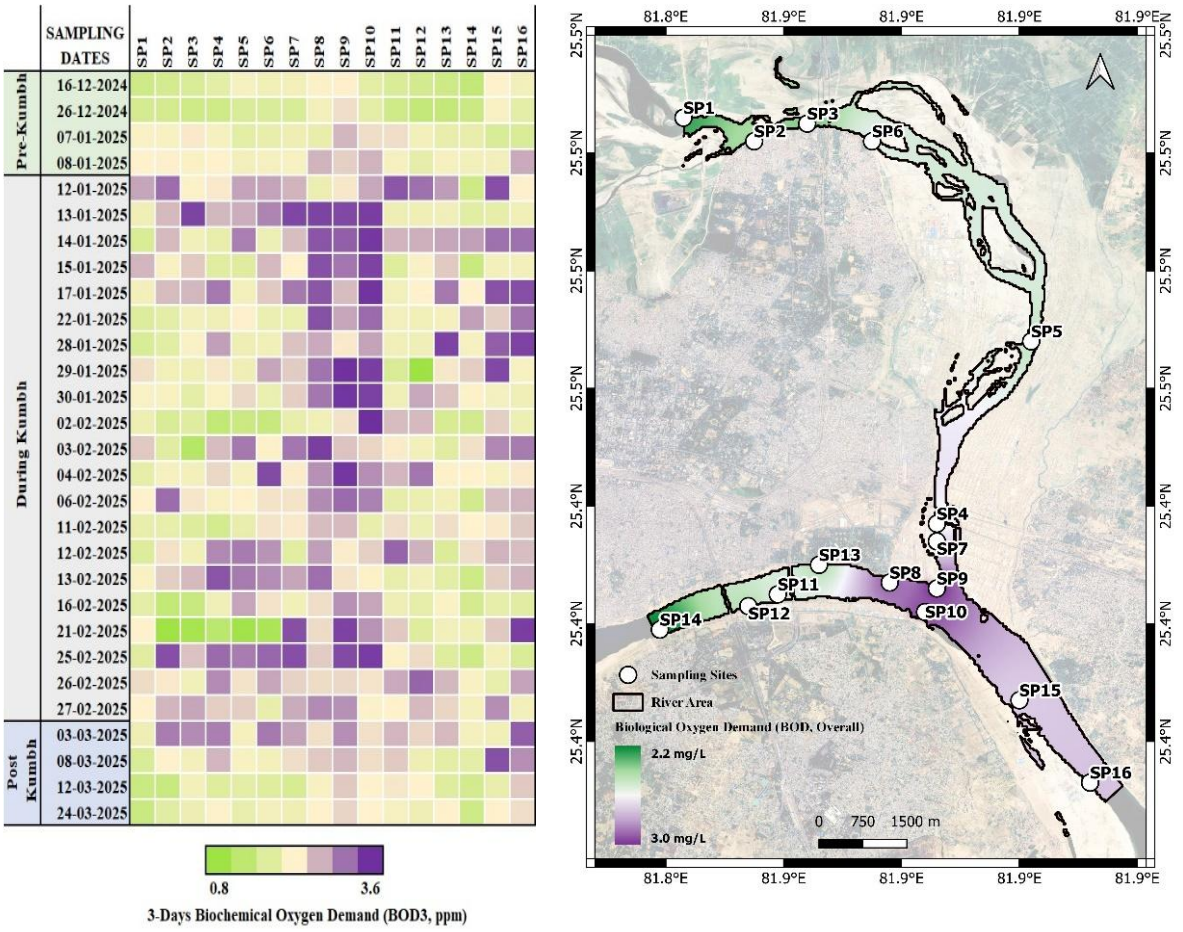
(a) (b)

Figure 2.10. Variation of nitrate ion in ppm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.8 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) measures the amount of dissolved oxygen required by aerobic microorganisms to decompose organic matter present in water and thus serves as an indirect indicator of organic pollution. CPCB recommends a maximum value of 3 mg/L of 3 days-BOD for outdoor bathing. Heatmap (Figure 2.11a) results show that BOD value observed

were well within this permissible limit for most of the cases ranging from 0.8 to 3.6 mg/L. Elevated BOD (3.6 mg/L), are observed particularly in confluence (SP8, SP9 and SP10) area and Ganga downstream (SP15 and SP16) on major bathing and its subsequent days. This may be due to combined contribution of decaying organic matter, food waste, and ritual offerings amplifies this effect (Figure 2.11b). Elevated BOD not only compromises aquatic life but also reduces the self-purifying capacity of the river, prolonging the recovery time after the event. Similarly, spatial distribution of mean values at sites indicates hotspots (higher values) at confluence and downstream sites. In contrast, BOD levels return to their lower, pre-event concentrations in the post-Kumbh period at most of the sites, highlighting the transient yet potent environmental impact of the event.



(a) (b)

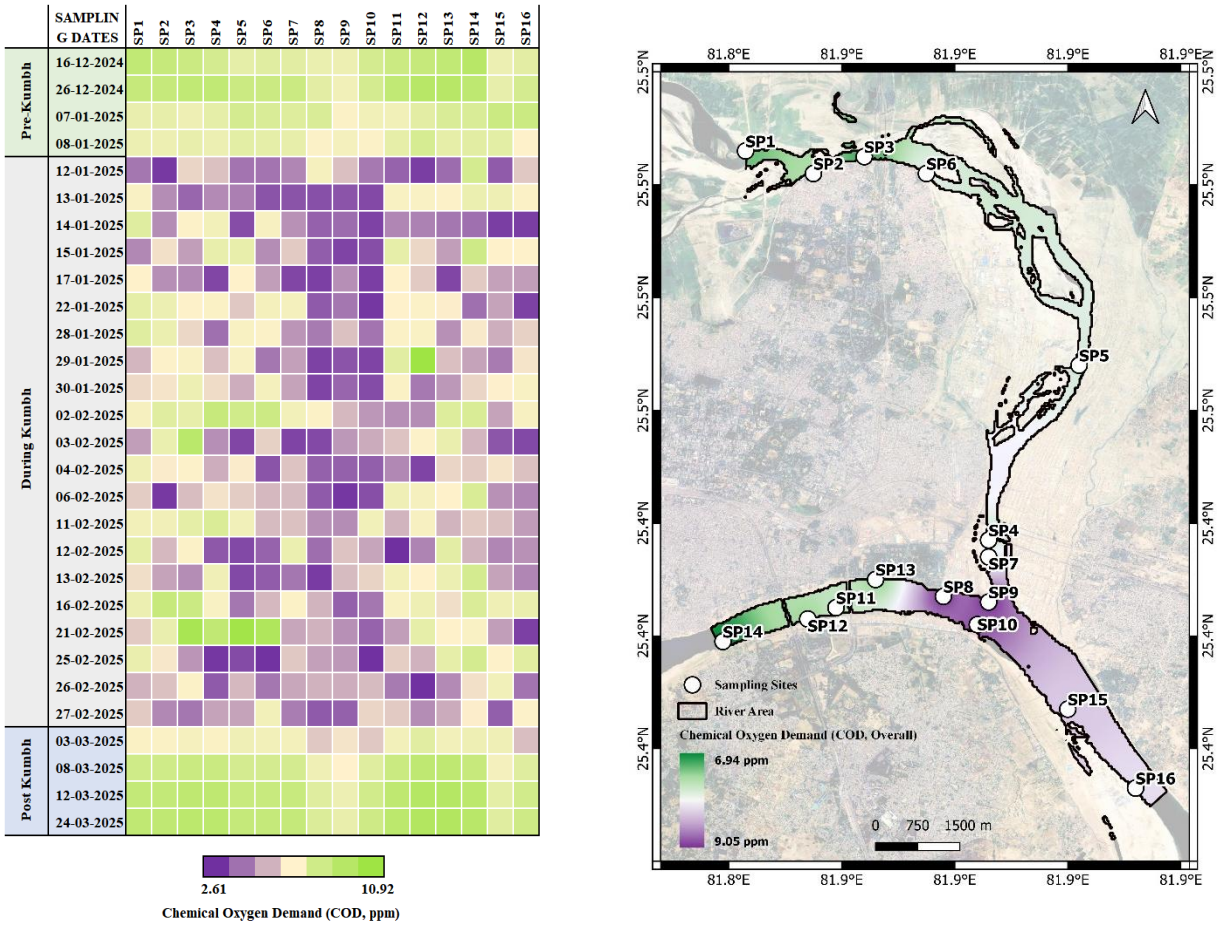
Figure 2.11. Variation of BOD in ppm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.9 Chemical Oxygen Demand (COD)

Like BOD, Chemical Oxygen Demand (COD) measures the amount of oxygen required to oxidize organic and inorganic pollutants in water. COD thus, provides a faster and more

comprehensive estimate of the total oxidizable load, including compounds that are resistant to biological degradation. It is particularly useful in identifying industrial and domestic pollution, as it reflects the overall strength of wastewater. Heatmap (Figure 2.12a) and spatial map (Figure 2.12b) represent the variation in COD for pre, during and post Kumbh at different sampling sites.

COD variation suggests that higher values are more prominent during Kumbh, while post-event the values return to their lower pre-Kumbh values. This temporary but substantial increase correlates with the mass gathering, suggesting a considerable influx of non-biodegradable and biodegradable organic matter into the aquatic system due to the large-scale congregation. Values are overall found to vary from 2.61 to 10.92 ppm at all sites, with higher values dominating the *Sangam* region. Similarly, spatial distribution of mean values at sites indicates hotspots (higher values) at confluence and downstream sites.

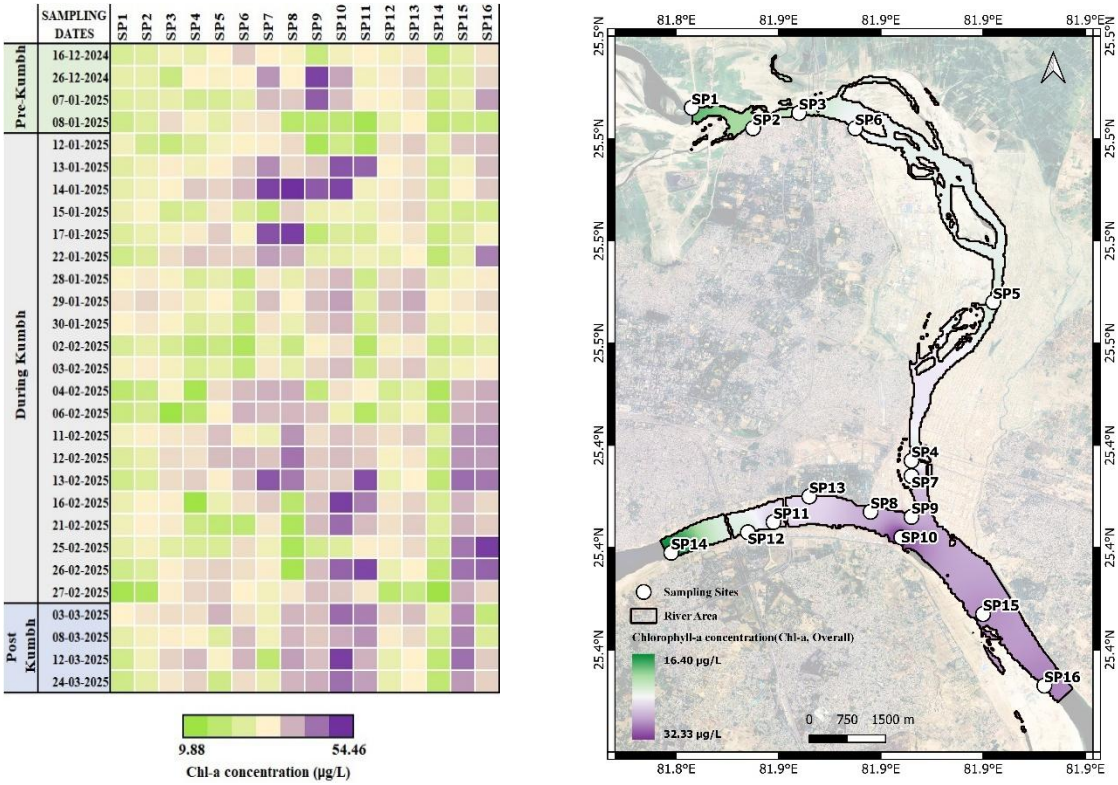


(a) (b)

Figure 2.12. Variation of COD in ppm, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.1.10 Chlorophyll-a (Chl-a) Concentration

Monitoring Chlorophyll-a (a primary pigment found in algae and aquatic plants for photosynthesis) concentration in aquatic water bodies is essential for understanding trophic status, as higher concentrations often indicate eutrophic or nutrient-enriched conditions. This parameter is often influenced by nutrient availability (notably nitrate and phosphate), light penetration, water temperature, and hydraulic residence time. As a result of mass bathing events like Kumbh, various unintentional additions like soaps, detergents, food offerings, and organic matter releases nitrogen and phosphorus into the river, creating favourable conditions for phytoplankton growth leading to rise in Chl-a levels. However, due to its dependence on other factors (as mentioned above), its distribution often follows sporadic pattern as is evident from the heatmap (Figure 2.13a). Still, it can be observed that major bathing sites like SP8, SP9, and SP10 show higher Chl-a levels. Further, downstream sites SP15 and SP16 show higher accumulated concentration of the Chl-a . Finally, interpolated result (Figure 2.13b) shows that hotspots occur at sampling point SP10 (mean value of 32.33 µg/mL) indicated as chlorophyll hotspot. In contrast, both the Pre- and Post-Kumbh periods exhibit substantially lower Chlorophyll-a concentrations, reflecting a return to baseline ecological conditions.



(a) (b)

Figure 2.13. Variation of Chlorophyll-a in µg/L, (a) heatmap representation of variation at sampling sites during sampling days, (b) mean spatial variation across all sites

2.4.2 Correlation Analysis

Table 2.4 shows that average or arithmetic mean and standard deviation (SD) for the physio-chemical parameters of water samples collected from all sixteen sampling locations in Pre, during, and post Kumbh phases. Further, inter-relationships of these water quality parameters were assessed to study the mutual responses of them to mass-bathing impacts during the three phases of Kumbh (Figure 2.14). This was done using Pearson's correlation coefficient (r-value) which ranged from -1 (least similar in their behaviors) to +1 (most similar in their behaviors). This was performed for the mean values at all sites for the three sampling phases (pre, during, and post-Kumbh) as well as for 'overall' mean values for the entire sampling period.

Table 2.4. Mean and SD of different parameters across all sampling locations during the three analytical phases of Kumbh.

Parameter	Unit	Pre-Kumbh			During Kumbh			Post-Kumbh		
		mean	±	SD	mean	±	SD	mean	±	SD
WST	°C	17.67	±	0.40	20.31	±	0.27	27.28	±	0.17
pH		7.70	±	0.32	8.41	±	0.05	8.23	±	0.17
Turbidity	FNU	22.52	±	5.66	49.01	±	22.78	39.78	±	14.51
EC	µS/cm	629.00	±	160.81	669.77	±	199.04	671.78	±	198.44
TDS	ppm	314.44	±	80.16	334.91	±	99.40	335.92	±	99.21
DO	ppm	8.15	±	0.19	8.39	±	0.29	6.98	±	0.51
Nitrate	ppm	17.32	±	1.63	25.01	±	6.01	22.74	±	6.48
BOD	mg/L	2.24	±	0.20	2.66	±	0.24	2.50	±	0.28
COD	ppm	6.01	±	0.55	8.66	±	0.65	5.79	±	0.79
Chl-a	µg/L	22.31	±	4.22	24.71	±	4.30	27.38	±	7.79

Overall (arithmetic mean over all sites for all sampling days) correlation results of water quality parameters (Figure 2.14a) show a very strong positive correlation between BOD and COD (+0.983) with significantly positive correlation in EC-TDS (+0.992), and pH-COD (+0.817), while DO negatively correlated with nitrate (-0.428), Chl-a (-0.441), BOD (-0.555), and COD (-0.609). Pre-Kumbh (Figure 2.14b) correlation results show strong positive correlation of pH with WST (+0.844), with BOD (+0.812), and with COD (+0.872). Further, BOD-COD exhibited a strong correlation of +0.983. Lowest correlation was observed for DO-BOD (-0.371). However, if one observes closely, as Kumbh progresses it starts to shift towards more similar nature (-0.193 during and -0.123 post Kumbh). During Kumbh (Figure 2.14c), strong positive correlation was observed for pH with BOD (+0.770), and COD (+0.881) with highest correlation between EC-TDS (+0.989) and BOD-COD (+0.921). WST positively correlated with COD while DO negatively correlated with most of the water quality parameters. An

interesting observation for the mean values during Kumbh reveals that DO exhibited a slight positive correlation with WST (+0.136) as measured for all sites. Similarly, post-Kumbh (Figure 2.14d) reveals highest correlation between EC-TDS (+0.996) and TDS-Nitrate (+0.721), while the lowest correlation was observed for WST-DO (-0.776) and DO-Chl-a (-0.372).



	WST	pH	Turbidity	EC	TDS	DO	Nitrate	BOD	COD
pH	0.127								
Turbidity	-0.384	0.693							
EC	0.646	0.767	0.257						
TDS	0.647	0.767	0.256	0.992					
DO	-0.064	-0.475	-0.478	-0.403	-0.404				
Nitrate	0.701	0.522	-0.024	0.874	0.875	-0.428			
BOD	0.2	0.799	0.707	0.747	0.747	-0.555	0.505		
COD	0.178	0.817	0.737	0.719	0.718	-0.609	0.459	0.983	
Chl-a	0.279	0.611	0.404	0.686	0.686	-0.441	0.598	0.871	0.82

(a) Overall

	WST	pH	Turbidity	EC	TDS	DO	Nitrate	BOD	COD
pH	0.844								
Turbidity	0.577	0.565							
EC	0.24	0.5	0.196						
TDS	0.241	0.501	0.196	0.991					
DO	-0.05	-0.149	-0.297	-0.166	-0.167				
Nitrate	0.737	0.622	0.328	0.553	0.554	-0.222			
BOD	0.683	0.812	0.736	0.613	0.614	-0.371	0.587		
COD	0.868	0.872	0.78	0.474	0.474	-0.283	0.675	0.947	
Chl-a	0.4	0.538	0.413	0.499	0.5	-0.364	0.501	0.72	0.617

(b) Pre-Kumbh

	WST	pH	Turbidity	EC	TDS	DO	Nitrate	BOD	COD
pH	0.835								
Turbidity	0.45	0.557							
EC	0.19	0.365	0.245						
TDS	0.19	0.366	0.245	0.989					
DO	0.136	0.125	-0.166	-0.226	-0.227				
Nitrate	0.624	0.568	0.289	0.645	0.646	-0.116			
BOD	0.621	0.77	0.749	0.613	0.613	-0.193	0.607		
COD	0.79	0.881	0.738	0.415	0.415	0.022	0.647	0.921	
Chl-a	0.311	0.412	0.391	0.54	0.54	-0.306	0.509	0.713	0.545

(c) During Kumbh

	WST	pH	Turbidity	EC	TDS	DO	Nitrate	BOD	COD
pH	0.391								
Turbidity	0.158	0.567							
EC	0.072	0.29	0.151						
TDS	0.073	0.29	0.151	0.996					
DO	-0.776	-0.042	-0.099	-0.149	-0.15				
Nitrate	0.206	0.451	0.195	0.72	0.721	-0.134			
BOD	0.179	0.653	0.678	0.586	0.586	-0.123	0.575		
COD	-0.304	0.64	0.613	0.327	0.327	0.437	0.466	0.711	
Chl-a	0.307	0.32	0.335	0.486	0.487	-0.372	0.483	0.607	0.259

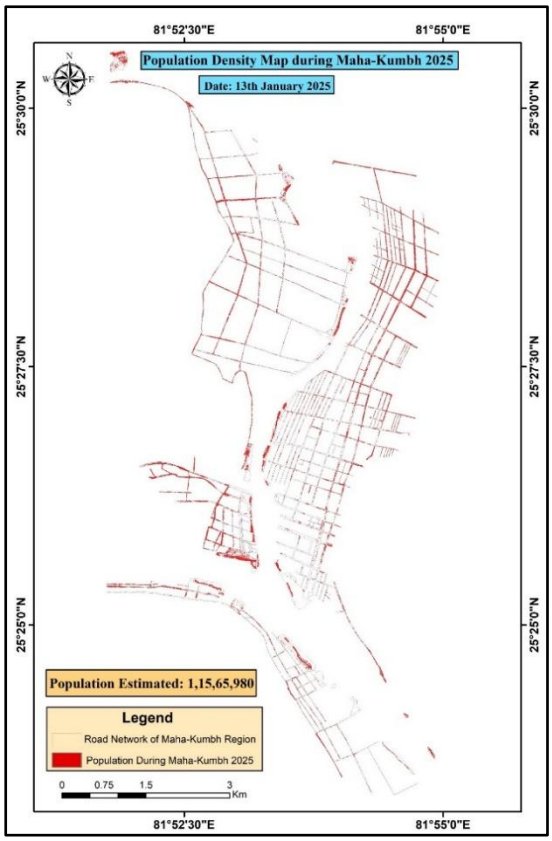
(d) Post-Kumbh

Figure 2.14. Correlation analysis between water quality parameters (a) Overall, (b) Pre-Kumbh, (c) During-Kumbh Kumbh, and (d) Post-Kumbh.

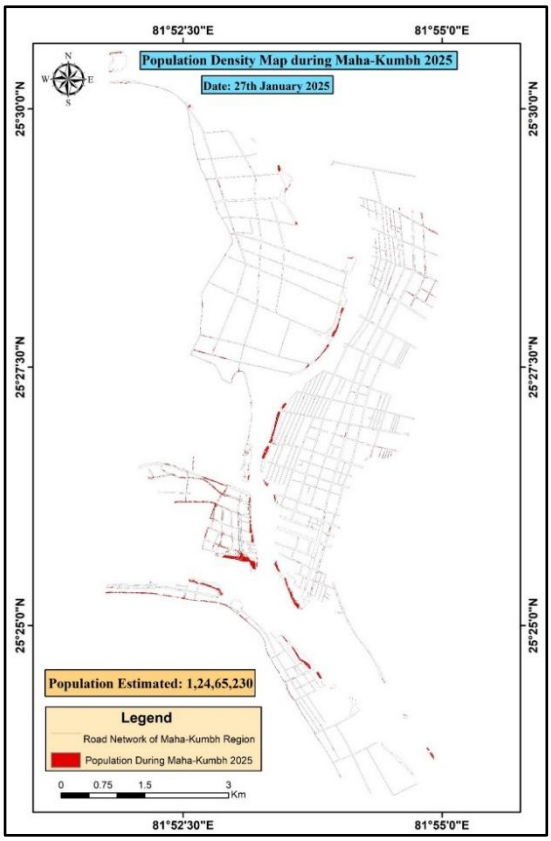
2.4.3 Remote Sensing Aspects

2.4.3.1 Population estimation

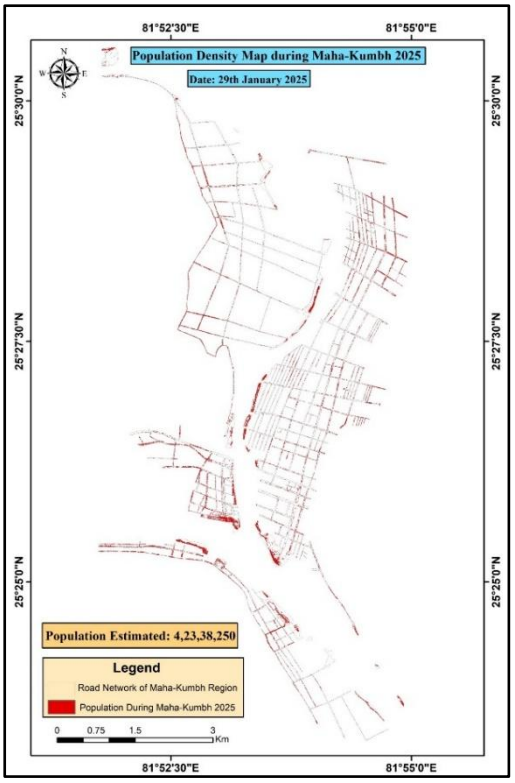
Floating population density estimation provides a realistic approximation of the mass gathering of devotees (floating population) during major bathing days. Geospatial analysis of high-resolution data helps in mapping sector-wise distribution of floating population to identify hot-spots. The population density map of major bathing days is illustrated in Figure 2.15a-f. Spatial distribution indicates mass population concentration is aligned along the major road networks and near riverfront areas, as highlighted in red. With the help of this approach, estimated population was 1,15,65,980, 1,24,65,230, and 4,23,38,250 for January 13th, 27th, and 29th, respectively. The estimated floating population for February 3rd, 10th, and 26th was 2,28,41,100, 1,95,19,700, and 1,64,98,200, respectively.


Population Density Map during Maha-Kumbh 2025
Date: 13th January 2025
81°52'30"E
81°55'0"E
25°30'0"N
25°27'30"N
25°25'0"N
Population Estimated: 1,15,65,980
Legend
Road Network of Maha-Kumbh Region
Population During Maha-Kumbh 2025
0 0.75 1.5 3 Km

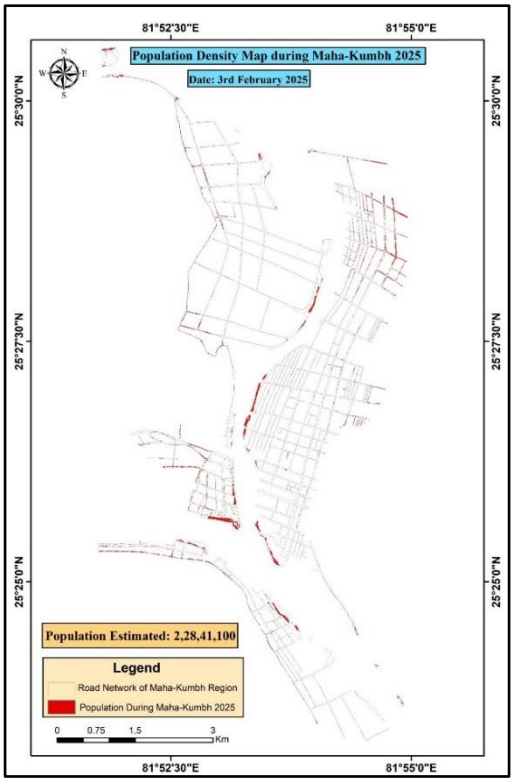
(a)


Population Density Map during Maha-Kumbh 2025
Date: 27th January 2025
81°52'30"E
81°55'0"E
25°30'0"N
25°27'30"N
25°25'0"N
Population Estimated: 1,24,65,230
Legend
Road Network of Maha-Kumbh Region
Population During Maha-Kumbh 2025
0 0.75 1.5 3 Km

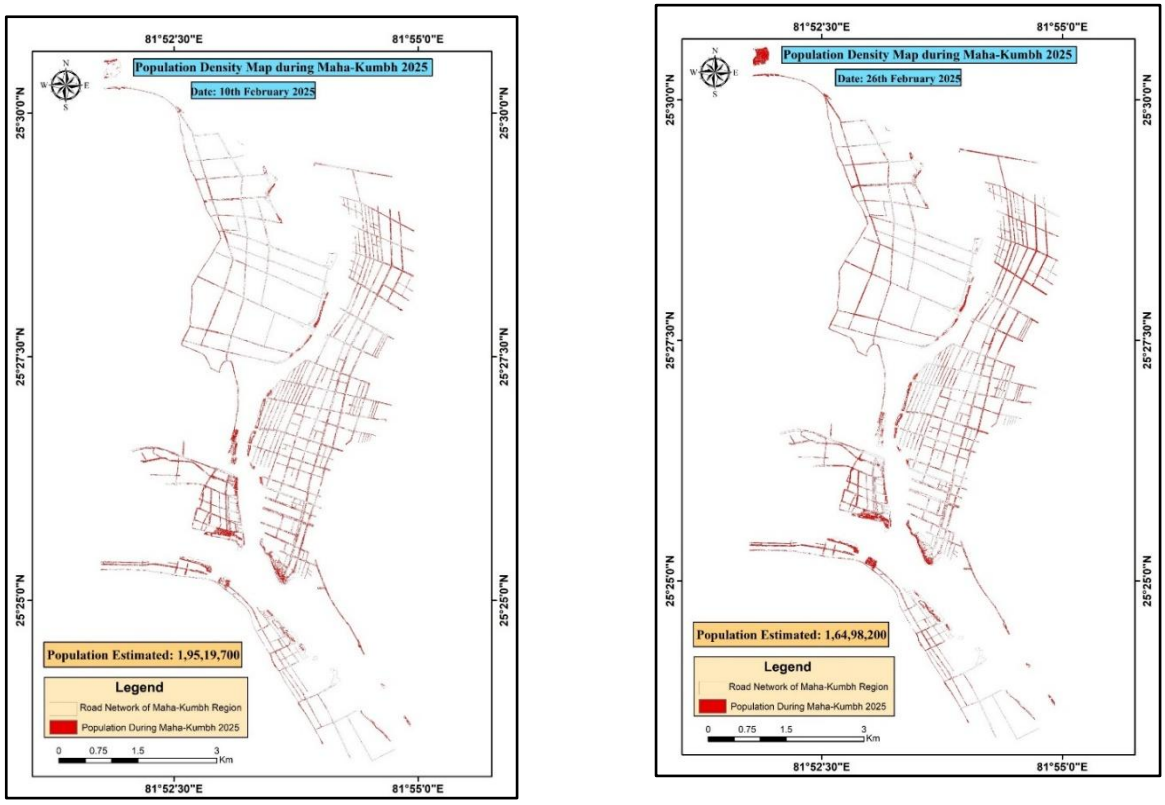
(b)


Population Density Map during Maha-Kumbh 2025
Date: 29th January 2025
81°52'30"E
81°55'0"E
25°30'0"N
25°27'30"N
25°25'0"N
Population Estimated: 4,23,38,250
Legend
Road Network of Maha-Kumbh Region
Population During Maha-Kumbh 2025
0 0.75 1.5 3 Km

(c)


Population Density Map during Maha-Kumbh 2025
Date: 3rd February 2025
81°52'30"E
81°55'0"E
25°30'0"N
25°27'30"N
25°25'0"N
Population Estimated: 2,28,41,100
Legend
Road Network of Maha-Kumbh Region
Population During Maha-Kumbh 2025
0 0.75 1.5 3 Km

(d)



(e) (f)

Figure 2.15. Estimated Population density map during Maha-Kumbh 2025

(a) 13/01/2025, (b) 27/01/2025, (c) 29/01/2025, (d) 03/02/2025, (e) 10/02/2025, (f) 26/02/2025

However, these estimated results were compared with official data obtained from the Prayagraj Mela Authority that indicate a notable discrepancy during different bathing dates. Fig 2.16 shows the comparison of estimated population with mela authority's data. In January (13th and 27th) and February (3rd and 10th), Mela Authority values were higher than geospatial estimates, whereas on 26th February both results conversed more closely. The geospatial data-based approach shows underestimation mainly due to limitations of resolution of satellite data as well as estimating people present at a certain during the satellite data acquisition. These comparative results show systematic variation and provide a holistic understanding that a comprehensive approach can be taken in future that encapsulate both approaches (Mela authority and remote sensing data) to attain much better estimates of headcounts for such mass gatherings.

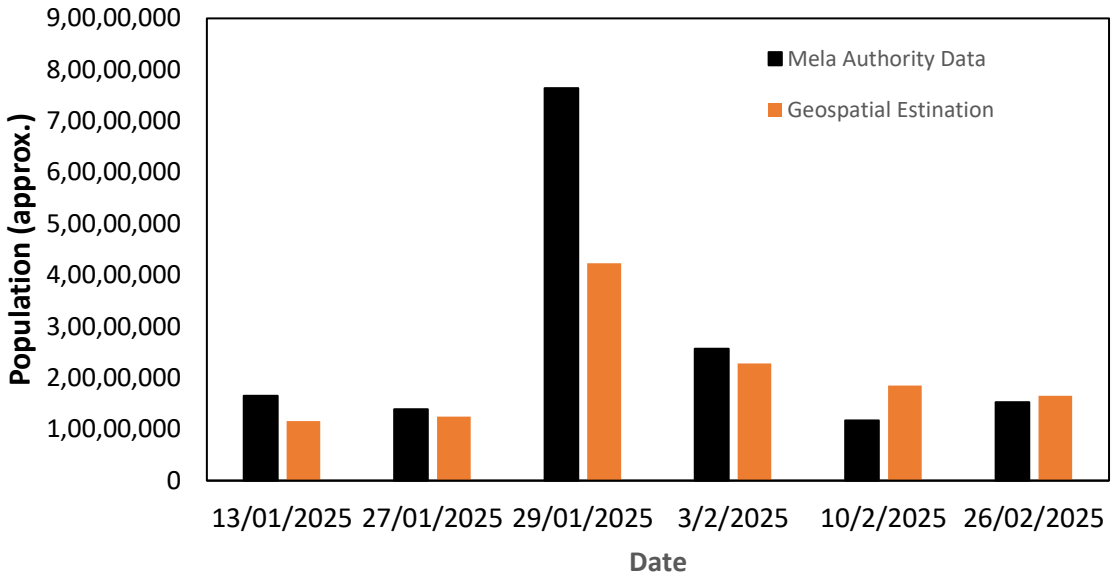
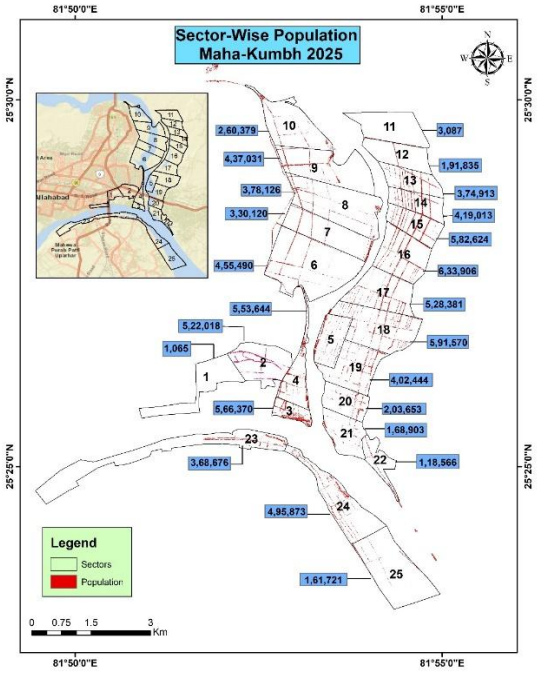


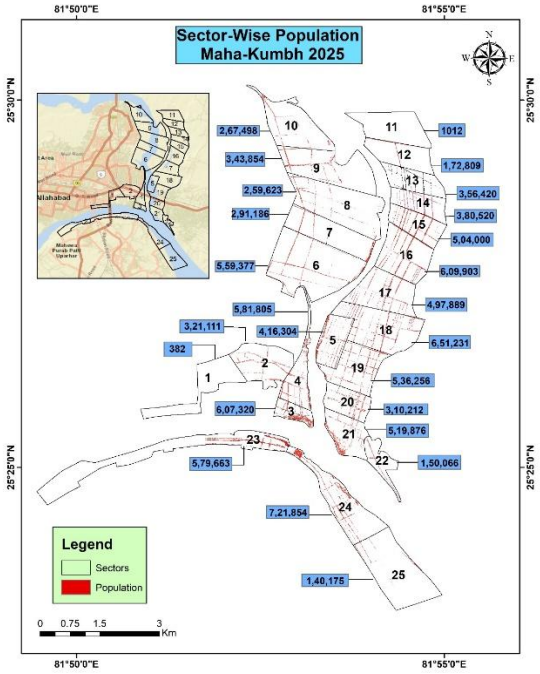
Figure 2.16. Comparison of population (approx.) reported by Mela Authority and estimated from the geospatial Approach.

2.4.3.2 Sector-wise crowd density estimation

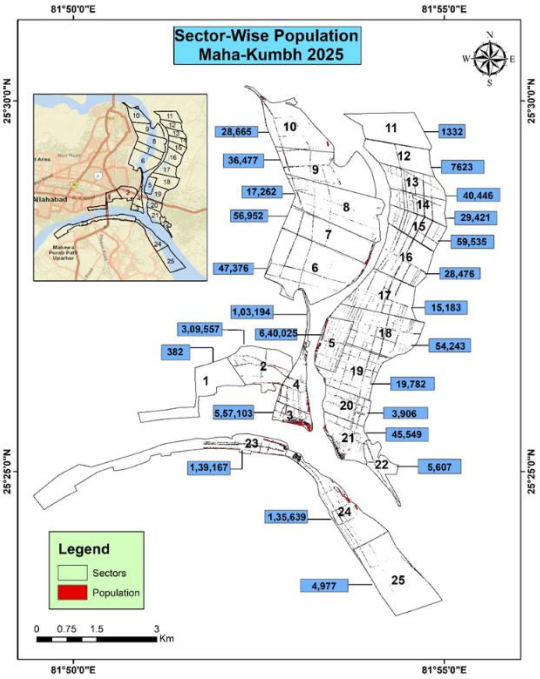
To manage the surge of millions of pilgrims estimated to attend the Maha Kumbh 2025, the Mela authority divided the entire mela area into a total of twenty-five sectors. Therefore, sector-wise estimation of population is essential to understand their distribution and identify hotspots. All available satellite imageries were processed using NDRE-based thresholding to differentiate populated zones from background areas, and population was calculated by multiplying pixel counts with per-pixel head-count estimates. Sector-wise crowd presence was estimated using high-resolution remote sensing data to capture the spatial distribution of pilgrims across the Maha-Kumbh area (Fig. 2.17a-j). The maximum population was estimated in Sector 3 (Sangam nose and VIP ghat area), Sector 21 (Arail ghat), and Sector 24 (Ganga downstream), which were also major bathing locations. Sampling sites SP7 and SP8 were in Sector 3, whereas SP15 and SP16 were in Sector 21 and 24, hence, these sites showed maximum impacts on water quality during peak-bathing events. Thus, sector-wise population density is crucial for correlating mass gathering pressure with water quality assessments during Kumbh, especially during major bathing events.


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
2,60,379
4,37,031
3,78,126
3,30,120
4,55,490
5,53,644
5,22,018
1,065
5,66,370
3,68,876
4,95,873
1,61,721
3,087
1,91,835
3,74,913
4,19,013
5,82,624
5,33,906
5,28,381
5,91,570
4,02,444
2,03,653
1,68,903
1,18,566
Legend
Sectors
Population
0 0.75 1.5 3
Km

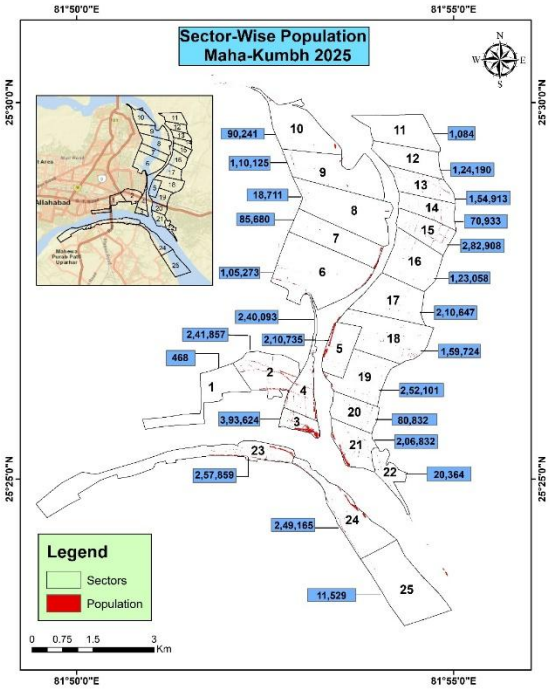
(a)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
2,67,498
3,43,854
2,59,623
2,91,186
5,59,377
5,81,805
3,21,111
4,16,304
382
6,07,320
5,79,663
7,21,854
1,40,175
1012
1,72,809
3,56,420
3,80,520
5,04,000
6,09,903
4,97,889
6,51,231
5,36,256
3,10,212
5,19,876
1,50,066
Legend
Sectors
Population
0 0.75 1.5 3
Km

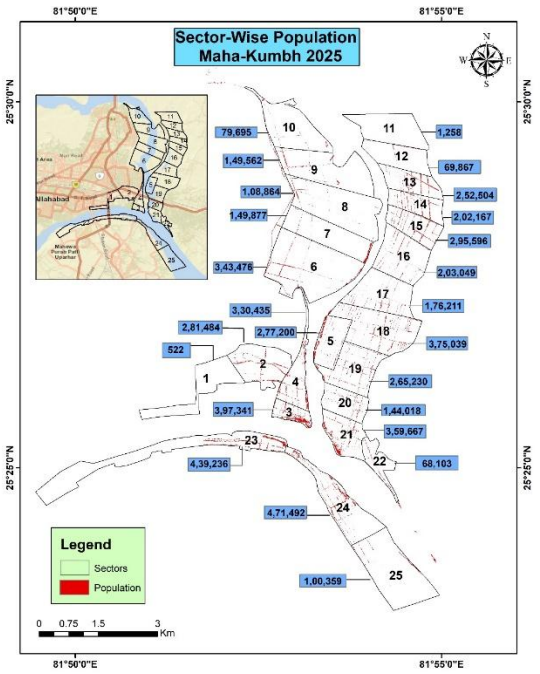
(b)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
28,665
36,477
17,262
56,952
47,376
1,03,194
3,09,557
6,40,025
382
5,57,103
1,39,167
1,35,639
4,977
1332
7623
40,446
29,421
59,535
28,476
15,183
54,243
19,782
3,906
45,549
5,607
Legend
Sectors
Population
0 0.75 1.5 3
Km

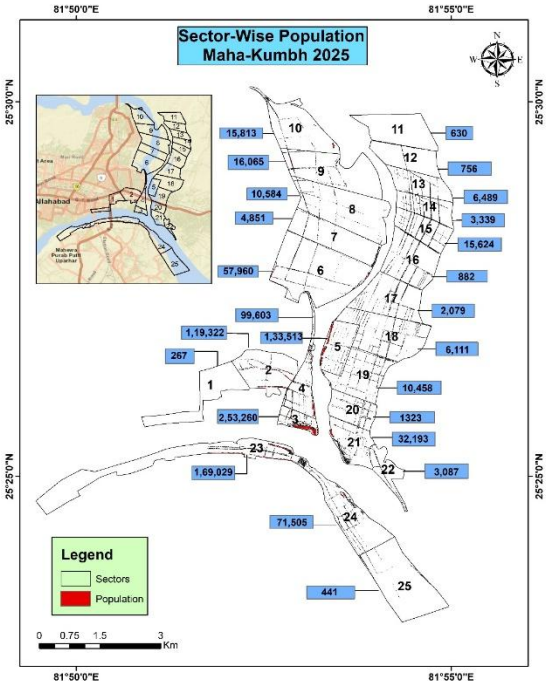
(c)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
90,241
1,10,125
18,711
85,680
1,05,273
2,40,093
2,41,857
2,10,735
468
3,93,624
2,57,859
2,49,165
11,529
1,084
1,24,190
1,54,913
70,933
2,82,908
1,23,058
2,10,647
1,59,724
2,52,101
80,832
2,06,832
20,364
Legend
Sectors
Population
0 0.75 1.5 3
Km

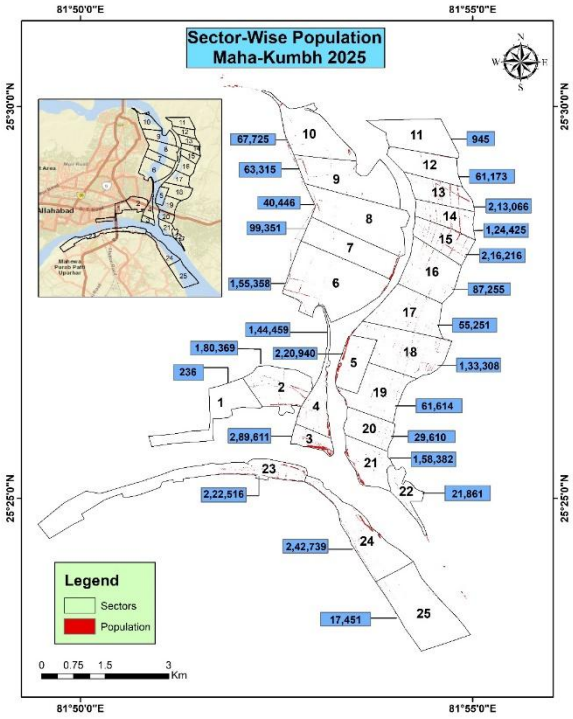
(d)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
79,695
1,49,562
1,08,884
1,49,877
3,43,476
3,30,435
2,81,484
2,77,200
522
3,97,341
4,39,236
4,71,492
1,00,359
1,258
69,867
2,52,504
2,02,167
2,95,596
2,03,049
1,76,211
3,75,039
2,65,230
1,44,018
3,59,667
68,103
Legend
Sectors
Population
0 0.75 1.5 3
Km

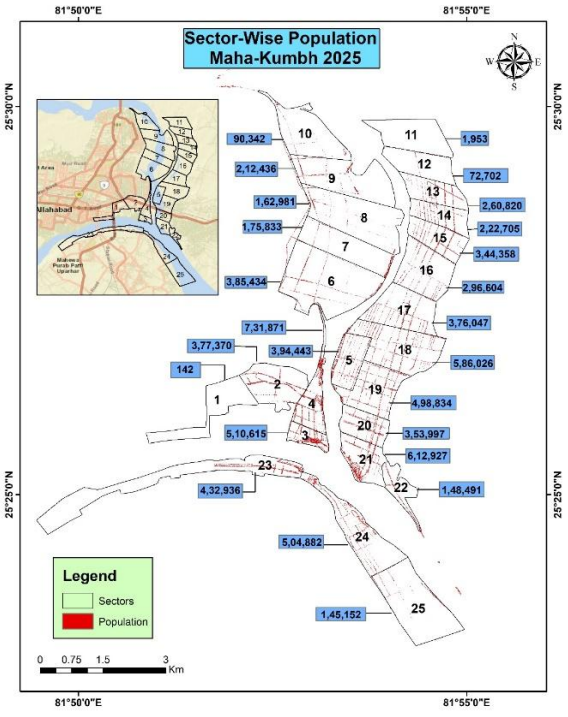
(e)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
15,813
16,065
10,584
4,851
57,960
99,603
1,19,322
1,33,513
267
2,53,260
1,69,029
71,505
441
630
756
6,489
3,339
15,624
882
2,079
6,111
10,458
1323
32,193
3,087
Legend
Sectors
Population
0 0.75 1.5 3
Km

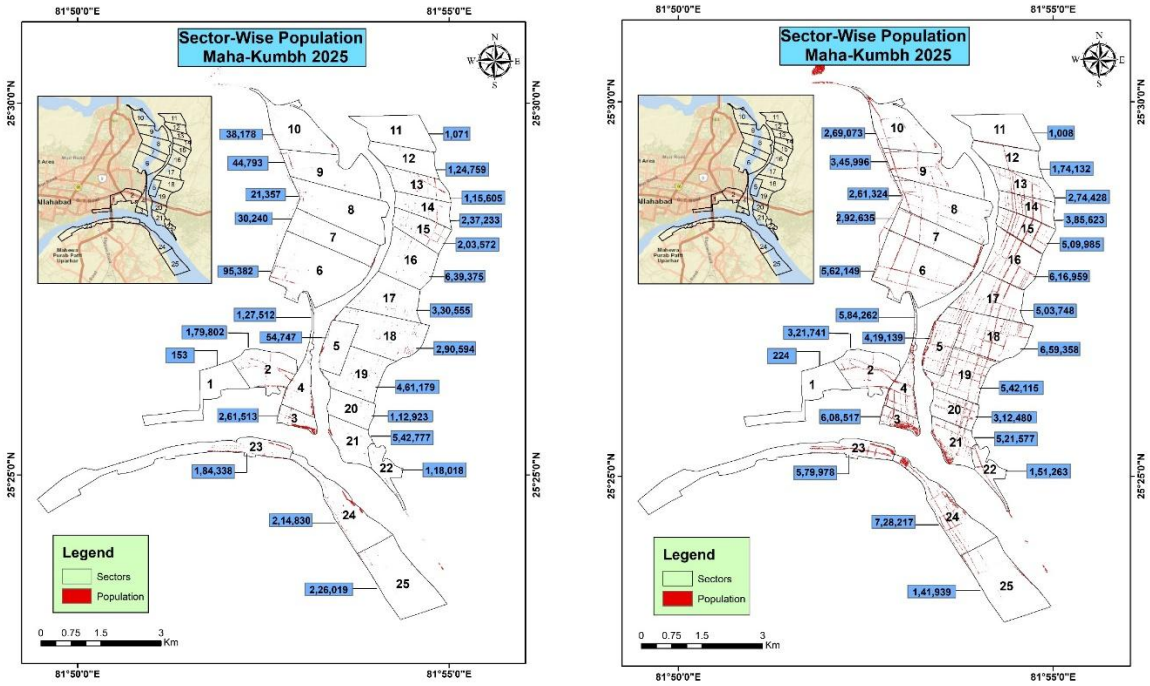
(f)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
67,725
63,315
40,446
99,351
1,55,358
1,44,459
1,80,369
2,20,940
236
2,89,611
2,22,516
2,42,739
17,451
945
61,173
2,13,066
1,24,425
2,16,216
87,255
55,251
1,33,308
61,614
29,610
1,58,382
21,861
Legend
Sectors
Population
0 0.75 1.5 3
Km

(g)


Sector-Wise Population
Maha-Kumbh 2025
81°50'0"E
81°55'0"E
25°30'0"N
25°25'0"N
90,342
2,12,436
1,62,981
1,75,833
3,85,434
7,31,871
3,77,370
3,94,443
142
5,10,615
4,32,936
5,04,882
1,45,152
1,953
72,702
2,60,820
2,22,705
3,44,358
2,96,604
3,76,047
5,86,026
4,98,834
3,53,997
6,12,927
1,48,491
Legend
Sectors
Population
0 0.75 1.5 3
Km

(h)



(i) (j)

Figure 2.17. Crowd estimation, sector-wise

(a) 17/01/2025, (b) 22/01/2025, (c) 25/01/2025, (d) 27/01/2025, (e) 29/01/2025, (f) 01/02/2025, (g) 03/02/2025, (h) 10/02/2025, (i) 16/02/2025, and (j) 26/02/2025

2.5 Summary

Managing the floating population and maintaining the water quality for bathing and other ritual activities is a challenging task. Heatmap and spatial map of various water quality parameters show that pH, BOD and COD indicate a hike in major bathing days during Kumbh at SP9, Sangam regions and their cumulative effect is observed in SP15 and SP16 sampling sites. Both Overall population density and sector-wise population density data supplement each other and are positively linked with water quality deterioration mainly on major bathing days. Additionally, DO negatively correlates with BOD, COD and temperature. Nitrate is constantly high in the Yamuna River and Sangam area, and this accumulation of nitrogen-containing waste has impacts on the Ganga downstream. Chlorophyll-a positively correlated with temperature and nitrate, and its distribution is also linked to high BOD and DO fluctuations, showing a potential for eutrophication. The Post Kumbh reduction in contaminants and return to baseline indicated successful self-purification and short-term recovery across all sampling locations for different parameters. However, the geospatial map shows lower DO and higher temperature in the post-Kumbh phase, primarily due to seasonal variation. The process of self-purification for

river restoration is prolonged due to the sudden surge in mass gathering for ritual activities. Additionally, the controlled release of freshwater is necessary during the major bathing days to dilute pollutants and maintain water quality standards. Collectively, the findings highlight that while the river demonstrates an inherent capacity for partial recovery post-event, the scale of pollutant loading during the Kumbh poses a considerable challenge to its assimilative capacity. The study underscores the urgent need for proactive measures, including enhanced sewage treatment infrastructure, regulated discharge management, timely flow augmentation from upstream barrages, and sector-wise monitoring strategies. Implementation of such measures can mitigate peak-event water quality deterioration, protect aquatic biota, and safeguard public health.

2.6 Key Takeaways for Stakeholders for Future Events

The present study, although, depicts that the river demonstrates an inherent capacity for partial recovery post-event, the scale of pollutant loading during the Kumbh poses a considerable challenge to its assimilative capacity. It thus underscores an urgent need for certain proactive measures like enhanced STP infrastructure, regulated discharge management, timely flow augmentation from upstream barrages, and sector-wise monitoring strategies for such future events. At present, though several temporary Wastewater Treatment setups (eg, STPs and Geo-tubes) are being used, still more focused Nature-Based Treatment approaches (constructed wetland) can be considered to achieve sustainable management of domestic wastewater in such large-scale events. This requires more accurate predictions about mass gathering with respect to freshwater discharge, which may further help in maintaining water quality for outdoor bathing and other ritual activities. Implementation of such measures can mitigate peak-event water quality deterioration, protect aquatic biota, and safeguard public health. Further, sufficient sanitation and volunteers (*Safai Mitras* and *Ganga Sewa Dost*) need to be appointed for collecting various ritual offerings, including certain non-biodegradable wastes (plastic wrappers and bottles) left by pilgrims. Regular real-time water quality monitoring may further provide immediate assurance safety of pilgrims and alert water management authorities to appropriate responsive strategies.

Chapter 3: Geospatial Data for Infrastructure Mapping

3.1 Introduction

This chapter presents the background of the Maha Kumbh 2025, addressing its immense scale, and the associated logistical, public health, and environmental challenges. It reviews existing literature on monitoring mass gatherings, identifies critical research gaps in infrastructure mapping, and outlines the necessity for an advanced, scalable geospatial detection pipeline.

The 2025 Maha Kumbh saw over 660 million cumulative footfalls and daily peaks of 6 to 7 million at any given time ("Press Release:Press Information Bureau," 2025). Preparations were made for up to 400-450 million attendees, supported by the deployment of nearly 150,000 tents and 150,000 to 160,000 toilets across 4,000 hectares, division into 25 sectors, and an extensive transportation, sanitation and administrative system with a major metropolis ("Mahakumbh 2025 Facts and Stats: Know About Prayagraj Kumbh Mela in Numbers and Records," 2025.). Figure 3.1 shows the location map of the study area. In this figure, a very high-resolution satellite image with a spatial resolution of 30 cm and eight multispectral bands was used to identify temporary infrastructure such as tents, toilets, pontoon bridges, major bathing ghats, and other related facilities.

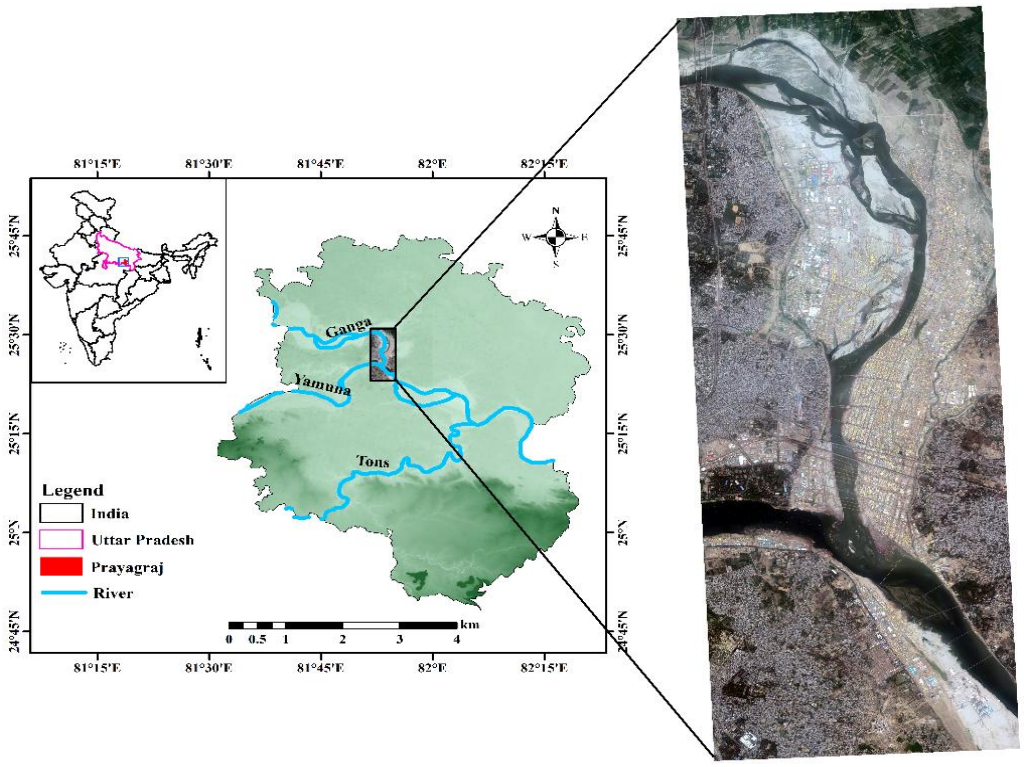


Figure 3.1. Location map of the Study Area

Historically, management relied on manual surveys, field census methods, and paper maps that were slow, labor-intensive, and fundamentally incapable of capturing the dynamic on-ground realities (AG Horizon, 2025). Recent years have seen a shift towards digital solutions: satellite imagery, Earth Observation (EO) platforms, and artificial intelligence are now integrated into event monitoring, crowd counting, and resource planning ("Maha Kumbh Mela Captured by ISRO's Satellite; Space Organisation Releases Images - The Economic Times," 2025). Several studies have addressed the monitoring of mass gatherings using remote sensing (Sirmacek & Reinartz, 2013). However, previous research is constrained by the quality of the data and methods employed. The current availability of very high-resolution satellite data offers a significant opportunity to enhance the analysis for events like the Kumbh Mela. Nevertheless, many existing object detection approaches are unsuitable because standard algorithms using horizontal bounding boxes fail in the context of dense, closely-packed infrastructure (such as tent clusters), leading to high overlap and inaccurate counts (Sariturk & Seker, 2023). This technical challenge creates a critical gap for developing a consistent and automated pipeline capable of precise, multi-class object detection. While some literature addresses the detection of specific object classes, there remains a lack of an integrated system that combines automated detections with other manually digitized layers (roads, toilets, ghats) into a single, cohesive geospatial database.

3.2 Objectives

The main objectives of this chapter are defined below:

1 Create a labeled dataset for Maha Kumbh infrastructure classes using Very High Resolution (VHR) Satellite image.
2 To identify temporary infrastructure through Deep Learning object detection and manual annotation.
3 To analyze the spatial density of the temporary infrastructure.

3.3 Methodology

Figure 3.2 shows the overall methodology adopted in this study. The process begins with the acquisition of high-resolution satellite imagery from Maxar Technologies. This imagery undergoes a pre-processing sequence that includes band stacking, pansharpening to enhance spatial detail, and tiling the large image into smaller 1024x1024 patches. These patches are then used to create a custom dataset through labeling, splitting into train/validation/test sets, and data augmentation.

The core of the automated workflow is the fine-tuning of a YOLO11 OBB (Oriented Bounding Box) model. This stage encompasses hyper-parameterization, the main model training process, and a final accuracy assessment to produce the best-performing model weight (best.pt). In parallel, a manual feature creation process is undertaken in a GIS environment to digitize other essential infrastructure, such as sectors, roads, bridges, ghats, and parking areas.

In the final stage, the outputs from both workflows are integrated. The detected bounding boxes from the YOLO model are geocoded to translate them into real-world geographic coordinates. This is followed by a manual annotation step to add any undetected tents or toilets, ensuring a complete dataset. Finally, all layers of the automated detections, manual corrections, and manually created features are overlaid on the satellite image and a basemap to produce a comprehensive geospatial database of the Mela infrastructure. The model training setup, accuracy assessment, and additional components are discussed in detail in the following sections.

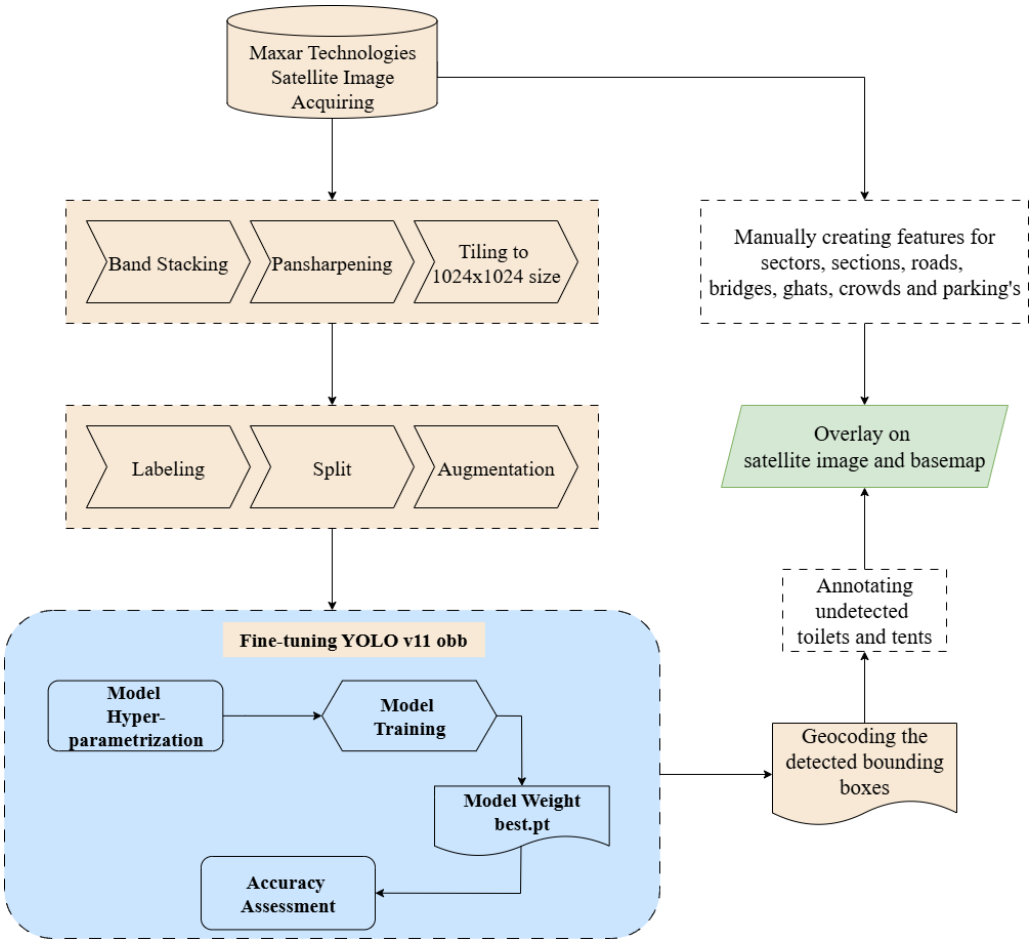


Figure 3.2. Flowchart of the methodology, covering data-to-detection.

3.3.1 Evolution and Limitations of YOLO Model

The YOLO family of models has seen continuous advancements since its debut in 2015. The original YOLO introduced a fast, single-stage object detection system using the Darknet framework. It has continued to evolve across numerous versions, leading up to YOLOv9 and YOLOv10 (2024), which introduced the PGI and GELAN architectures. These architectural improvements, along with consistent dual assignments, support more efficient, NMS-free object detection.

3.3.2 Data and Pre-processing

This section details the geospatial dataset used for this research and the pre-processing steps undertaken to prepare it for the deep learning model.

3.3.3 High-Resolution Satellite Image

This study uses very-high-resolution (VHR) satellite imagery, which covers the Kumbh Mela area in Prayagraj. The imagery was acquired from the WorldView Legion satellite operated by Maxar Technologies on January 29, 2025. The dataset included a high-resolution panchromatic band with a ground sampling distance (GSD) of 30 cm and eight multispectral bands (Coastal, Blue, Green, Yellow, Red, Red-Edge, and Near-Infrared 1 and Near-Infrared 2), all with a GSD of 1.2 m. The imagery was provided in a UTM Zone 44N projection with a WGS 84 datum.

3.3.4 Pansharpening

To enhance the spatial detail of the imagery for accurate tent detection, pansharpening was performed using the pansharpening tool by GDAL in QGIS. This process fuses the high-resolution panchromatic band with the lower-resolution multispectral bands to create a single, high-resolution color image. A Lanczos resampling kernel was selected for this process due to its effectiveness in preserving sharp edges and fine details, which is critical for identifying small, man-made structures like tents. The final pansharpened image achieved a ground resolution of 30 cm, providing a high-resolution color composite suitable for detailed analysis.

3.3.5 Image Tiling

The resulting large-scale pansharpened GeoTIFF image was too large to be processed directly by the deep learning model. Therefore, the image was systematically divided into 816 non-overlapping tiles, each with dimensions of 1024x1024 pixels. This tiling process creates manageable image patches in PNG format, suitable for annotation and for feeding into the YOLO11-OBB model during training and inference.

3.3.6 Training subset labelling and augmentation

The training subset for the YOLO11-OBB model was curated from a larger pool of 816 tiled images. To ensure the model focused on relevant features, only tiles containing visible temporary infrastructure were selected for annotation, effectively excluding empty landscapes from the training process.

To create the custom dataset, the Computer Vision Annotation Tool (CVAT), an open-source platform developed by Intel, was used in this study. CVAT works through a web interface and supports different types of annotation tasks. It was chosen for its ability to handle large amounts of data and support complex annotation shapes, thus matching the object detection requirements. In this setup, about 1,500 tents and 500 toilets were manually labeled in high-resolution satellite image tiles (examples shown in Figure 3.3). Since the settlements were dense and irregular, normal bounding boxes didn't fit well; therefore, this study used the oriented bounding box option in CVAT. This approach enhanced the detection of shape and direction of infrastructure more accurately, providing a reliable ground-truth data for training.

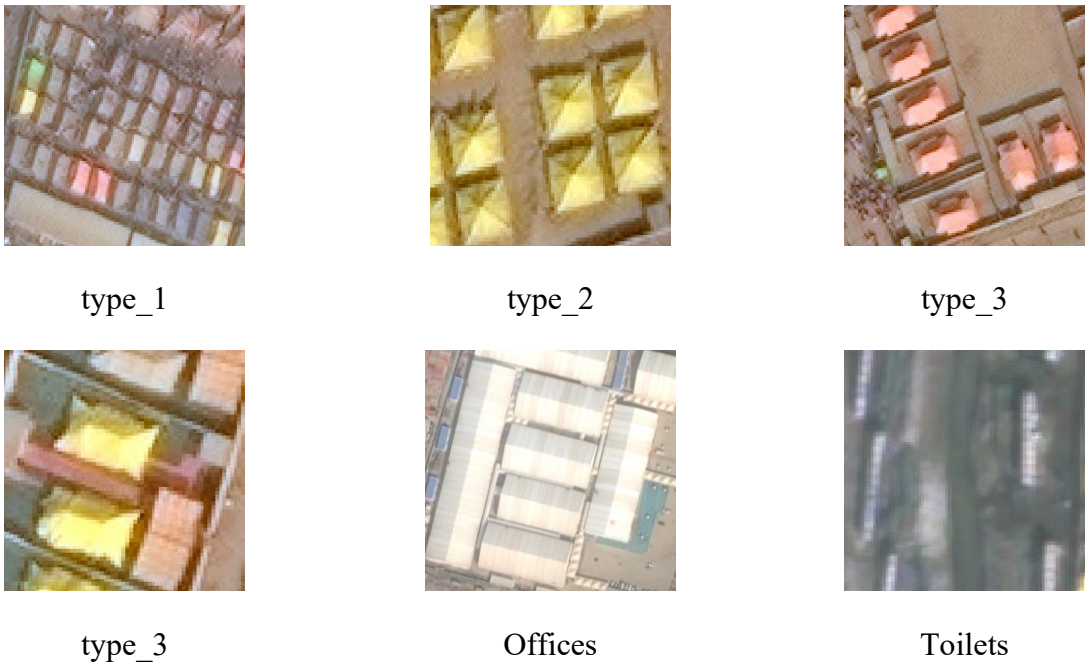


Figure 3.3. Features of Interest in the Study Area.

After finishing the annotation, the set of image patches sized 1024x1024 pixels, were acquired (Table 3.1). These were then split into training, validation, and test groups using a 70:20:10 ratio. To make the model more flexible and better at handling different light conditions and object looks, we boosted the training set using data augmentation. This included flipping the images (both ways), rotating them, and adding a bit of shear. Furthermore, different image

interpretation keys were applied such as converting to grayscale, tweaking hue, saturation, brightness, and even adding a touch of blur and noise. These steps helped the model learn from a wider range of characteristics, enabling it to handle unseen satellite images more confidently.

Table 3.1. Information about the dataset

Attribute	Value
Image Size	1024 × 1024
Total Raw Images	816
Train Augmented Images	6,281
Validation Augmented Images	163
Test Augmented Images	82

3.3.7 Manually digitized infrastructure layer

In parallel to the automated detection workflow, several other key infrastructure features were manually digitized in QGIS using the pansharpened satellite image as a basemap. These features were saved as separate vector shapefiles and include:

- Sector Boundaries
- Road Network
- Pontoon Bridges
- River Ghats
- Crowd hotspots
- Parking Areas

To create a comprehensive geospatial database of the study area, critical infrastructure (Figure 3.4) and administrative features were manually digitized using QGIS. This process was conducted over the high-resolution satellite imagery, which served as the georeferenced basemap for all digitization tasks.

Distinct vector layers were created for each feature class to accurately represent its unique spatial form, an area, a line, or a point. The methodology for each geometry type is detailed below:

- Polygon Features (Areas): Features that occupy a distinct area were captured using polygon geometry. This included the delineation of administrative sector boundaries, mapping of designated parking areas, and identification of significant crowd hotspots.

Each polygon was carefully traced to match the visible extent of the feature on the satellite imagery, providing an accurate representation of land use and administrative divisions.

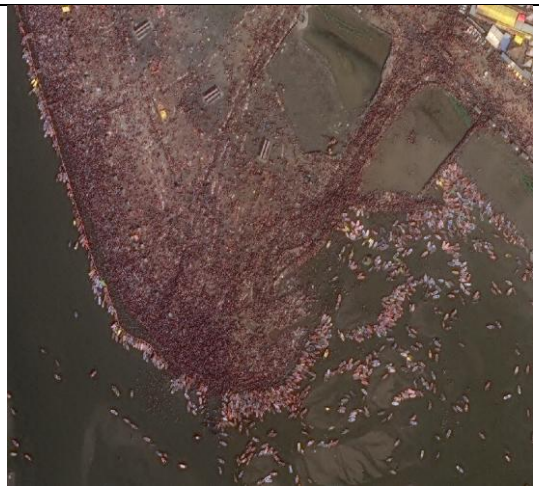
- Line Features (Linear Networks): Linear infrastructure, essential for understanding connectivity and movement, was digitized using line geometry. This method was used to trace the road network within the study area. Similarly, temporary pontoon bridges, which are used for crossing the river, were also mapped as line features, capturing their precise location and span.
- Point Features (Discrete Locations): Specific locations of interest were marked using point geometry. This approach was used to pinpoint the exact locations of ghats, which are the primary access points to the river for pilgrims. Each point represents a discrete feature whose precise location is more critical than its area.

The manual digitization process resulted in a multi-layered GIS database. Each shapefile corresponds to a specific feature class, creating a structured and organized dataset ready for subsequent spatial analysis, visualization, and integration with the results from the automated detection models.

Finally, to ensure the proper detection of features, tents, toilets and all the features were manually digitized wherever the automated detection model failed to detect it.



(a) Car parking



(b) Crowd at Ghats



(c) Sectors and Road network



(d) Pontoon bridges

Figure 3.4. Critical infrastructure in the study (a) Car parking, (b) Crowd at Ghats. (c) sectors and road network and (d) pontoon bridges

3.3.8 Tools and Platforms Used

- **QGIS**: Data visualization, post-processing, and mapping
- **Google Colab**: Coding environment for data pre-processing, evaluation, graph visualization, and data analysis
- **Jupyter Notebook**: Bulk data downloading, model training, inference and geocoding.
- **CVAT**: Preparation of the training dataset – Data annotation & augmentation

3.3.9 Model Training Setup & Performance Analysis

The YOLO11-OBB model, pre-trained on the COCO dataset, was fine-tuned for tent detection using the custom dataset of pansharpened satellite images described in the previous section. The default hyperparameters provided by the Ultralytics framework are highly optimized for general object detection tasks and were used as a baseline, as they typically yield robust performance in fine-tuned applications.

Training was conducted with a batch size of 8 for a total of 100 epochs. The learning rate was set to 0.01. The input image size was maintained at 1024x1024 pixels to leverage the full resolution of the prepared data tiles. The entire training process took approximately 2 hours on an NVIDIA RTX 5000 ADA-32GB GPU.

3.3.10 Geocoding

After the YOLO11-OBB model was run, its predictions must be converted from image pixels into real-world map coordinates. The process known as geocoding makes the results usable for GIS analysis.

The output of a YOLO model for each detected tent is a set of coordinates within the corresponding image, such as its center point (e.g., x=350, y=512 pixels from the corner), its size in pixels, and its angle of rotation. The goal of geocoding is to convert this pixel-based information into a precise geographic location on the map.

The geocoding process for each image detection follows these steps:

- It takes the known map coordinate of a tile's corner (e.g., the top-left) as a starting point.
- It then calculates the real-world distance of the detected tent's center from that corner by using the image's ground resolution (i.e., 30 cm per pixel). For example, a tent at pixel coordinate (100, 200) is 30 meters (100 pixels * 0.30 m/pixel) east and 60 meters (200 pixels * 0.30 m/pixel) south of the corner.
- This calculated offset is then added to the tile's starting map coordinate to find the final, precise geographic center of the tent.
- Similarly, the width and height of the tent's bounding box are multiplied by the pixel size to get their actual dimensions in meters.

This entire process is automated and repeated in a loop for thousands of detections across all image tiles. The outputs are stored in a standard GIS format (such as a shapefile), containing all oriented bounding boxes with their corresponding geographic coordinates. This file can then be loaded into QGIS and overlaid on the satellite imagery, allowing for clear visual inspection and final spatial analysis.

3.3.11 Land Use Land Cover Classification of Prayagraj

Land Use Land Cover (LULC) change analysis is an essential component in understanding the dynamic interactions between human activities and the environment. In the context, Maha Kumbh 2025, LULC becomes particularly important for assessing the impact of the floating population on sewerage systems. The temporary but massive influx of pilgrims during the event significantly alters land use patterns, especially in terms of built-up expansion, open areas, and waterbody dynamics. LULC patterns across different time periods able to identify

spatiotemporal changes that influence wastewater generation, drainage congestion, and environmental stress.

The study utilized the multi-temporal satellite data for 14 January 2019 (pre-event baseline) and 22 January 2025 (during Maha Kumbh) for LULC classification. Five major land cover classes were considered: waterbody, agricultural land, forest, built-up area, and barren land. The classification process allowed for a clear delineation of how each class has evolved over time, reflecting the growing anthropogenic footprint in the study area.

To ensure the accuracy of LULC classification, accuracy assessments were carried out on the classified maps using both training and validation process. For the 2025 LULC map the overall classification accuracy was 0.94 and the kappa coefficient was 0.92, indicating excellent agreement between the classified and reference data. Validation results yielded an overall accuracy of 0.88 and a kappa coefficient of 0.85, demonstrating strong classification reliability in real-world conditions. For 2019, the training overall accuracy was slightly lower at 0.89, with a kappa coefficient of 0.85. Validation performance indicated an overall accuracy of 0.78 and a kappa coefficient of 0.70, reflecting a moderate level of agreement. The higher accuracy in the 2025 classification compared to 2019 highlights the improved classification performance, due to enhanced data quality and better ground reference availability during the recent period.

Overall, the LULC analysis effectively captures the spatial and temporal changes between 2019 and 2025 (Table 3.2, Figure 3.5, Figure 3.6). The classification results, supported by strong accuracy assessment metrics, provide a robust foundation for evaluating how the expansion of built-up areas and reduction in natural land covers may directly impact sewerage infrastructure during the Maha Kumbh event. The implications of these changes are significant. The increase in built-up land indicates greater settlement and congregation areas, which directly contribute to higher wastewater generation. Simultaneously, the reduction in open or barren areas reduces natural infiltration capacity, leading to increased surface runoff and pressure on drainage systems. Waterbodies may also face contamination risks due to overloading of sewerage networks. These spatial changes, when linked with the floating population dynamics, highlight the urgent need for strengthening sewerage infrastructure and adopting integrated waste management strategies to mitigate environmental and public health challenges during the Maha Kumbh.

Table 3.2. LULC area distribution of Prayagraj

Sr. No	Class (Level 1)	LULC 2019 (Area in km^2)	LULC 2025 (Area in km^2)	Difference (% Area)
1	Waterbody	144.025	109.507	23.96 % ↓
2	Agricultural Land	4302.24	3619.14	15.88 % ↓
3	Forest	532.604	330.025	38.03 % ↓
4	Built – Up	436.843	765.577	75.25 % ↑
5	Barren Land	676.606	1268.06	87.41 % ↑
	Total Area	6092.3	6092.3	

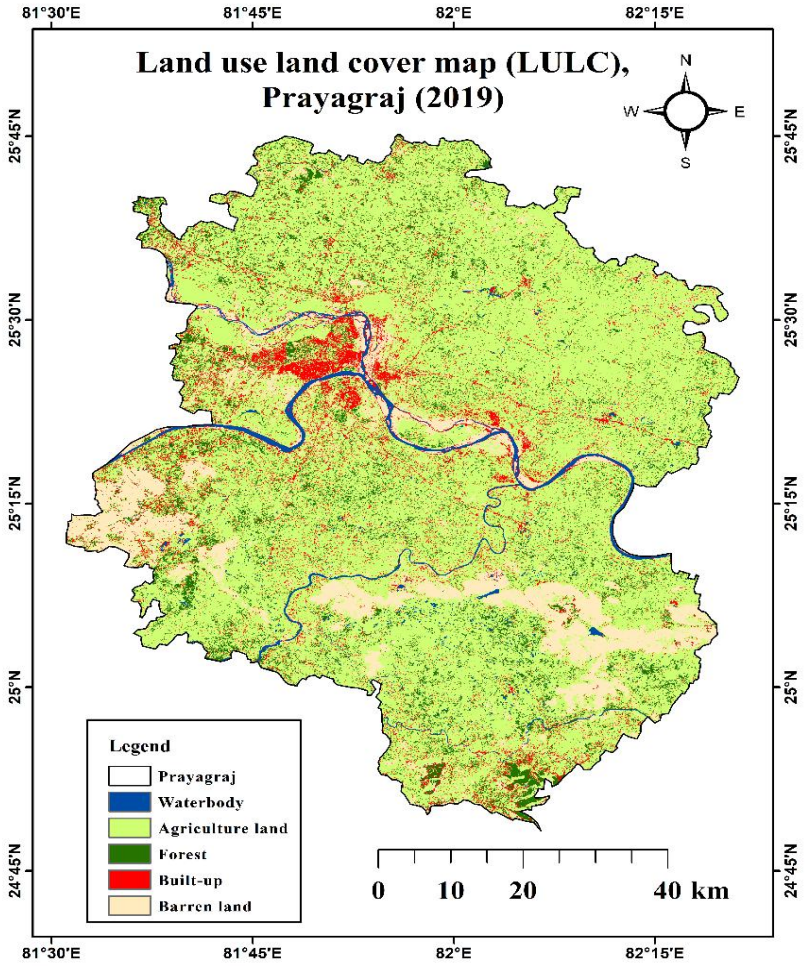


Figure 3.5. LULC Map of Prayagraj (14 January 2019)

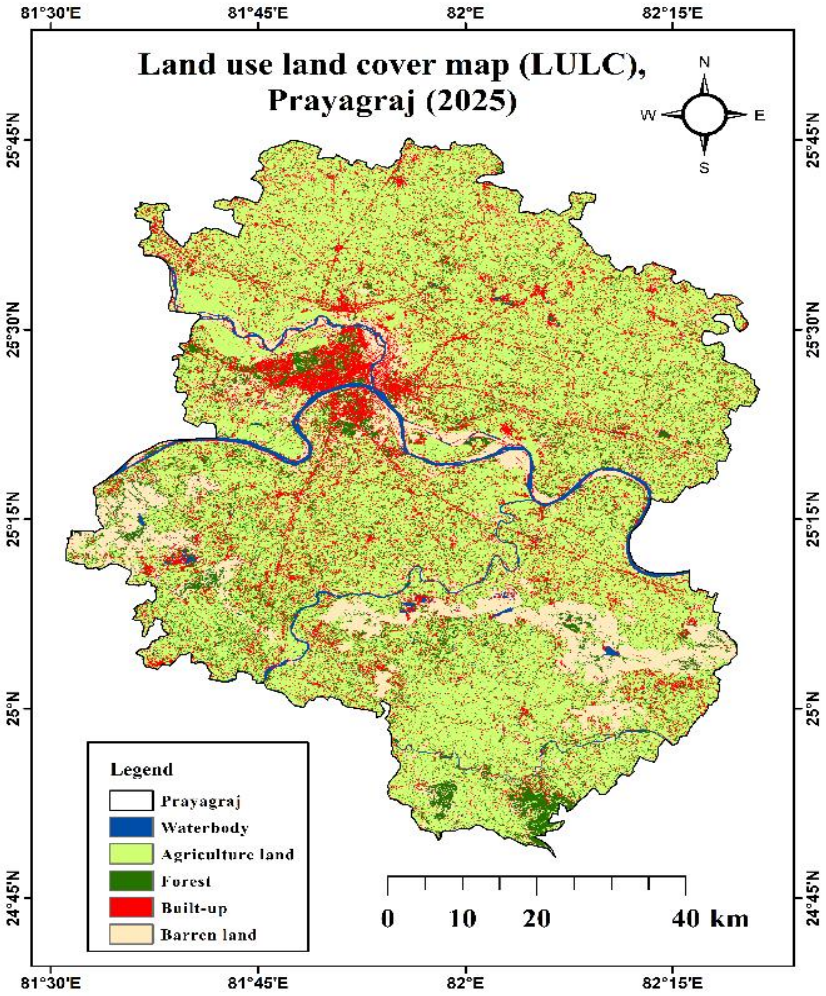


Figure 3.6. LULC Map of Prayagraj (22 January 2025).

3.4 Results and Discussion

3.4.1 Mapping of Infrastructure

A detailed analysis of the mapped infrastructure reveals a highly structured and deliberate urban plan for the Kumbh Mela 2025. Far from being a random assortment of temporary structures, the layout demonstrates a sophisticated understanding of crowd management, public health, and the functional priorities of the pilgrimage. The spatial patterns observed are a direct reflection of a planning strategy centered around the event's primary religious activities. From the very high-resolution satellite imagery acquired on January 29, 2025, the automated detection model identified a substantial amount of temporary infrastructure, including 75,306 individual tents and 2,368 toilet complexes. According to the Mela authorities the total number of installations over the entire duration of the event was projected to be significantly higher, with estimates around 150,000 tents and between 150,000 to 160,000 toilets. The discrepancy between the model's detection and the official figures is attributed to the dynamic nature of the

event; the satellite image captures the infrastructure present on a single day (January 29, 2025), while the official numbers account for the progressive installation of facilities throughout the entire Mela period. Satellite data also cannot detect toilets inside tents and tents and other facilities. The geospatial analysis reveals a highly organized and expansive temporary city. The distribution of tents and toilets, as shown in Figures 3.7 and 3.8, respectively, covers massive areas on both banks of the Ganga and Yamuna rivers.

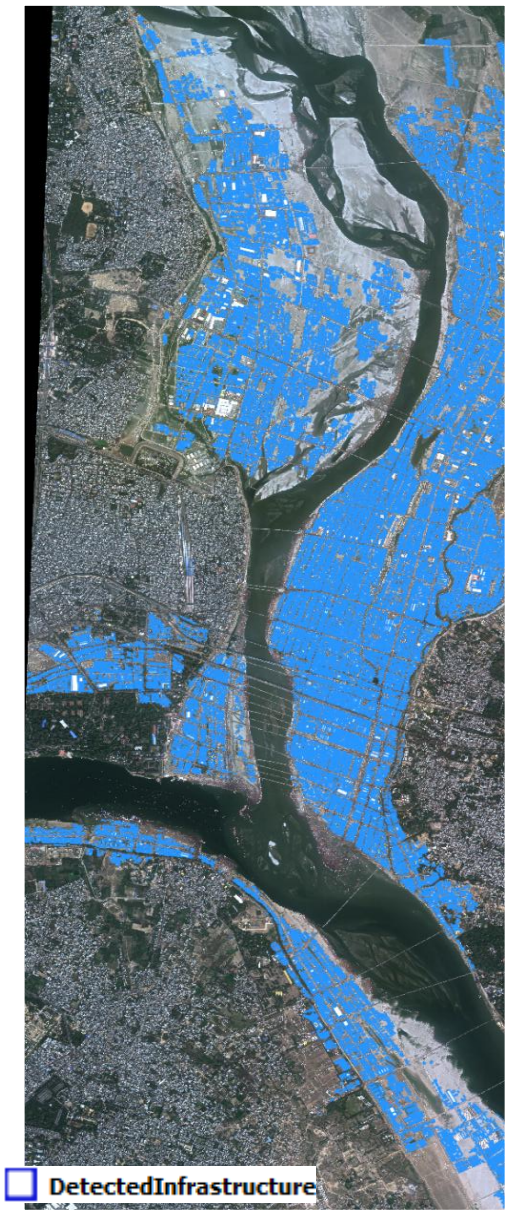
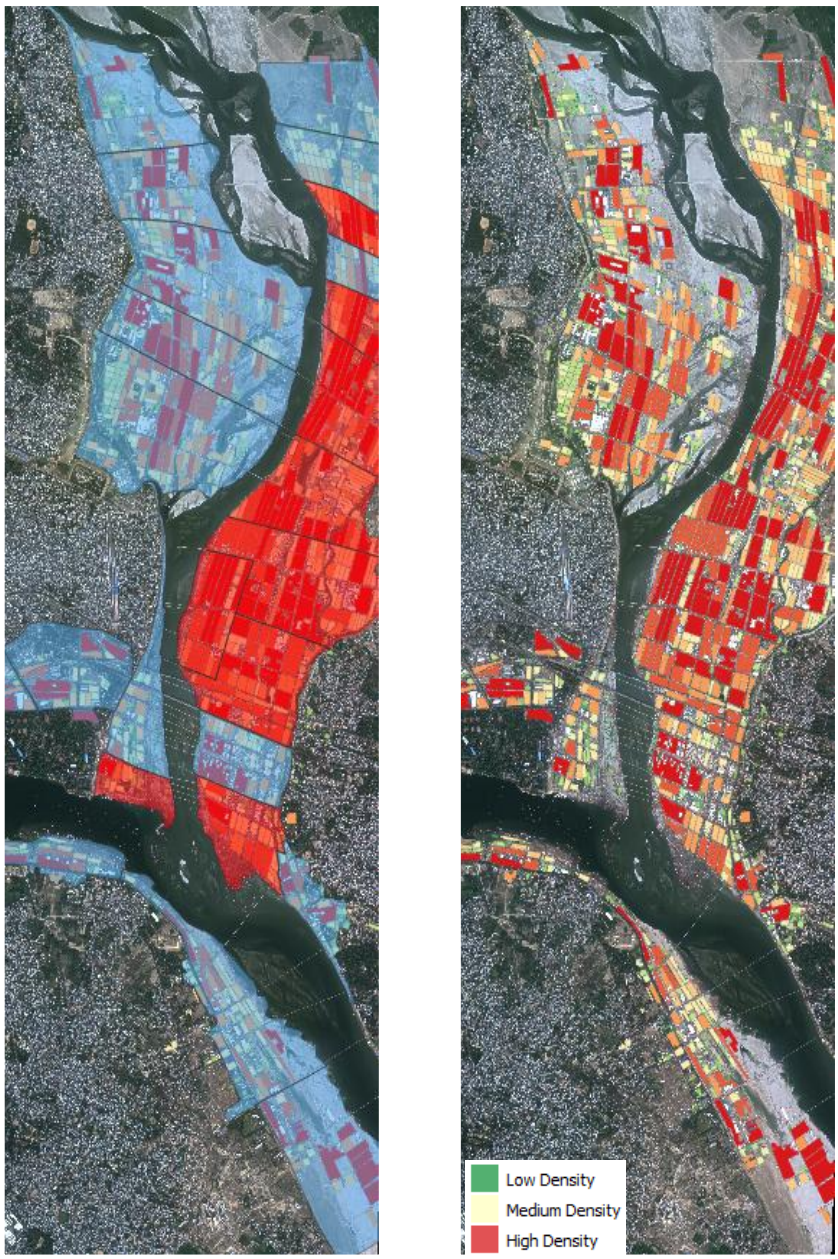


Figure 3.7. Spatial distribution of tents over the Kumbh Nagri (Scale – 1:27,500).



Figure 3.8. Spatial distribution of toilets (Scale – 1:27,500).



(a) (b)

Figure 3.9 (a). Sectors of importance (crowd influencing water quality); (b)Spatial distribution of tents by aggregating into sections.

Finally, to understand settlement patterns, density analysis was performed by aggregating the detected tents into pre-defined sections. The resulting choropleth map (Figure 3.9 (a and b) highlights distinct zones of high, medium, and low population density. The areas marked in red indicate the most densely populated sectors, which are strategically connected by a network of primary roads and pontoon bridges that were manually digitized (Figures 3.10-3.13). These

transportation arteries are crucial for channeling the flow of pilgrims from their accommodations and designated parking areas toward the primary bathing ghats.



Figure 3.10. Road Network.



Figure 3.11. Pontoon Bridges (peepa pul).



Figure 3.12. Parking space for vehicles.

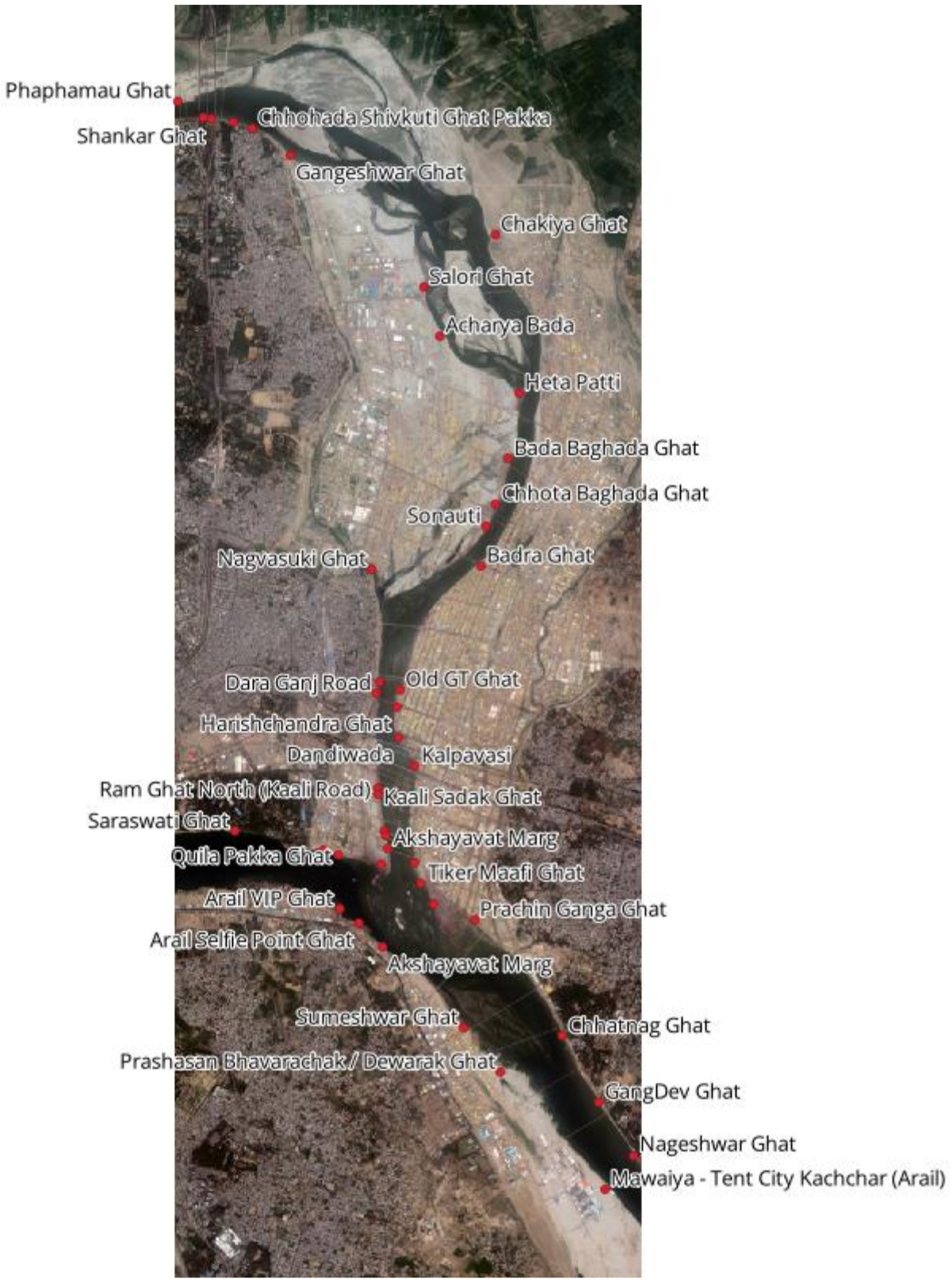


Figure 3.13. Major bathing ghats.

The placement of sanitation facilities follows a deliberate pattern. Toilet complexes are strategically located along the road networks to ensure accessibility for pilgrims. However, a

detailed analysis of the Ganga river stretch reveals a lower density of toilets relative to the high concentration of tents and visible crowd accumulation in that area (Figure 3.14).

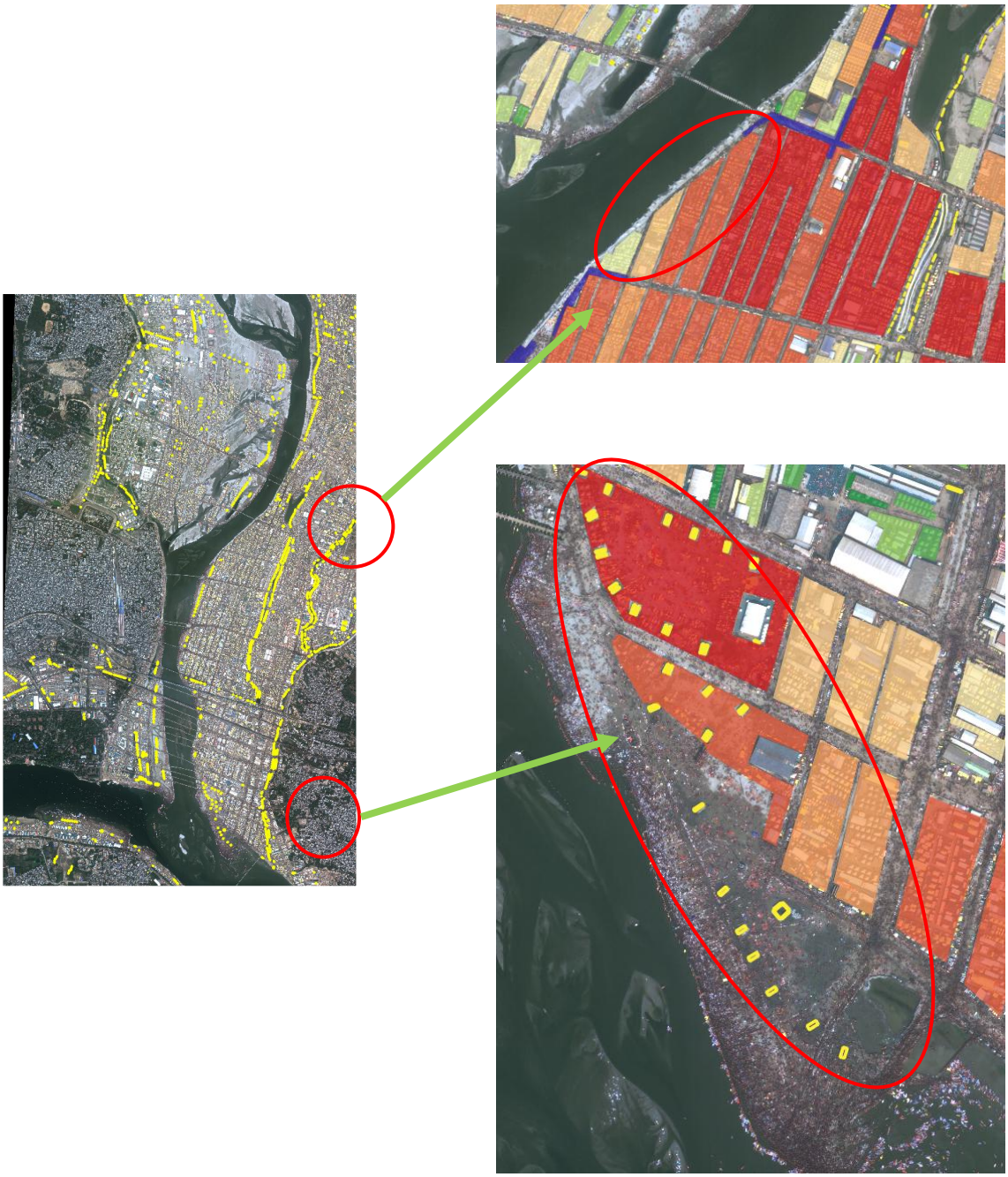


Figure 3.14. A smaller number of toilets (on the left) are also observed on the Ganga stretch with respect to tents and crowds

Field-level information confirms a deliberate strategy to maintain the sanctity and cleanliness of the bathing areas, toilet complexes were generally placed approximately 100 meters away from the most densely ghats, with individual complexes spaced at least 50 meters apart. This

layout is designed to provide convenient sanitation while facilitating unobstructed movement for the large number of pilgrims accessing the river.

3.4.2 Comparative analysis of infrastructure change year 2019 and 2025

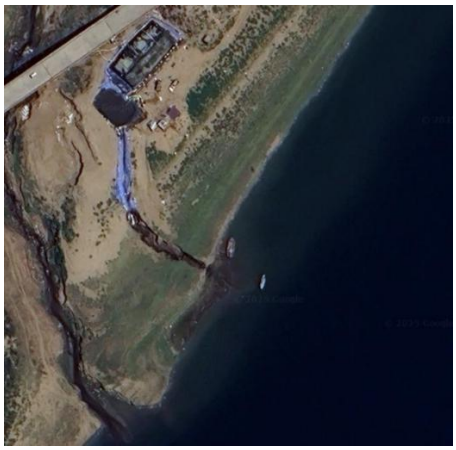
A comparative analysis between the 2019 and 2025 events reveals significant developments in wastewater management infrastructure, along with notable changes in water quality and the physical landscape of the riverine environment.

2019 Ardh-Kumbh	2025 Maha Kumbh
	
a) Ponghat 10 MLD STP	b) Ponghat 10 MLD STP
	
	

c) Salori 14 MLD STP



d) Salori 14 & 29 MLD STP



e) Sasur Khaderi



f) Sasur Khaderi Geotube



g) 2019 Ganga river channel

h) 2025 Ganga river channel

Figure 3.15. Changes in infrastructure in 2025 with respect to 2019.

To handle the much larger expected crowd in 2025, the wastewater treatment capacity was significantly increased. A new 29 MLD Sewage Treatment Plant (STP) was added to the existing 14 MLD STP. The area around these plants, which was empty in 2019, was changed to include offices and pilgrim tents in 2025, showing the larger scale of the event (Figure 3.15 e, f).

Even with more treatment capacity, the quality of the discharged water showed mixed results:

- The discharge point released clean water in 2019 (Figure 3.15 a) but exhibited foamy water in 2025 (Figure 3.15 b). The presence of foam typically indicates elevated levels of phosphates, suggesting the STP was overloaded and unable to achieve adequate nutrient removal during the treatment process.
- On the other hand, another discharge point that released foamy water in 2019 (Figure 3.15 c) showed a clear, clean discharge in 2025 (Figure 3.15 d). This clear improvement was due to the planned installation of a geotube filter system nearby, which provided effective extra water treatment during the busy period. This technology was also newly used on the Yamuna river in 2025 to improve water quality management (Figure 3.15 h).

Major physical changes were also observed in the riverine environment. Specifically, the shape of the river itself changed; a section that was straight in 2019 had formed a clear bend by 2025 (Figure 3.15 i, j).

Concurrently, this period witnessed a significant territorial expansion of the temporary city. To accommodate the large number of pilgrims, settlements were established extending to the far limits of the Ganga riverbanks. In total, the area of Kumbh city in 2025 covered nearly 4,000 hectares, underscoring the immense scale and resultant environmental challenge of the event.

3.4.3 Accuracy Assessment

An evaluation of the model's training run demonstrates a robust and successful learning process. Further, the model exhibited a strong capacity for generalization to unseen data, confirming its potential for real-world application.

The model shows a clear learning curve, with training and validation losses decreasing consistently over the 100-epoch cycle. This steady improvement confirms that the model was effectively learning the features required to identify the target objects. Importantly, the validation loss closely tracked the training loss throughout this process. This is a critical result, as it indicates the model learned generalizable patterns for identifying tents and toilets, rather than simply memorizing the training images. The flattening of these curves around the 80-epoch mark shows the model had converged, reaching its peak performance without succumbing to significant overfitting.

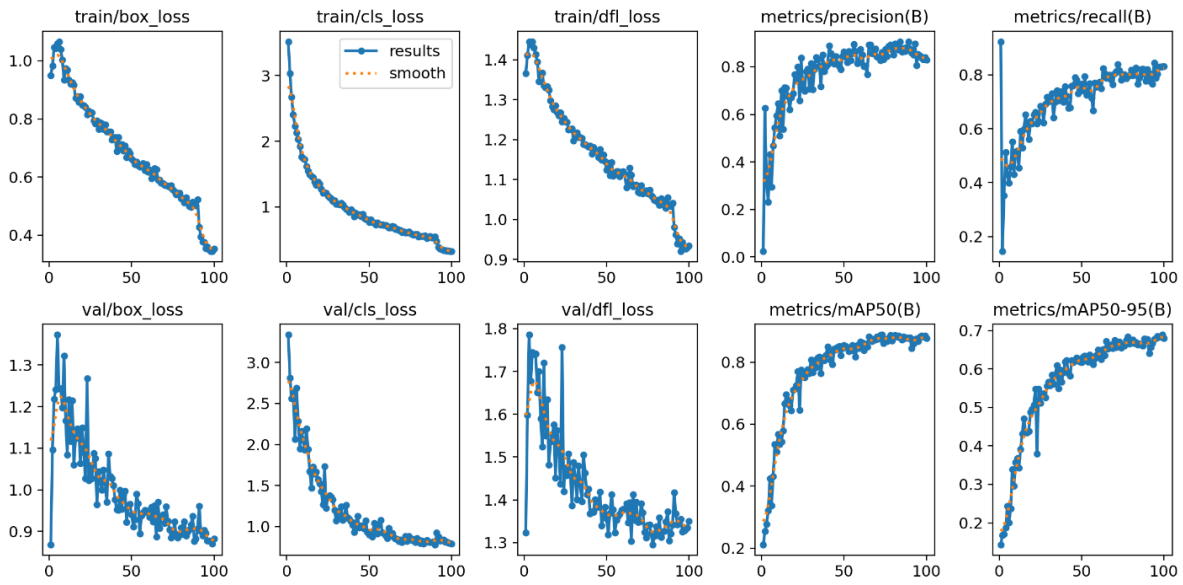


Figure 3.16. Performance trends across fine-tuning for tent detection.

In practical terms, these learning characteristics translated into excellent detection performance (Figure 3.16). The model achieved a fine balance between a precision of approximately 90% and a recall of 80% (Figure 3.17). Based on this, an F1 score of 0.86 was calculated. This indicates that the majority of the model's detections are reliable, and it successfully identified most of the targeted objects. The overall accuracy is best summarized by the mean Average Precision (mAP@0.5) value, which stabilized at a strong 0.80.

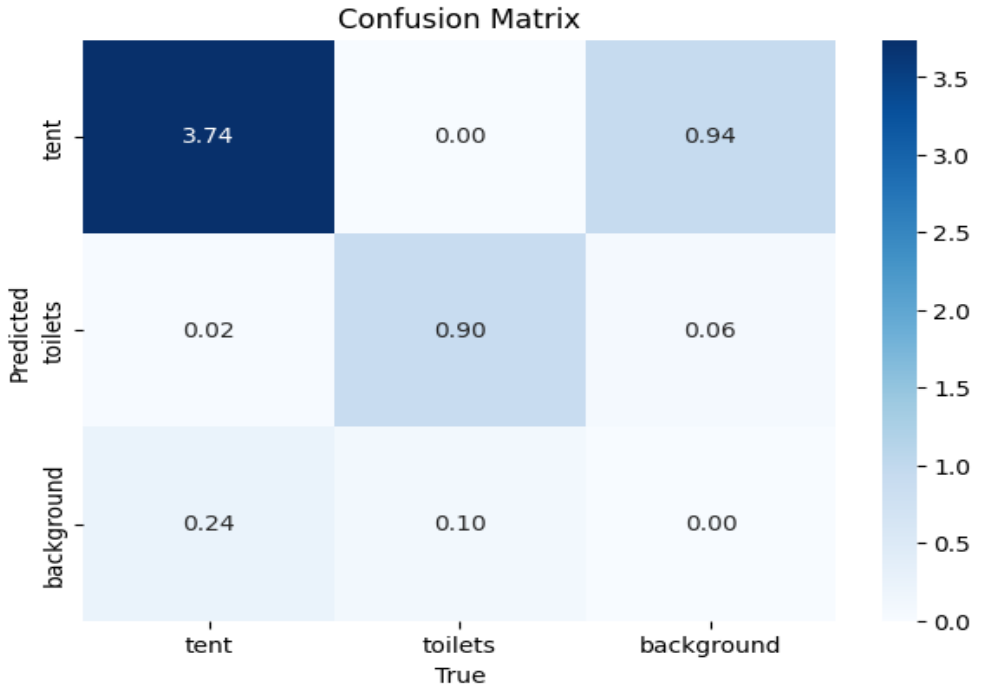
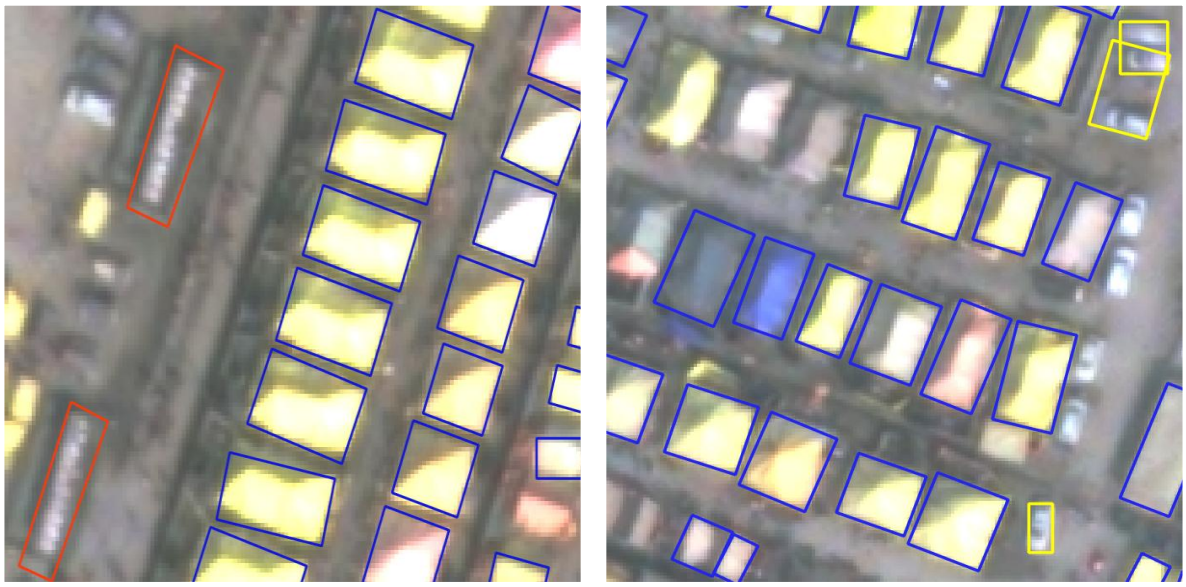


Figure 3.17. Confusion matrix for tent and toilet detection.

Notably, the confusion matrix reflects the model's nuanced ability to handle the distinct characteristics of both tents and toilets. The high recall was maintained despite challenges like the variable shapes and dense clustering of tents, and the smaller size of the toilets. Furthermore, achieving a mAP@0.5:0.95 score of 0.70 is significant, as this stricter metric confirms the model was proficient at generating precise bounding boxes for both the geometrically uniform toilets and the more irregular tent structures (Figure 3.18a and b).



(a) (b)

Figure 3.18 (a). Correct classification of tents and toilets; (b) Misclassification of tent-like looking structures (cars).

3.5 Summary

The spatial organization of infrastructure at the Kumbh Mela reveals a highly deliberate and strategic approach to crowd management and pilgrim facilitation, i.e. sanitation. The analysis of the settlement layout demonstrates a clear zonation strategy designed to optimise the pilgrim experience while ensuring safety and sanitation.

Land use and Land Cover (LULC) analysis comparing 2019 and 2025 further revealed notable shifts in land conversion around the Sangam area. This involved the expansions of built-up zones near major sites and reductions in agricultural and barren land. The majority of the converted land was temporarily utilized for the establishment of tents, parking facilities, and other temporary infrastructure critical to the Maha Kumbh event.

A key finding is the intentional placement of residential tent settlements at a considerable distance from the primary bathing ghats. This separation effectively decongests the most crowded ritual spaces, which are the focal points of pilgrim activity. In contrast, essential sanitation facilities, such as toilets and changing rooms, are distributed with high frequency and proximity to these high-traffic areas, underscoring convenience for the attendees and acknowledgement towards keeping the water bodies free from any pollution.

Furthermore, the areas immediately adjacent to the ghats are reserved for administrative and religious structures, separating functional operations from the main pilgrim flow. The most significant planning intervention observed is the establishment of a 100-meter buffer zone around the main Sangam ghats. Within this critical area, infrastructure is strictly limited to essential amenities that support the bathing ritual. This design choice is instrumental in preventing bottlenecks and ensuring unimpeded movement for the immense number of pilgrims accessing the sacred confluence area.

In essence, the infrastructure mapping reveals a sophisticated model for managing large-scale temporary human settlements, balancing the need for accommodation with the critical requirements of crowd flow, accessible sanitation, and unobstructed access to ritualistic spaces.

As per the analysis of these results, the following takeaway are suggested for the respective stakeholders:

1. Toilets near the ghats in sectors 3 and 21 (Sangam area) are evenly distributed, ensuring pilgrims have convenient access to sanitation facilities before and after performing their ritual dips.
2. The strategic placement maintains an optimal distance from the river, balancing easy accessibility for pilgrims while preserving the sanctity and cleanliness of the holy river.
3. The average spacing between toilet complexes is less than 50 meters, reflecting deliberate efforts to provide sufficient sanitation facilities and to prevent overcrowding and overuse of any single complex during the event.
4. Sector 17 presents a case where crowd hotspots near the ghat are not matched by a proportional number of public urinals, suggesting the need for targeted sanitation infrastructure expansion in such areas, likely addressed in later phases of the Kumbh.

Chapter 4: River water quality monitoring using remote sensing and in-situ measurements

4.1 Background

This chapter presents the background of river water quality monitoring during large mass-gathering events, with specific focus on the Kumbh. It highlights the importance of integrating field measurements with remote sensing algorithms to capture spatio-temporal variations in water quality parameters pre-, during-, and post-Kumbh. Firstly, we identify critical gaps in monitoring approaches from the existing literature and underscore the need for comparative analysis across different temporal phases. The chapter articulates the use of geospatial and in-situ datasets for reliable prediction and assessment of river water quality dynamics.

Water quality plays a vital role in sustaining aquatic ecosystems, ensuring safe water supply, and supporting human health and livelihood. Rivers serve as a lifeline for millions of people in South Asia, providing drinking water, irrigation, fisheries, transportation, and religious services. Mass gatherings such as religious festivals, pilgrimages, and fairs place enormous pressure on river systems by increasing sewage discharge, solid waste, and direct human interaction with water bodies. These activities often trigger sudden changes in turbidity, nutrient loading, and microbial contamination, posing risks to both public health and aquatic ecosystems. Monitoring water quality during such events is crucial to identify pollution hotspots, quantify short-term impacts, and assessing the effectiveness of temporary management measures. Integrating in-situ observations with geospatial and statistical tools ensures evidence-based strategies for safeguarding water resources during and after mass events. Traditionally, water quality has been evaluated through in-situ field sampling and laboratory analysis. Parameters such as turbidity, chlorophyll-a, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), pH, nitrate, and phosphate concentrations are measured using portable probes and sensors, spectrophotometers, and standardized wet-lab techniques. These measurements are highly accurate but inherently spatially restricted and resource-intensive, as they require manual collection, laboratory processing, and frequent monitoring to capture temporal variations. For dynamic environments such as rivers, where water quality can change within hours due to rainfall, sewerage discharges, and cultural practices. The limitations of conventional monitoring methods have led to the adoption of remote sensing technologies, which provide spatially continuous and temporally frequent data over large areas. Satellite missions such as Sentinel-2, Landsat-8/9,

and MODIS offer multispectral and hyperspectral data that can be used to retrieve proxies of water quality parameters. Algorithms derived from reflectance characteristics of water bodies allow estimation of turbidity, suspended sediment concentration, chlorophyll-a, and dissolved organic matter (Pardeshi et al., 2023).

The remote sensing approaches used in this study are empirical models that establish statistical correlations between spectral indices (e.g., Normalized Difference Chlorophyll Index, Normalized Difference Turbidity Index) and field-measured parameters. These models enable monitoring at multiple spatial and temporal scales. However, their accuracy depends on calibration and validation with in-situ datasets, emphasizing the importance of hybrid methods. To overcome these limitations, this study proposes an integrated framework that utilizes field-based datasets to calibrate and validate satellite retrieval algorithms. This approach not only enhances the reliability of remote sensing models but also ensures that spatially extensive monitoring is grounded in field truth. By leveraging multispectral indices such as the NDTI and NDCI, alongside ground-measured parameters, the framework investigates a scalable solution.

The study aims to assess river water quality dynamics across the pre-, during-, and post-Kumbh phases through an integrated monitoring and analytical framework. Satellite-derived indices such as the NDTI and NDCI were employed to analyze spatial and temporal variations in turbidity and chlorophyll concentrations, thereby capturing event-driven fluctuations. These remotely sensed indices were calibrated and validated using in-situ measurements of turbidity, BOD, ensuring accurate interpretation of water quality conditions. By integrating satellite-derived indices with field-based observations, the study established both direct and indirect linkages between spectral trends and water quality parameters. Furthermore, hotspot analysis identified zones of critical water quality deterioration through spatial overlay of remote sensing-derived indices with anthropogenic infrastructure, including ghats, sewage treatment plants (STPs), and geotube structures. This process enabled the identification of areas most influenced by human activity and temporary arrangements during the event. The study is guided by three research questions: (i) How do water quality indices vary across the three temporal phases of the Kumbh? (ii) To what extent do remote sensing indices correlate with in-situ measurements? (iii) Where are the pollution hotspots, and how are they linked to the event infrastructure.

4.2 Water Quality Monitoring Framework

Historically, water quality monitoring frameworks have relied on in-situ observations to assess parameters such as BOD, turbidity, chlorophyll-a, and nutrient concentrations. However, such

methods are often spatially and temporally limited, particularly for large river systems. Recent advancements integrate remote sensing and geospatial approaches with conventional sampling to achieve synoptic, repeatable, and near-real-time assessments.

Several study emphasizes that effective monitoring frameworks must balance spectral indices, bio-optical models, and machine learning algorithms for the retrieval of water quality indicators across varying spatio-temporal scales (Sagan et al., 2020). Furthermore, other research has demonstrated that water quality monitoring should not only provide continuous measurements but also identify pollution hotspots using a combination of satellite imagery and machine learning techniques (Mishra, et al., 2024).

4.3 Water Quality Indices

The study has utilized NDWI, NDCI, and NDTI for the estimation of water quality parameters such as chlorophyll-a and turbidity that are derived from satellite remote sensing, which condense complex physical, chemical, and biological water quality parameters into more simplified, comprehensive, and interpretable values. These indices are typically spectral indices formulated as band ratios or normalized difference equations using specific wavelengths of satellite imagery.

- **NDWI** delineates water bodies by utilizing the strong absorption of near-infrared light by water compared to its reflectance in the visible range (Hamrell, 2014).

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)} \quad (4.1)$$

- **NDCI** highlights chlorophyll-a by leveraging absorption in the red band and reflectance in the red-edge region (Mishra & Mishra, 2012).

$$NDCI = \frac{(Red\ Edge - Red)}{(Red\ Edge + Red)} \quad (4.2)$$

- **NDTI** quantifies turbidity by contrasting scattering in the green band with absorption in the red band (Lacaux et al., 2007).

$$NDTI = \frac{(Green - Red)}{(Green + Red)} \quad (4.3)$$

4.3 Integration of Remote Sensing and In-situ Data

Remote sensing provides spatially continuous observations; however it requires ground-truth calibration to ensure accuracy. Sagan et al. highlight that indices such as NDCI, NDTI, and derived reflectance measures can capture variations in turbidity, algal blooms, and suspended

solids (Sagan et al., 2020). However, their reliability depends on bio-optical complexity of inland waters and atmospheric correction uncertainties.

Previous research mentions that Sentinel-2 imagery alongside in-situ sampling, was analysed for turbidity and hotspot zones identification in the Varanasi stretch of the Ganga (Mishra et al., 2024). However, remote sensing alone is insufficient without field measurements for calibration and validation, especially in optically complex waters. Similarly, (Varma et al., 2022; Yadav K Bhatia, 2020) relied on extensive field sampling campaigns of parameters like BOD, turbidity, and microbiological load during mass bathing events at Kumbh, showing how in-situ data serves as the baseline for interpreting remote sensing-derived anomalies. Whereas satellites provide spatial extent and trends, while field data provide parameter-specific accuracy and statistical validation.

4.3.1 Geospatial & Statistical Integration with In-situ Data

Geospatial and statistical integration with in-situ data strengthens river water quality assessment during large events like the Maha Kumbh. Field parameters such as turbidity, BOD, and microbial load provide ground-truth accuracy, while statistical tools like PCA, correlation, and cluster analysis reveal key pollution drivers. Remote sensing indices (e.g., NDCI, NDTI), (Yadav K Bhatia, 2020) when calibrated with field data, enable spatial mapping of chlorophyll and turbidity patterns. Overlaying these maps with anthropogenic activity zones highlights pollution hotspots. This hybrid framework captures both dominant influencing factors and their spatial distribution, improving interpretability, guiding targeted interventions, and enhancing decision-making for event-based river management.

4.3.2 Spatio-temporal Dynamics and Event-based Studies

Rivers like the Ganga exhibit strong temporal variability, influenced by seasonal flows, urban discharge, and religious/cultural events; consequently, spatio-temporal monitoring is crucial for detecting episodic disturbances. Past Kumbh studies show that during mass bathing events, BOD and microbial contamination increased sharply, while DO levels decreased, reflecting immediate stress on water quality (Varma et al., 2022; Yadav K Bhatia, 2020). Such short-term dynamics are not adequately captured by long-term monitoring networks but can be effectively assessed through the combination of high-frequency sampling and satellite observations. Event-based studies also highlight recovery patterns, where water quality often improves within weeks after the event. Integrating spatio-temporal monitoring with remote sensing enables before-during-after event comparisons, mapping both impact intensity and restoration trajectories. Furthermore,

ML-aided spatio-temporal mapping can detect persistent hotspots versus temporary spikes (A. Mishra et al., 2024).

4.4 Methodology

This study adopts an integrated approach (Figure 4.19) combining remote sensing and ground-based observations to assess and monitor river water quality. The methodology is divided into several stages, beginning with comprehensive data collection and progressing through pre-processing, analysis, modelling, and visualization. Both spatial and non-spatial data sources were utilized to ensure a holistic evaluation of water quality across different parameters. To begin with, spatial data in the form of satellite imagery was acquired from Sentinel-2, known for its high-resolution multispectral capabilities. Alongside this, non-spatial data such as sewage treatment plant (STP) locations, ghats, and geotubes were collected from various reliable sources. This data provided the necessary ground truth and contextual information required for validating and correlating remote sensing results.

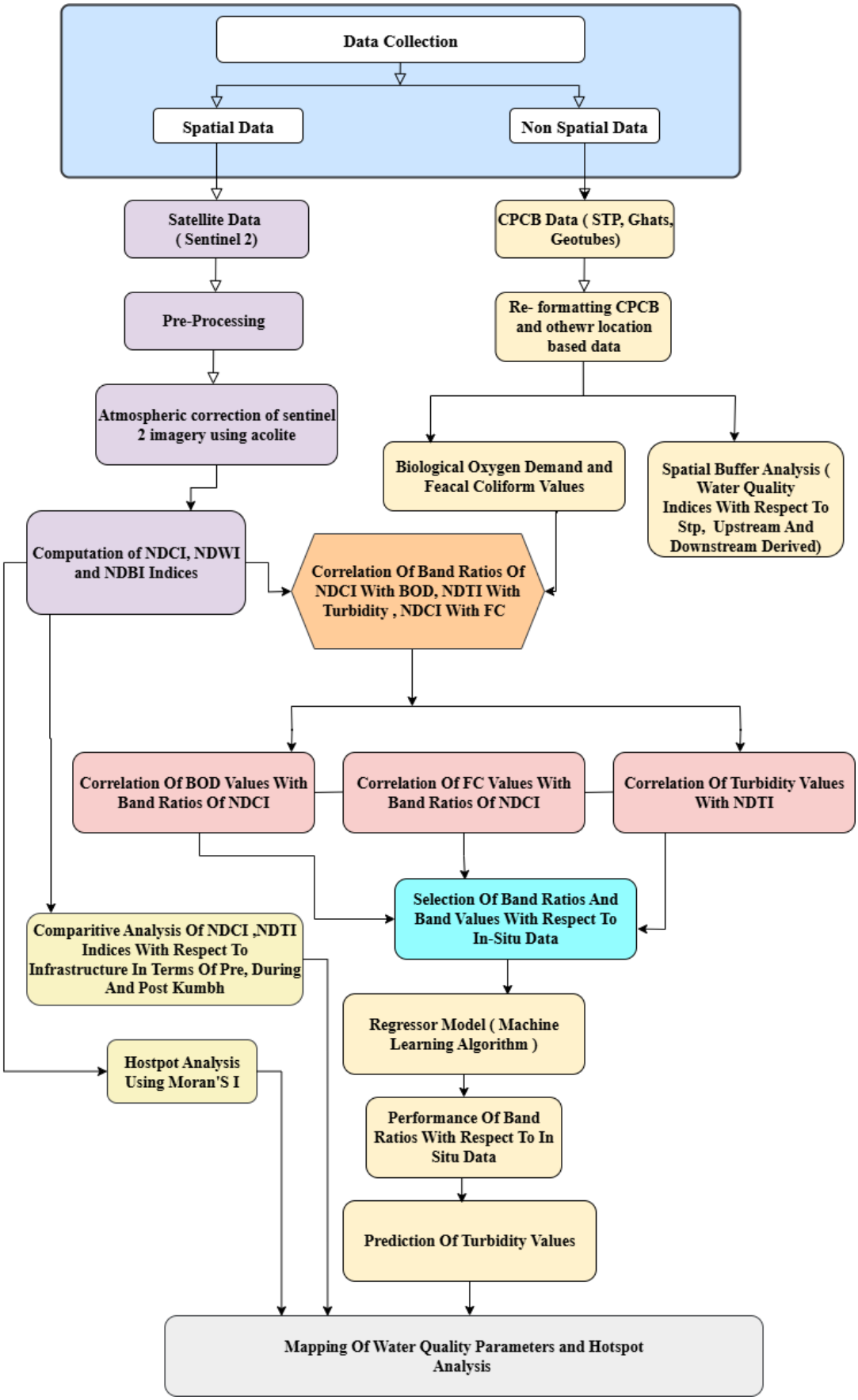


Figure 4.19. Methodology framework

The spatial data underwent pre-processing to enhance its accuracy and usability. This included atmospheric correction of the Sentinel-2 imagery using the ACOLITE tool, which adjusted for atmospheric distortions to reflect true surface conditions. Following this, multiple spectral indices were computed to capture various aspects of the water body and surrounding environment. These included the NDCI index for detecting chlorophyll concentration, the NDTI index for turbidity estimation, the NDVI index for monitoring riparian vegetation, the NDWI index for identifying water presence, and the NDBI index for mapping built-up areas. Simultaneously, the non-spatial data was reformatted and aligned with the satellite data. Special focus was given to the BOD and Turbidity values, which are crucial indicators of organic pollution and microbial contamination in water. Buffer zones were created around significant locations such as STPs, ghats, and upstream/downstream sections of the river to study spatial variation in water quality. This buffer analysis allowed the study to assess how specific infrastructure and activities influence local water conditions.

With the pre-processed and integrated data in place, correlation analyses were performed to quantify the statistical relationship between the computed spectral indices and the in-situ water quality parameters. NDCI was tested for its relationship with BOD and turbidity, while NDTI was analysed in relation to turbidity levels. The results of the correlations analysis identified the most effective spectral indices for quantifying changes in specific water quality indicators. Building on these insights, which included analysis of NDCI band ratios, a predictive model was developed using the Random Forest regression algorithm. This machine learning model leveraged the band ratios and indices to estimate water quality parameters with a high degree of accuracy. The model's performance was then evaluated against in-situ measurements to ensure the predictions were reliable and consistent with real-world data. To further enhance the analysis, a comparative study was conducted using satellite data from multiple years. This allowed for an evaluation of temporal changes in water quality, particularly around the dates of the Kumbh Mela, a major religious event known to influence river conditions significantly. Indices like NDCI, NDWI, and NDTI were compared across years to detect trends and anomalies.

Finally, the validated model was used to generate predictive maps of water quality, enabling the visualization of pollution distribution if present across the river system. These maps served as powerful tools for communication and decision-making. A hotspot analysis was also conducted to identify zones with critically high pollution levels, aiding in targeted policy intervention and environmental management. In summary, this methodology presents a robust

framework that combines remote sensing, geospatial analysis, and machine learning to monitor water quality dynamically. It not only captures the spatial variability of pollutants but also offers predictive capabilities, making it a valuable tool for sustainable water resource management.

4.4.1 In-situ Data Collection

Chl-a and Turbidity concentrations were measured on 18 December 2024, 22 January 2025, 27 January 2025, 1 February 2025, 6 February 2025, 11 February 2025, 16 February 2025, 21 February 2025, 3 March 2025, 8 March 2025, 15 March 2025, 23 March 2025 during the pre-, during-, and post-Kumbh phases respectively, which coincided with the dates of the satellite overpass. This specific set of dates was selected for water quality analysis to ensure optimal alignment with satellite overpasses. Water quality data were sourced both from CPCB monitoring stations and sample points collected during field visits, offering a mix of institutional and field-verified data. This study analyses and has created a dataset consisting of the values from all the indices and band ratios in-order to create a compact dataset which could be used for training and testing in the regressor model for the water quality analysis and selection of band ratios which will be apt for training the model. This study also takes up values of downstream and upstream of STPs with respect to NDCI and NDTI in-order to analyse the connection between the impact of sewage and infrastructure with respect to water quality over the river stretch.

4.4.2 Satellite data

The study utilized Sentinel-2 MSI Level-1C, Collection 1, Top-of -Atmosphere reflectance satellite imagery obtained from the Copernicus Data Space Ecosystem which can be accessed via https://dataspace.copernicus.eu/. The Copernicus Sentinel-2 mission of European Space Agency (ESA) uses two satellites, Sentinel-2A and Sentinel-2B, launched on 23rd June 2015 and 7th March 2017, respectively. Sentinel-2 satellites carries the Multispectral Instrument (MSI), a push-broom imaging spectrometer with a 290 km swath width for acquiring images in 13 spectral bands ranging from visible to near-infrared (NIR) and shortwave infrared (SWIR) at spatial resolution of 10 m, 20 m, and 60 m. Sentinel-2 is a wide-swath, high-resolution, multispectral imaging satellite with a global 5-day revisit frequency which has been widely used in monitoring of vegetation, crops, soil and water cover, land use and land cover classification, water quality assessment, burned area mapping, urban growth and infrastructure analysis and monitoring of inland waterways and coastal areas. The Sentinel-2 Level-1C, Collection 1 product provides Top-of-Atmosphere (TOA) reflectance data which is

radiometrically and geometrically corrected using a global Digital Elevation Model. Table 4.1 shows the details of bands used in Sentinel-2 satellite imagery. It provides a higher spatial resolution of 10 m for Blue, Green, Red and NIR bands which surpasses the 30-m resolution of LANDSAT satellite imagery (Skakun et al., 2021). The revisit time of Sentinel-2 imager's is 10 days which is reduced to 5 days when both Sentinel-2A and Sentinel-2B are in operation (Segal-Rozenhaimer et al., 2020). The study selected Sentinel-2 images captured during periods before Maha Kumbh (December 2024), during Maha Kumbh (Jan-Feb 2025) and post Kumbh (March-April 2024) for analysis of water quality parameters with images having a cloud coverage percentage of less than 5%. Table 4.1 provides the dates for which Sentinel-2 Level-1C satellite imagery are available at Copernicus Data Space Ecosystem.

Table 4.3. Date of availability of cloud-free Sentinel-2 Level-1C satellite imagery.

Sr. No	Date of availability	Sr. No	Date of availability
1	3 December 2024	13	15 March 2025
2	18 December 2024	14	23 March 2025
3	23 December 2024	15	28 March 2025
4	22 January 2025	16	7 April 2025
5	27 January 2025	17	12 April 2025
6	1 February 2025	18	17 April 2025
7	6 February 2025	19	22 April 2025
8	11 February 2025	20	24 April 2025
9	16 February 2025	21	2 May 2025
10	21 February 2025	22	1 June 2025
11	3 March 2025	23	6 June 2025
12	8 March 2025	24	11 June 2025

4.4.3 Random Forest regressor for prediction of water turbidity

Random Forest is one of the most popular ensemble learning techniques in machine learning due to its robustness, interpretability, and efficiency in handling complex datasets (Breiman, 2001). These models can be employed for both classification and regression, depending upon the target variable. Random Forest regressor is a specific application of Random Forest for regression problems with the goal of predicting a continuous target variable by averaging the results of

predictions of all the decision trees. Previous researchers have highlighted the efficiency of Random Forest models in water quality investigations for predicting various water quality parameters such as chlorophyll-a, turbidity etc. (Mishra et al., 2024; Najafzadeh et al., 2019; Najafzadeh & Niazmardi, 2021). These studies have emphasized better performance and accuracy of the model, which can manage multiple input variables, including spectral values of different bands and band ratio values of remote sensing datasets simultaneously to predict dependent variables such as Turbidity and Chlorophyll-a (Mishra et al., 2024; Xu et al., 2021). The present study combines multiple indices with spectral values of different bands and band ratios for making reliable and accurate estimations of optically active water quality parameters in surface water bodies. The spectral indices utilized in this study include NDWI, NDTI and NDCI. These spectral indices and band ratios are sensitive to Chlorophyll-a, and Turbidity makes them valuable tools for assessment of water quality (Table 4.2). These band ratios and band indices have been analyzed for different sampling locations for evaluating their performance with in-situ water quality data.

Table 4.4. Band ratios and indices used in the study.

Sr. No	Band Ratio	Name	References
1	(Band 5 - Band 6)/Band 4	BR1	Ha et al., 2017
2	(Band 5 - Band 4)/ (Band 5 + Band 4)	BR2 (NDCI)	S. Mishra & Mishra, 2012
3	Band 4/Band 2	BR3 (SRWC)	Zarco-Tejada & Ustin, 2001
4	(Band 3 - Band 8A)/ (Band 3 + Band 8A)	BR4 (NDWI)	Hamrell, 2014
5	(Band 2 - Band 3)/ (Band 4 + Band 8A	BR5	Ouma et al., 2020
6	(Band 3 - Band 4)/ (Band 3 + Band 4)	BR6 (NDTI)	Lacaux et al., 2007
7	Band 3/Band 2	BR7	Ouma et al., 2020
8	Band 5/Band 2	BR8	Bhattacharjee et al., 2022
9	(Band 5 + Band 3)/Band 2	BR9	Bhattacharjee et al., 2022
10	(Band 8 - Band 4)/ (Band 8 + Band 4)	BR11 (NDVI)	Rouse et al., 1974
11	Band 8A/Band 2	BR12	Bhattacharjee et al., 2022

12	Band 7/Band 4	BR13	Ha et al., 2017
13	Band 7/Band 2	BR14	Bhattacharjee et al., 2022

The study utilized machine learning to predict turbidity using input features such as band values/band ratio/ band indices selected using SHAP (SHapley Additive exPlanations) feature importance tool. The highly correlated features were removed to ensure better accuracy and performance of the model by removing redundancy using Variance Inflation Factor method. 70% of the data sets were used for model training, and the remaining 30% were used for testing the model. The method uses GridSearchCV to perform hyper-parameter tuning for the Random Forest model for model optimization. The model highlights the best combination of hyper-parameters for model training and testing, and the trained model predicts turbidity values.

4.4.4 Statistical indicators for model evaluation

The performance of the model for predicting turbidity has been evaluated using four metrices. These statistical measures include Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE) and R^2 score of the model.

- **Mean Absolute Error (MAE):** It measures the average absolute difference between predicted and actual turbidity values which indicates prediction accuracy.

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i| \tag{4.4}$$

- **Root Mean Squared Error (RMSE):** It measures the square root of the average squared differences emphasizing large errors.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{N}} \tag{4.5}$$

- **Mean Absolute Percentage Error (MAPE):** This measure calculates the average percentage error for non-zero actual values, providing a relative measure of error.

$$\mathrm{MAPE} = \frac{1}{n}\left(\sum_{i=1}^{n}\left(\frac{y_i - \hat{y}}{y_i}\right) * 100\right) \tag{4.6}$$

- **R^2 score:** This measure indicates the proportion of variance in turbidity explained by the model with high values (closer to 1) which indicates better fit of the model.

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y}_i)^2} \tag{4.7}$$

where y_i = value of ith observation, $\hat{y}$ = predicted value of y and $\bar{y}$ = mean value of y. These statistical measures have been used in the study for model evaluation. MAPE is one of the most commonly used measures for evaluating a model's accuracy due to its intuitive interpretation based on relative error (Kim & Kim, 2016). MAE is dimensionless and it gives the magnitude of errors.

4.4.5 Influence of Non-Spatial Data

Non-spatial data played a vital role in contextualizing the satellite-based observations during the Maha Kumbh. Although indices like NDCI and NDTI effectively detected spatial and temporal variations in chlorophyll and turbidity, their interpretation would have been incomplete without incorporating supporting datasets.

Crucial non-spatial inputs, such as the location of ghats, sewage treatment plants (STPs), temporary geotube installations, river flow directions, and crowd density during bathing dates, were vital in connecting observed spectral fluctuations to human and infrastructural influences. For example, elevated NDCI values near prominent ghats on main Snan days were strongly linked to nutrient enrichment and organic matter introduced by ritual bathing. Likewise, higher NDTI values corresponded to sediment disturbance and increased suspended solids in heavily used congregation zones. Comparisons of upstream and downstream conditions around STPs further highlighted infrastructure performance: well-functioning plants reduced turbidity and chlorophyll signals, while overburdened or temporary units coincided with sustained high index values during periods of heavy inflow.

Temporary facilities, including sanitation camps and toilets along the riverbanks, also played a role in shaping short-term water quality changes. Records of these setups helped explain the episodic surges in spectral indices and, when paired with satellite data, allowed identification of transient pollution hotspots. This integration also revealed the recovery patterns of the river once these structures were dismantled and crowd pressure subsided.

Ultimately, combining non-spatial information with geospatial analysis turned raw satellite measurements into a coherent account of human–river interactions at the Maha Kumbh. This approach distinguished natural hydrological variability from event-driven impacts, offering policymakers and river managers valuable insights into infrastructure effectiveness and guiding future strategies for managing mass-gathering events.

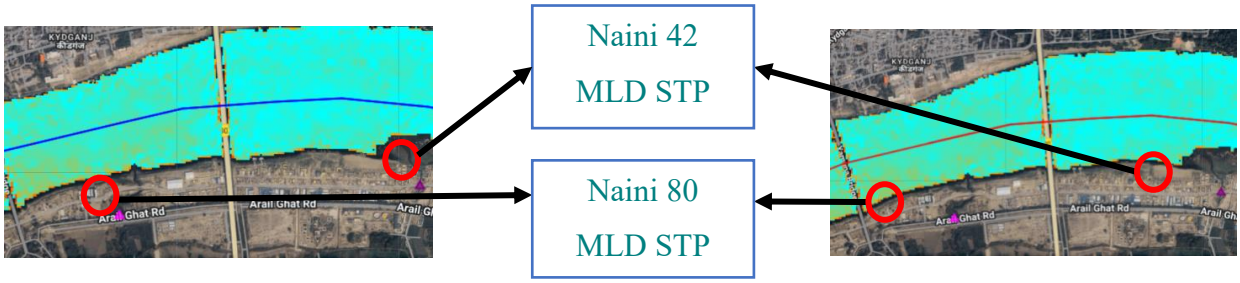


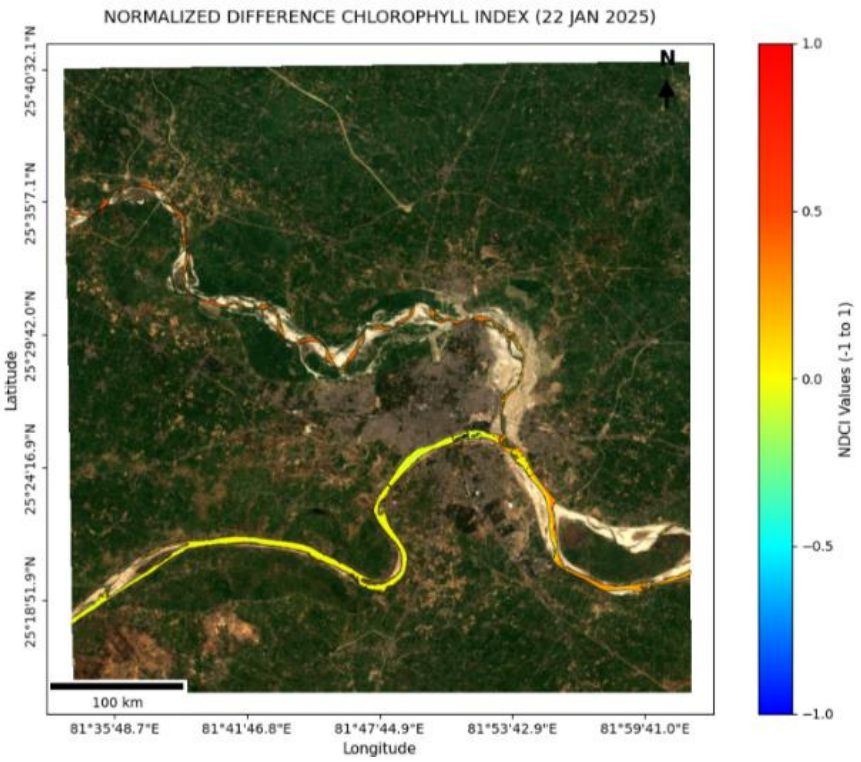
Figure 4.1. Visual Representation of STPs with respect to river for NDCI (Upstream and Downstream)

4.5 Results and Discussion

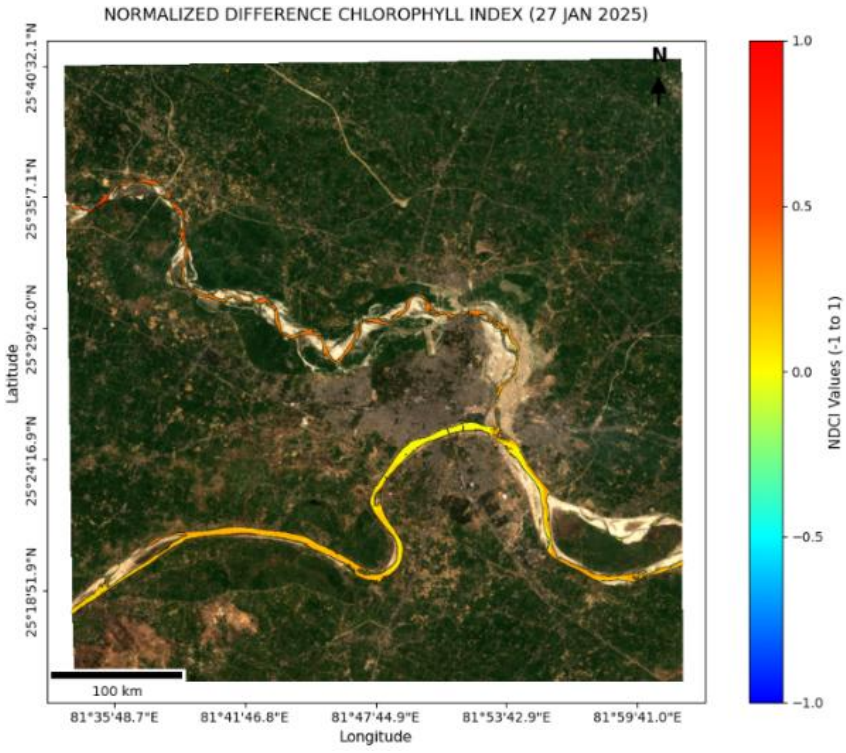
4.5.1 Mapping of water quality parameters using indices

The study utilized three water quality indices to assess water quality across the study region during the study periods i.e., Pre Kumbh (December 2024), During Kumbh (January-February 2025) and Post Kumbh (March -April 2025). These indices, NDCI and NDTI were calculated over the study region using atmospherically corrected Sentinel-2 images using the Google Earth Engine Platform. The NDWI Index indicates that the surface water level was comparatively higher in 2024 compared to 2023, reflecting better water quality on 18 December 2024 (Pre-Kumbh) than during the same period in 2023 which states that initiatives were taken in order to better water flowing throughout the river during Kumbh. The values of these indices were subsequently utilized for the preparation of a machine learning model to predict water turbidity, especially near the Sangam region of Prayagraj.

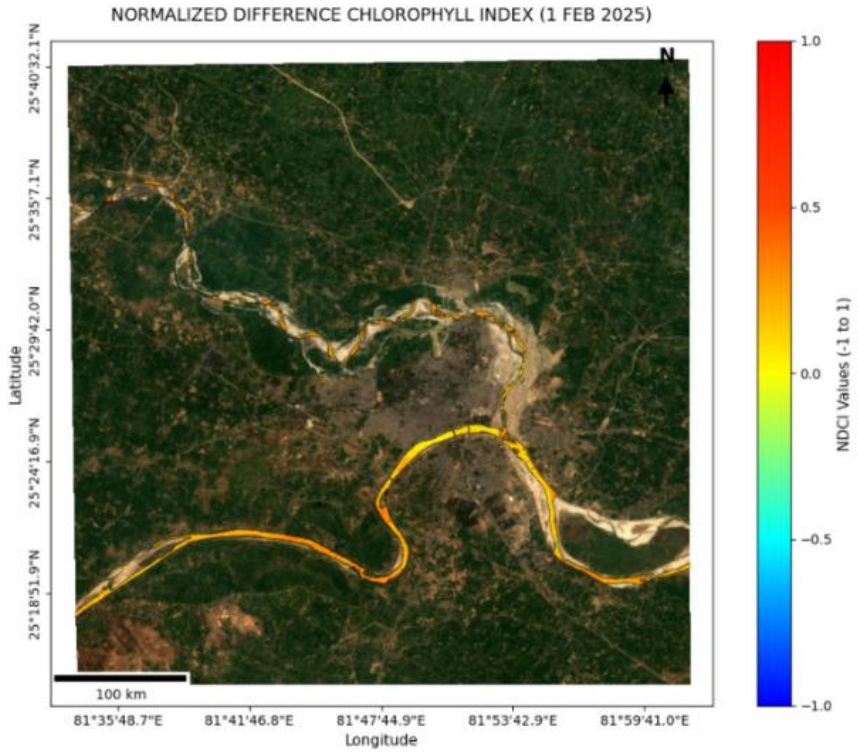
Figure 4.3 shows the values of NDCI values across the study region during the Maha Kumbh event. NDCI values for Yamuna River (0-0.1) are relatively lower as compared to Ganga River (0.2-0.5), suggesting a higher concentration of chlorophyll-a in the Ganga basin. NDCI values decreased in the Ganga River following the Kumbh event but showed an increase in Yamuna River. The highest NDCI values were observed at the confluence region (Sangam) during the active Kumbh phase, strongly suggesting high chlorophyll-a content in this critical area.



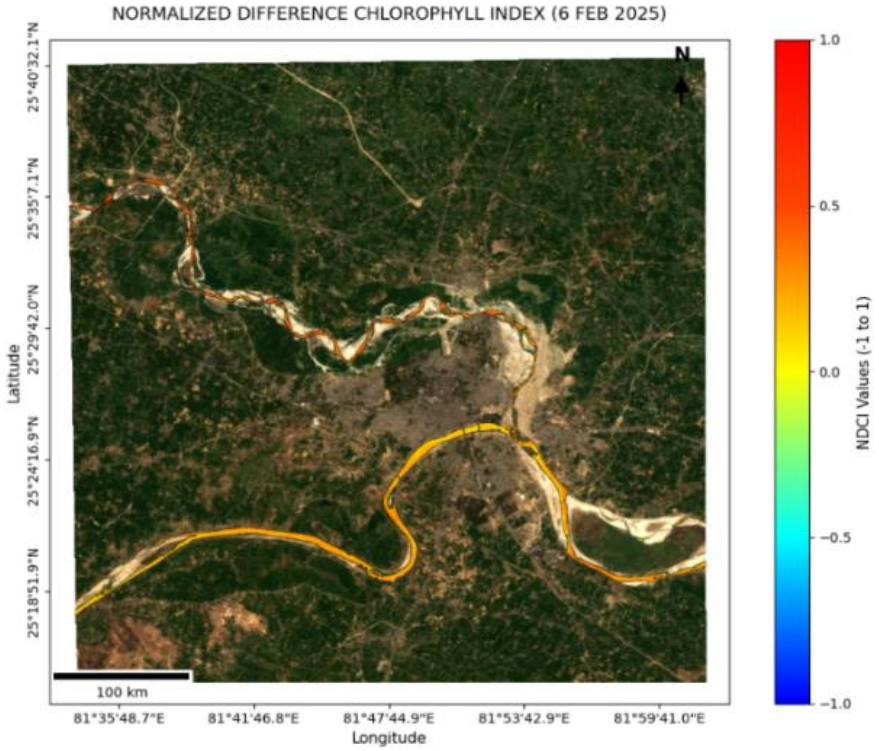
(a) 22 January 2025



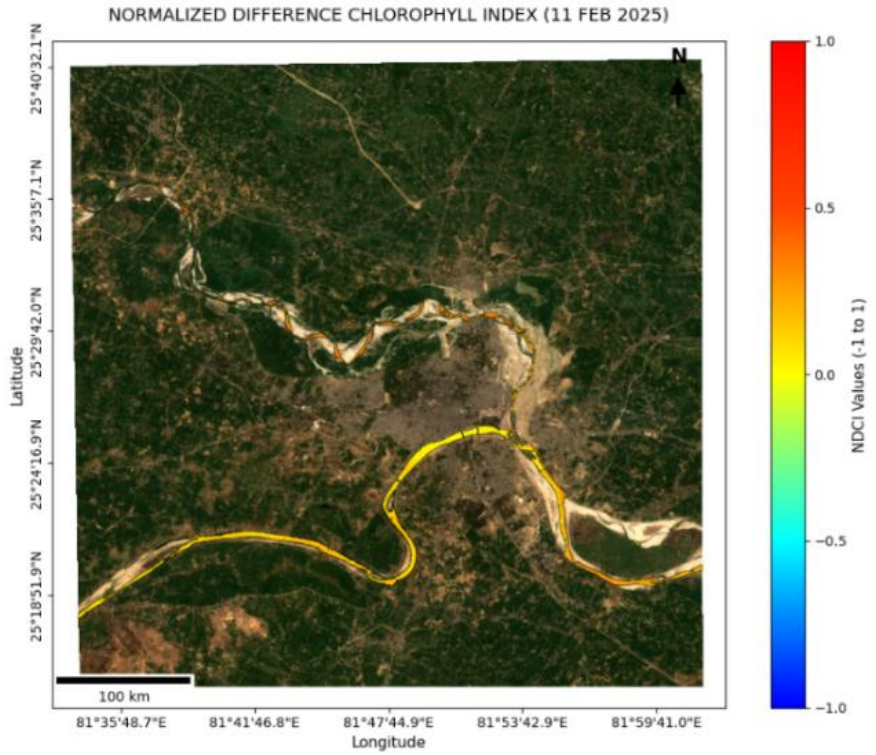
(b) 27 January 2025



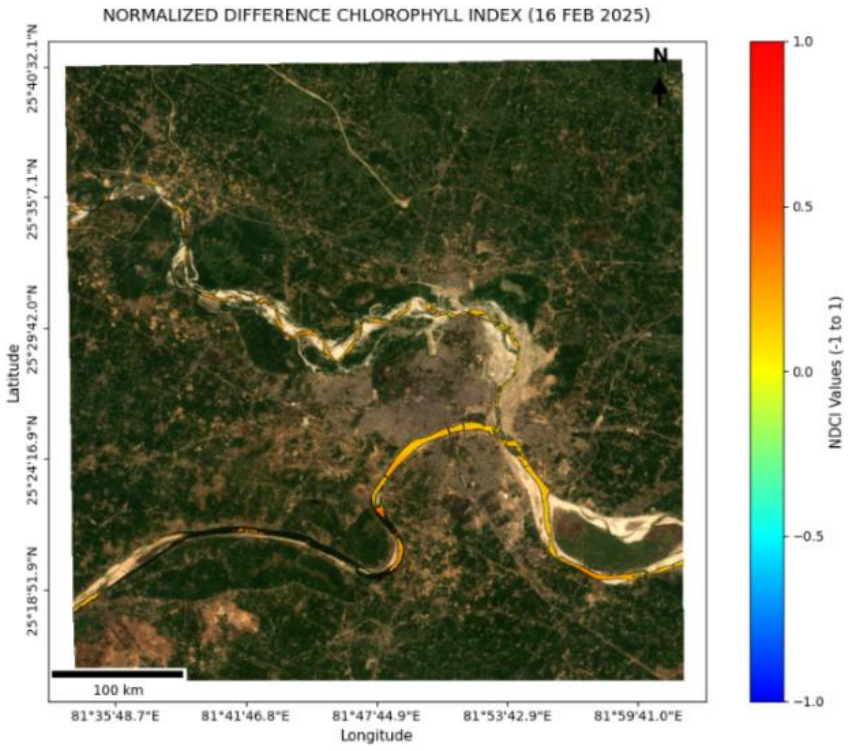
(c) 1 February 2025



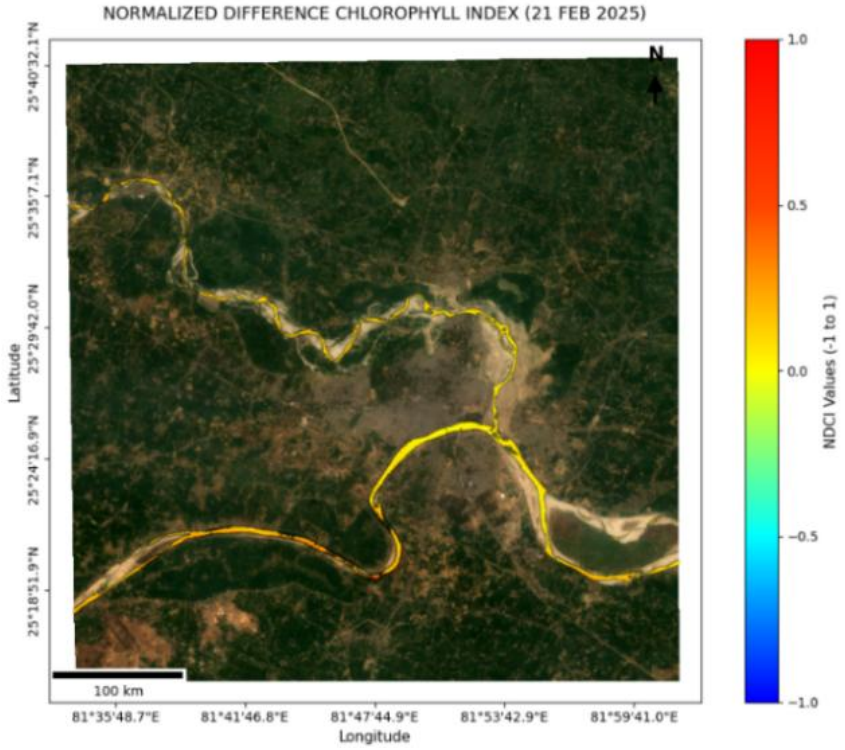
(d) 6 February 2025



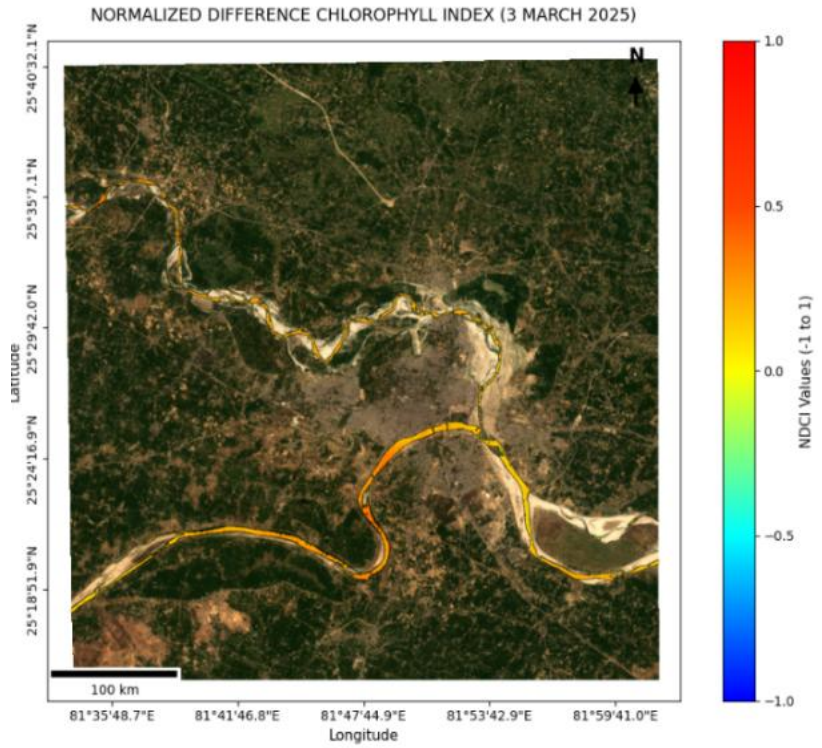
(e) 11 February 2025



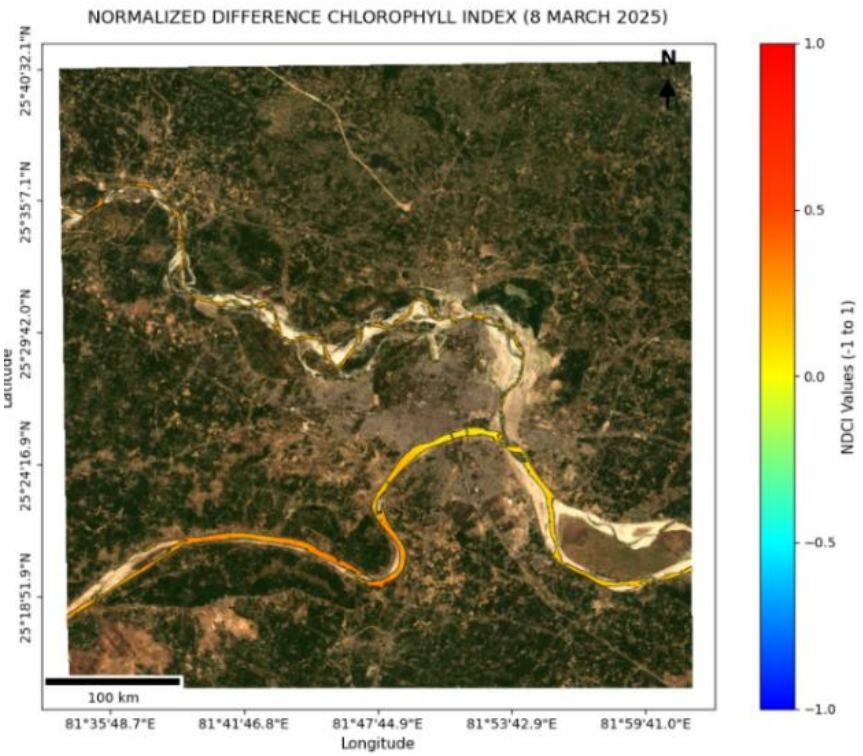
(f) 16 February 2025



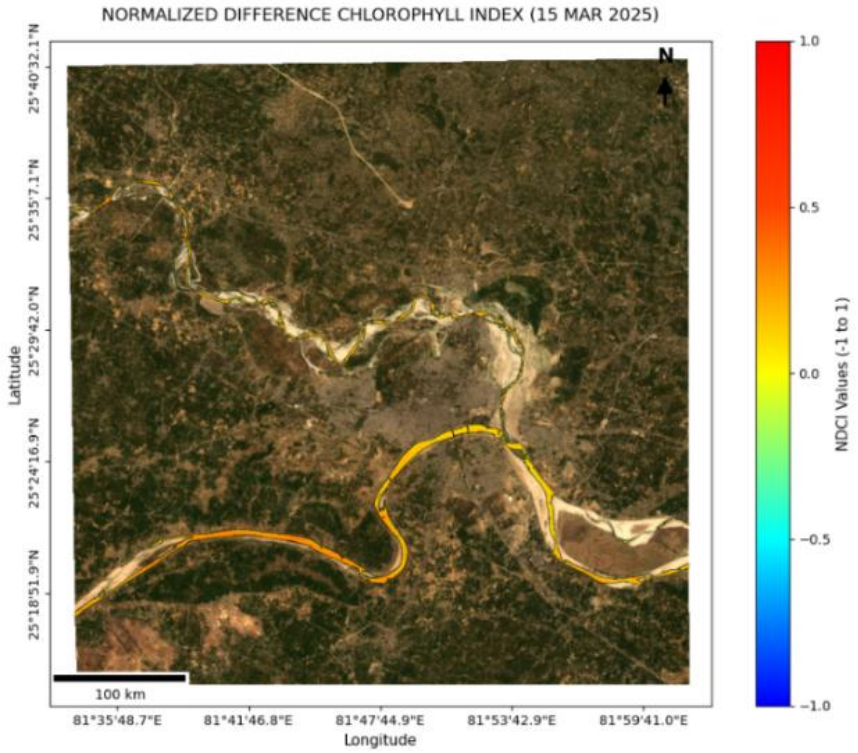
(g) 21 February 2025



(h) 3 March 2025

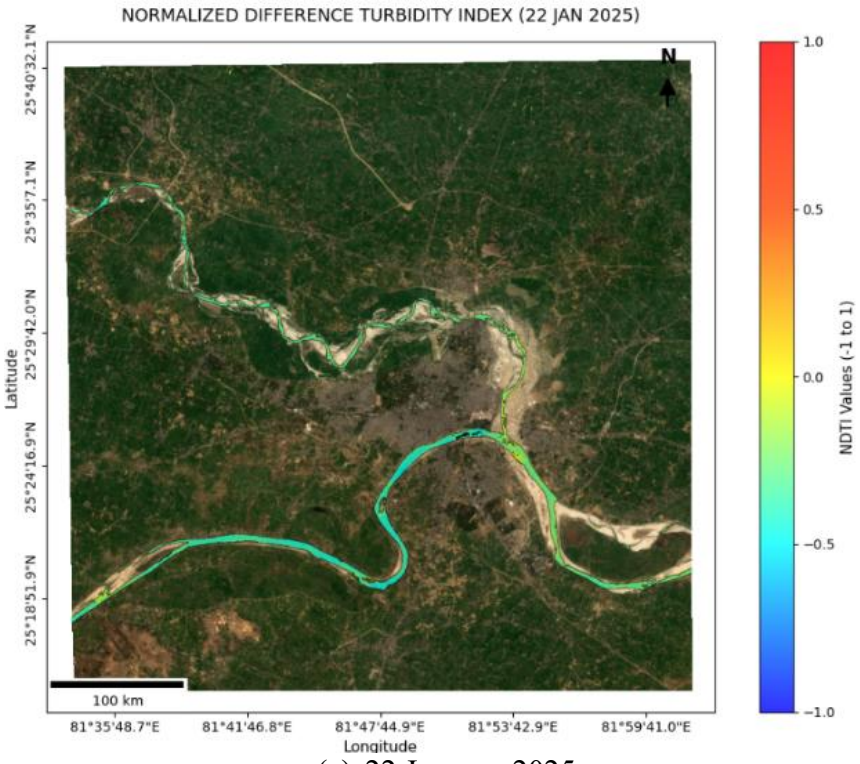


(i) 8 March 2025

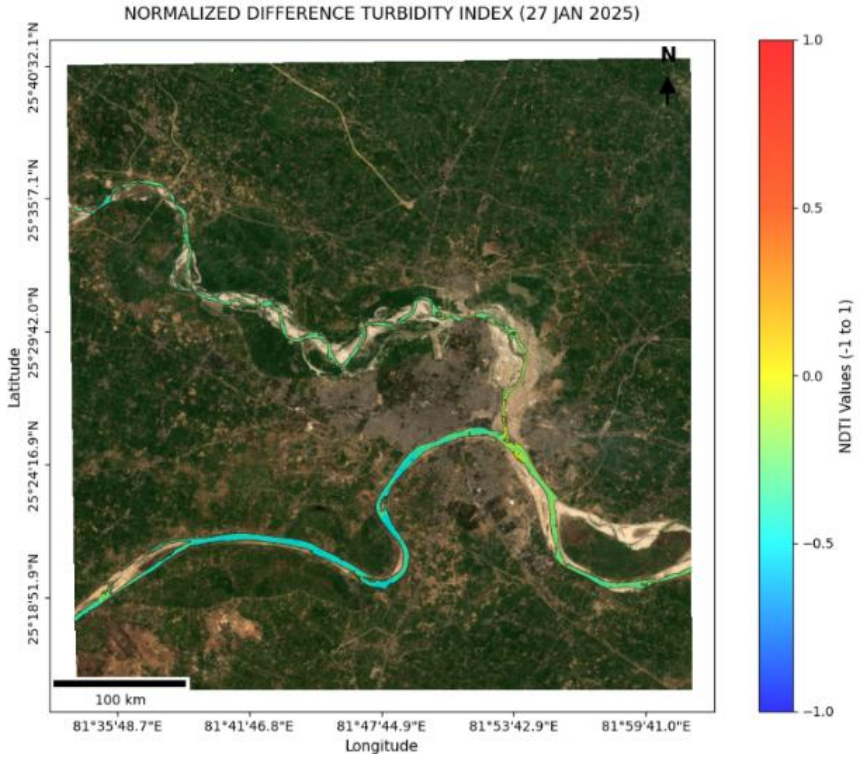


(j) 15 March 2025

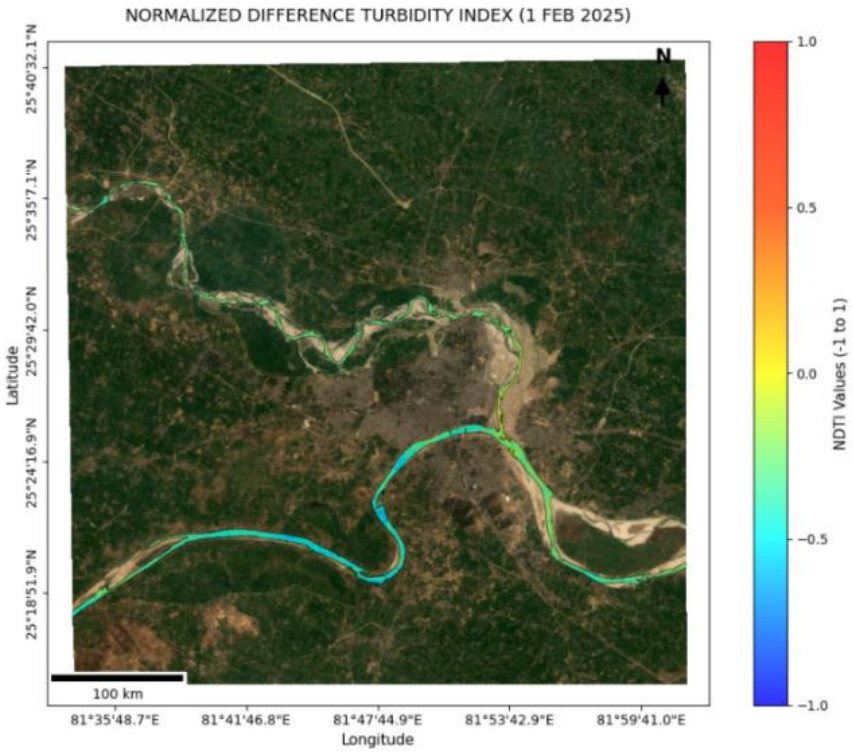
Figure 4.20. (a) – (j) NDCI values over the study region during Maha Kumbh 2025



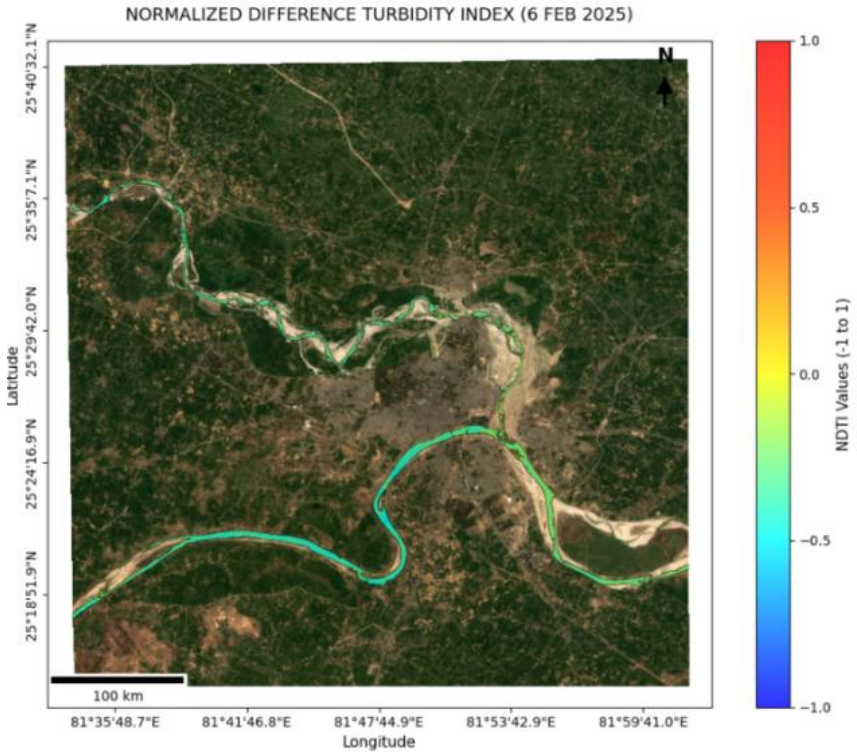
(a) 22 January 2025



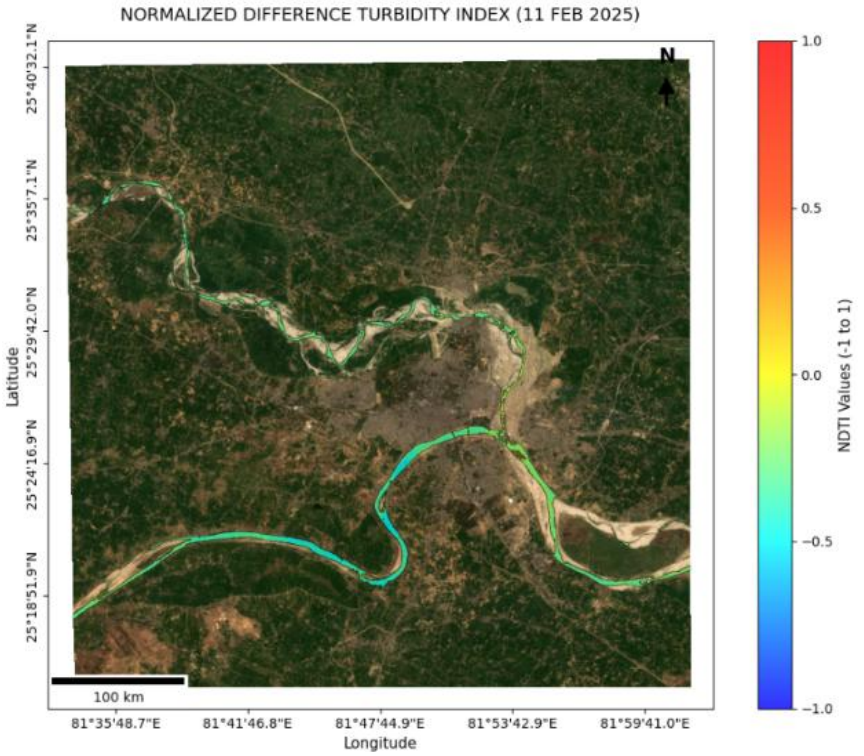
(b) 27 January 2025



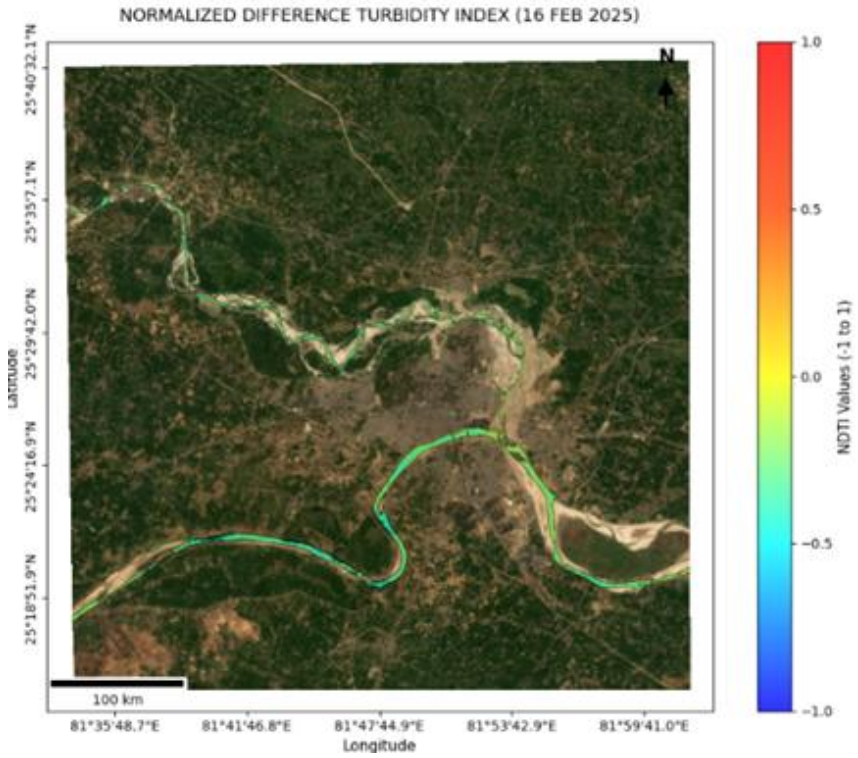
(c) 1 February 2025



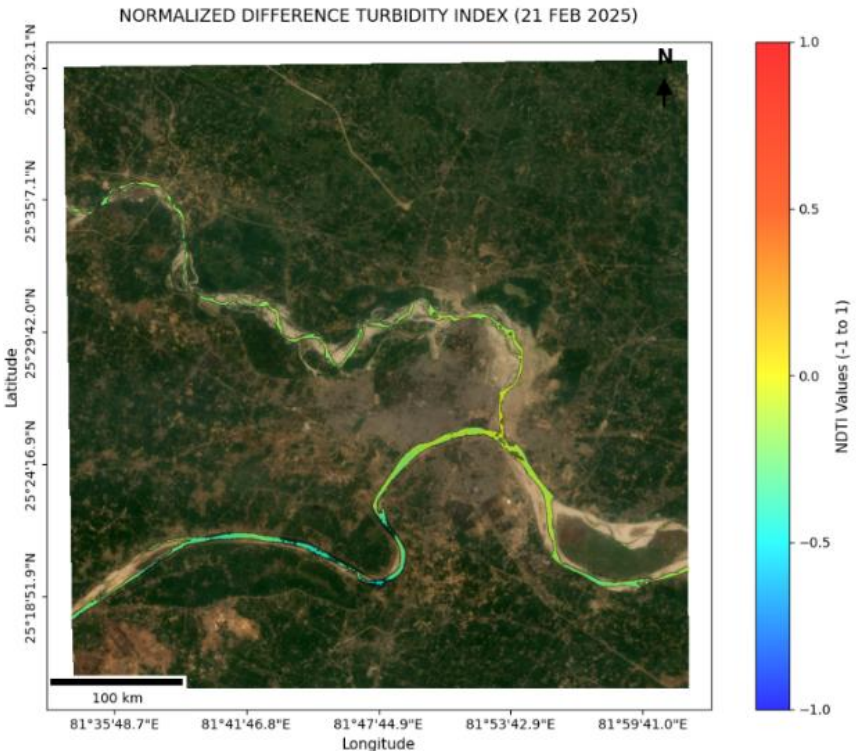
(d) 6 February 2025



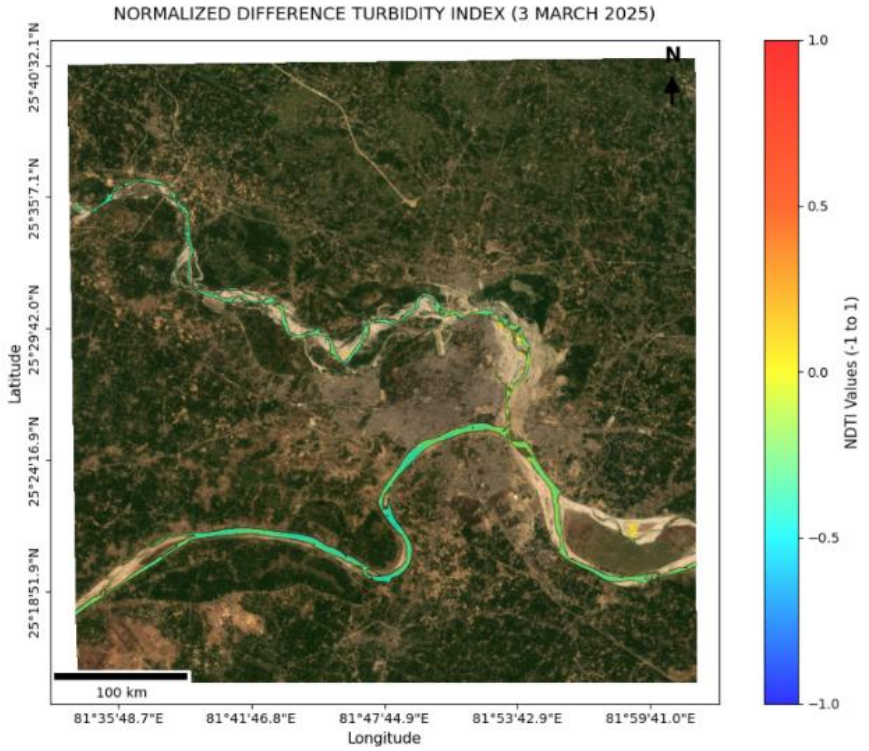
(e) 11 February 2025



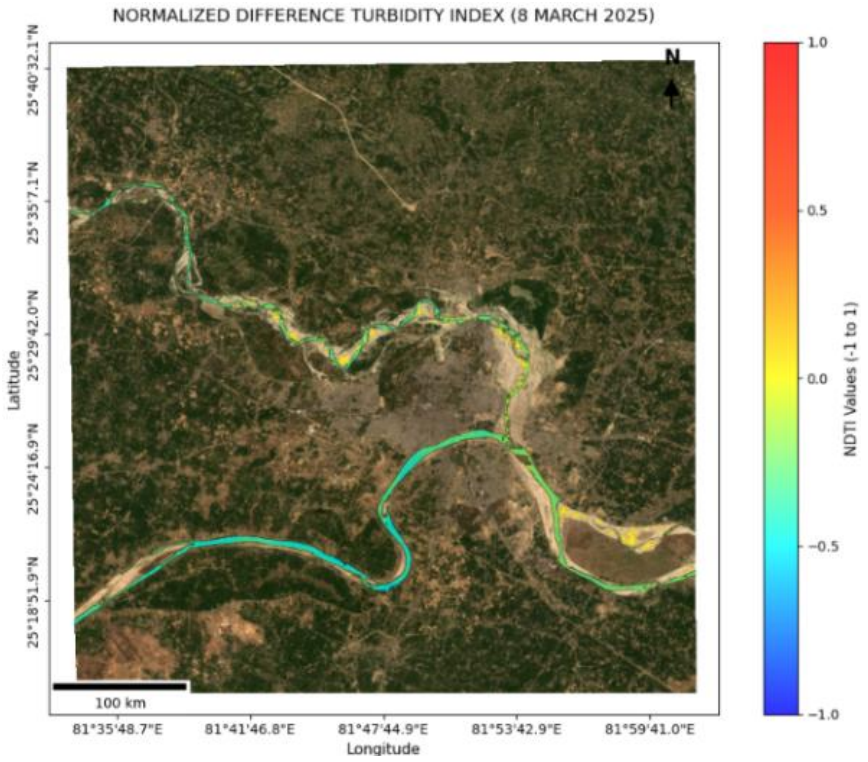
(f) 16 February 2025



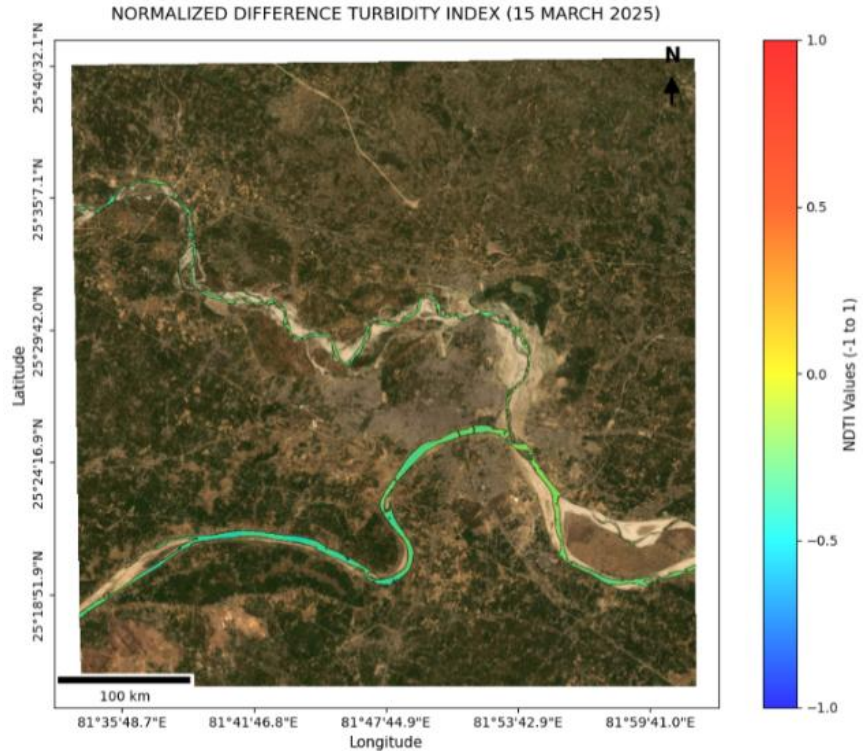
(g) 21 February 2025



(h) 3 March 2025



(i) 8 March 2025



(j) 15 March 2025

Figure 4.21 (a) – (j) NDTI values over the study region during Maha Kumbh 2025

Figure 4.4 (a)- (j) shows the values of NDTI values over the study region during the Maha Kumbh event. NDTI values were significantly higher (0.1-0.3) during Kumbh at the Sangam region and

near bathing ghats (22 January, 27 January, 1 February, 6 February, 11 February, 16 February and 21 February) while it decreases after Kumbh event (<0.1) for 3 March, 8 March, 15 March suggesting increase in water turbidity during the Kumbh event in the sangam region. The values of NDTI are higher (0.2-0.3) at the confluence region suggesting high water turbidity at the confluence region (Figure 4.4). These values are lower for Yamuna channel as compared to Ganga channel suggesting high turbidity in Ganga channel (Figure 4.4).

4.5.2 Model evaluation and performance for prediction of water turbidity

The study utilized a Random Forest regressor to predict water turbidity, using independent variables including specific spectral band values, band ratios and spectral indices such as NDWI, NDCI and NDTI. The model utilized SHAP feature importance tool to include only those predictors which have high SHAP values. The model excludes predictors which have high correlation among themselves using Variance Inflation Factor method. Figure 4.5 shows the correlation matrix for the independent or predictor variables. The independent variables include all those listed in Table 4.3 (the input variables for the regressor model). The dependent variables targeted for prediction by the random forest regressor model are BOD and turbidity.

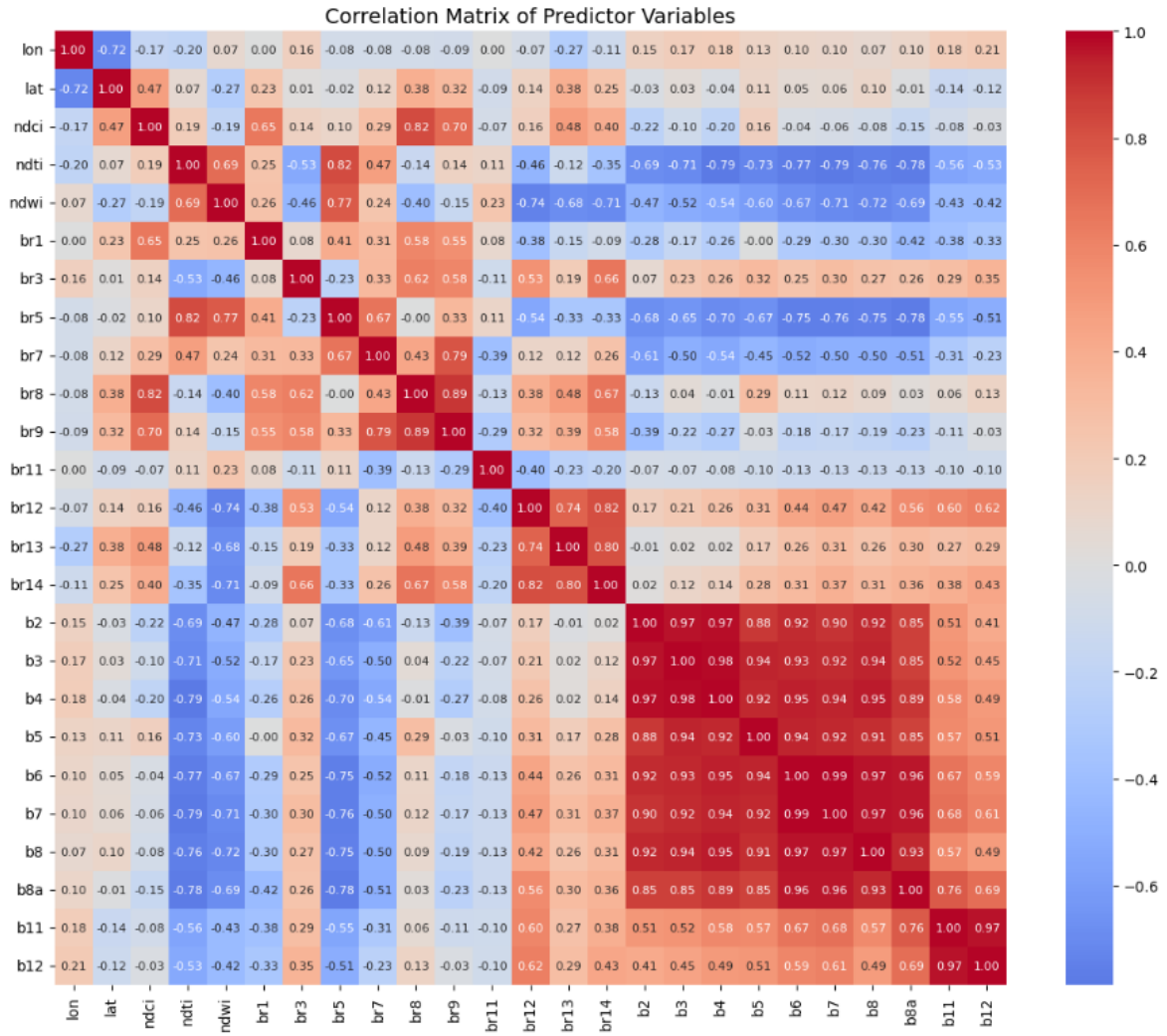
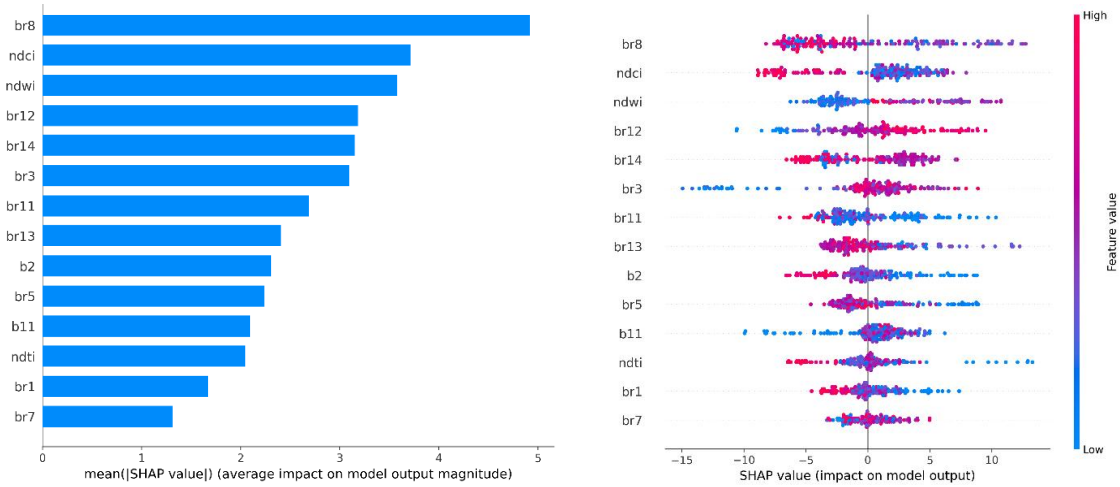


Figure 4.22 Correlation matrix for predictor variables

Figure 4.6 (a) shows the SHAP feature importance diagram for prediction of water turbidity using several predictor variables, which include band values, band ratios and band indices such as NDWI, NDCI and NDTI. The bar plot showing SHAP values suggests that BR8, NDCI and NDTI have high importance, and these are most influential predictors for predicting turbidity. The independent variables NDTI, BR1 and BR7 are least influential predictors of the model. The larger the bar for a predictor variable, the more influential is the predictor variable.

Figure 4.6 (b) shows the SHAP feature importance dot plot, which provides a granular information on how much each predictor variable influences the predicted turbidity. The plot suggests that positive SHAP values on right side of the plot for a predictor increase the value of predicted turbidity while negative SHAP values on the left side of the plot for a predictor variable decreases the value of predicted turbidity. In the plot, red dot shows higher feature values while the blue dot shows lower feature values. The distribution suggests that if red dots are present on

the right for a feature, high values of that feature increase turbidity and if blue dots are present on left side of the plot, then low values decrease turbidity. Consequently, the larger spread observed for BR8, NDCI and NDWI indicates their strongest impact on turbidity predictions. Specifically, high values of NDCI and BR8 significantly increase the predicted turbidity value.



(a) **(b)**

Figure 4.23 SHAP Feature Importance Plot. The bar plot (a) shows important features for making predictions of water turbidity and the dot plot (b) shows features having more importance and direction of prediction.

Figure 4.7 shows the scatter plot comparing the predicted and actual values of water turbidity with R^2 value equal to 0.326. Thus, the Random Forest regressor model predicts water turbidity with R^2 value of 0.326. The other parameters of the model have been shown in Table 4.5.

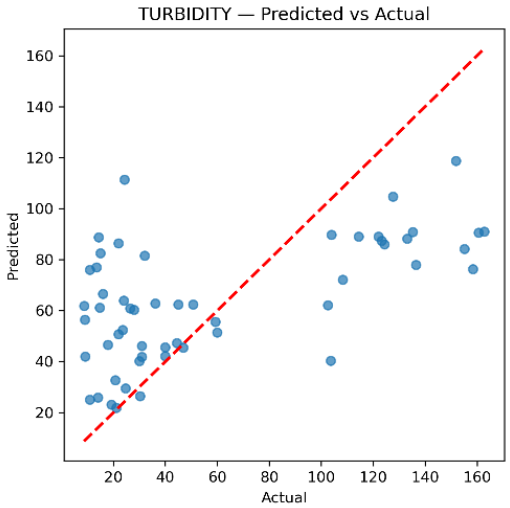


Figure 4.24 Actual and Predicted values of Turbidity

Table 4.5 Model Evaluation and Performance

Model Parameters	Value
R^2	0.326
MAE	34.22
RMSE	41.83

4.5.3 Correlation between NDTI and Turbidity

Turbidity, measured in Nephelometric Turbidity Units (NTU) as well as Formazin Nephelometric Units (FNU) (Figure 4.8-4.9), showed a moderate and consistent correlation with NDTI values for all CPCB Stations. The analysis of sampling locations shows a strong and positive correlation between the NDTI values, and the turbidity measurement taken during field visit (Figure 4.8). High turbidity values, especially during the Kumbh was noticed in the Ganga River Stretch such as Shringverpur Ghat, Lord Curzon Bridge and Shastri Bridge, were well-captured by elevated NDTI indices and Turbidity values (Figure 4.9). This correlation reaffirms the usefulness of NDTI as a non-invasive proxy for suspended sediment and particulate matter in water bodies. These correlations validate the effectiveness of satellite-derived indices as reliable proxies for field-based measurements. This is particularly beneficial for large-scale, continuous monitoring of water quality, especially in areas where regular ground sampling may not be feasible.

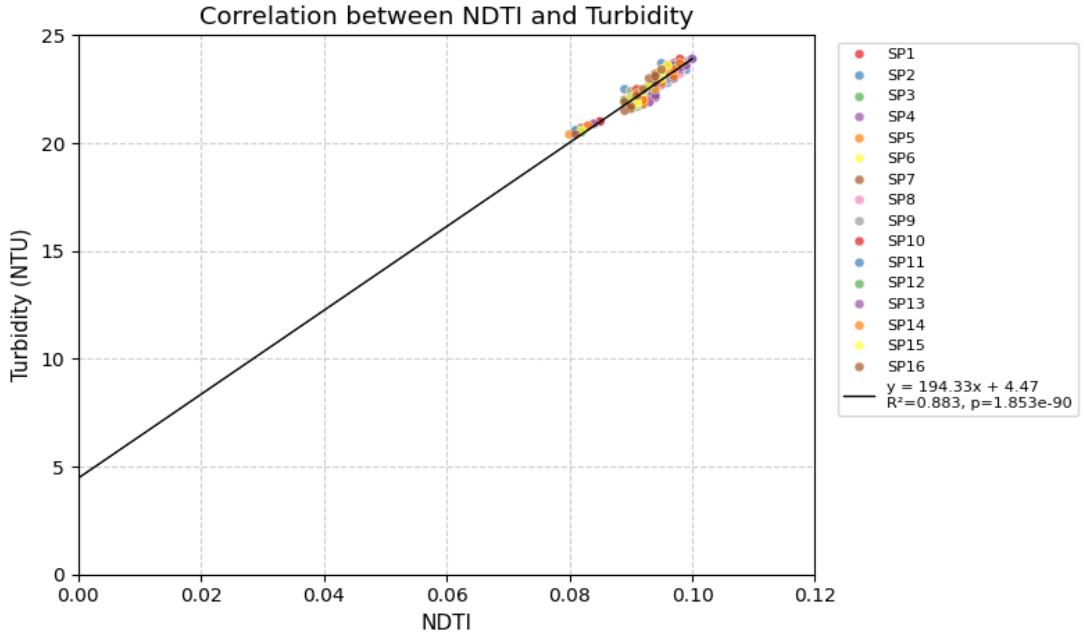


Figure 4.25 Correlation between NDTI and Turbidity for all sampling points) (R^2 = 0.883)

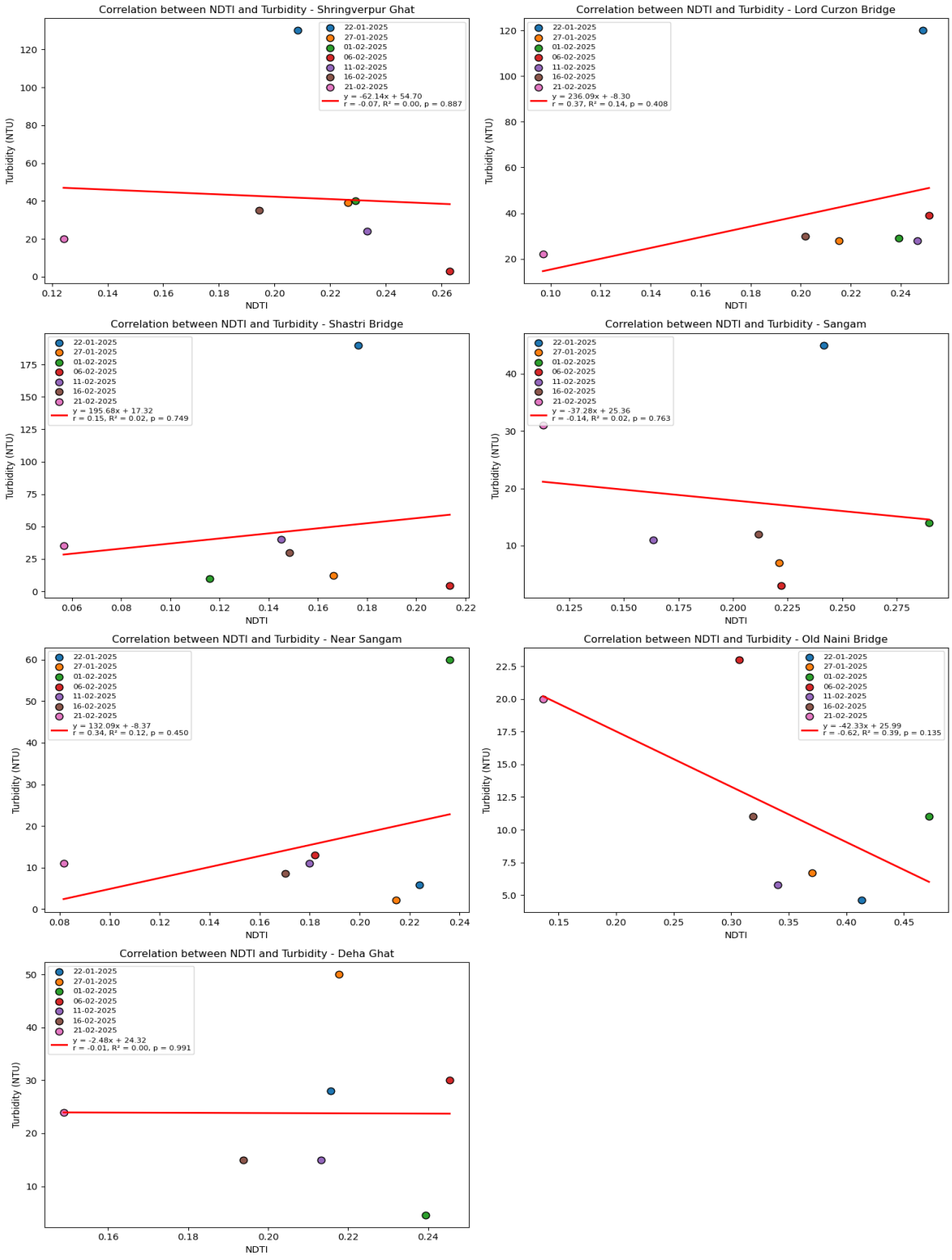


Figure 4.26 Correlation between NDTI and Turbidity for CPCB stations

Figure 4.9 displays the CPCB monitoring stations along the Ganga – Yamuna Stretch. Although the overall correlation between NDTI and Turbidity across these seven stations was statistically weak, a significant turbidity spike was observed on 22 January 2025 at the

Shringverpur Ghat, Lord Curzon Bridge and Shastri bridge stations highlighting localized, event-driven pollution.

4.5.4 Correlation between NDCI and BOD

Biological Oxygen Demand (BOD) showed moderate correlation with NDCI values across several sampling locations (Figure 4.10). Areas exhibiting high BOD, a few areas, typically indicative of organic pollution from untreated sewage or decomposing organic matter, also reflected elevated NDCI values during Kumbh. This was particularly noticeable in zones with stagnating water or limited flow, where organic load accumulation is common. BOD values demonstrated a moderately positive correlation with NDCI in densely populated or pilgrimage zones. These patterns validate the sensitivity of NDCI to biotic pollutants and its relevance in tracking human-induced microbial pollution.

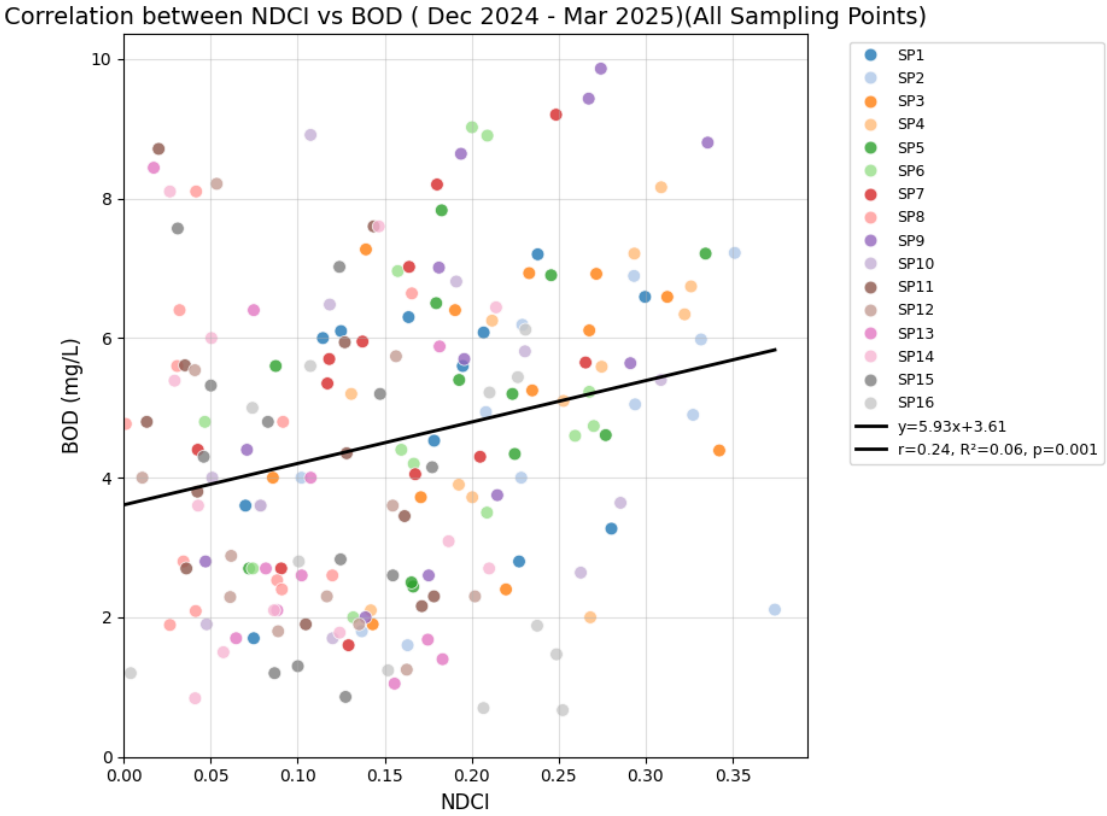


Figure 4.27 Correlation between NDCI versus BOD for all sampling points (R^2=0.06)

The Correlation graphs between NDCI versus BOD (Figure 4.11) showed a moderate positive correlation during Kumbh phase at specific locations, including Shringverpur Ghat and Lord Curzon bridge. Conversely, the correlation was weak or negative at the remaining three stations along the Ganga and Yamuna River stretches.

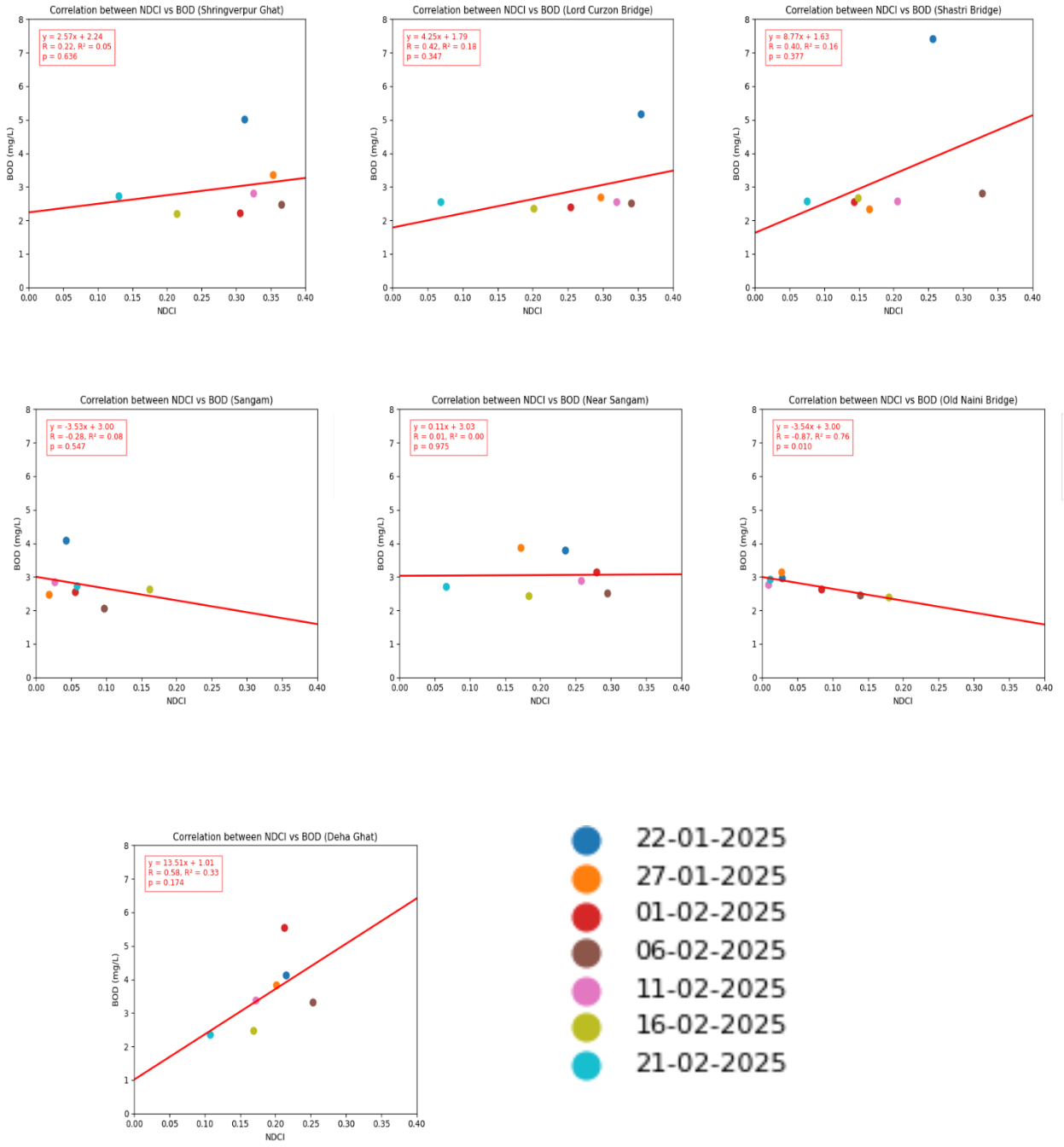


Figure 4.28 Correlation Graphs Between Normalized Difference Chlorophyll Index (NDCI) Versus BOD for CPCB Stations

4.5.5 Correlation between NDCI and Chlorophyll-a (Chl)

Figure 4.12 illustrates the relationship between the NDCI and chlorophyll-a (Chl) concentrations (mg/L) in water samples collected from December 2024 to March 2025. Each point represents measurements from different sampling locations (SP1–SP16), indicated by different colors. The black line shows the linear regression trend, indicating a very weak correlation between NDCI and Chl. Overall, the analysis indicates that NDCI alone may not reliably predict chlorophyll concentrations in the study area during the sampling period. Using hyperspectral data, NDCI for

the Ganga and Yamuna rivers can be predicted in the future by capturing high-resolution spectral reflectance of the water.

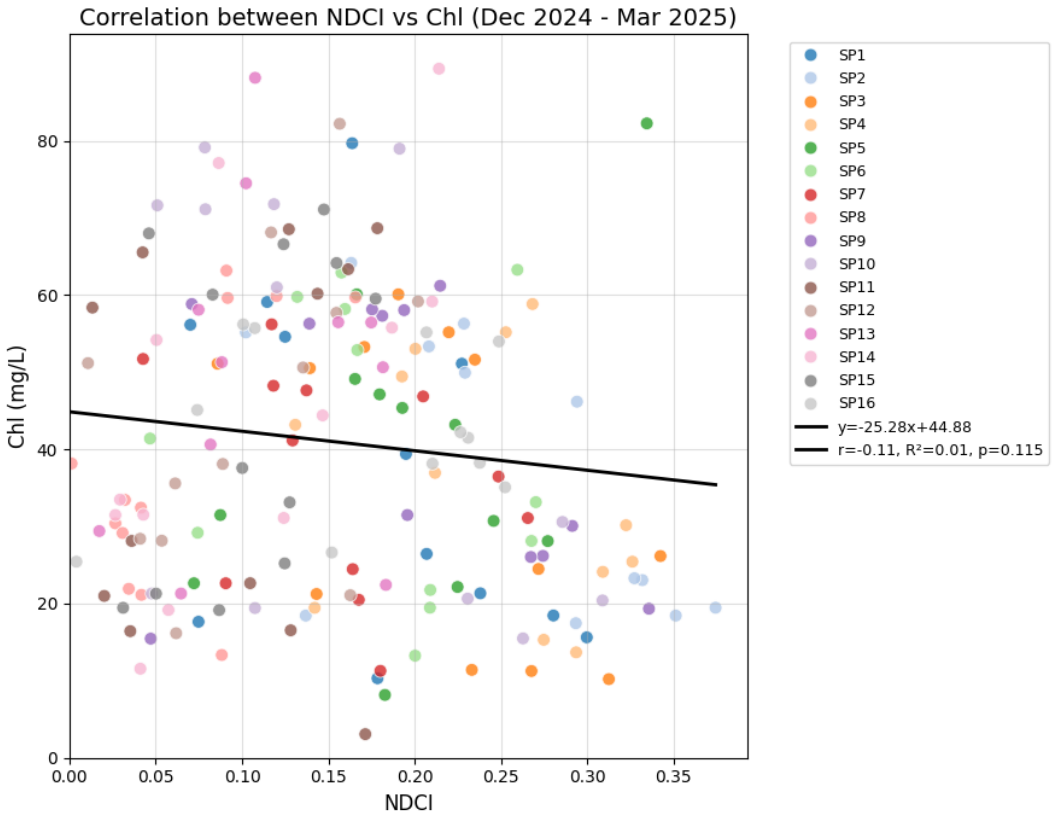


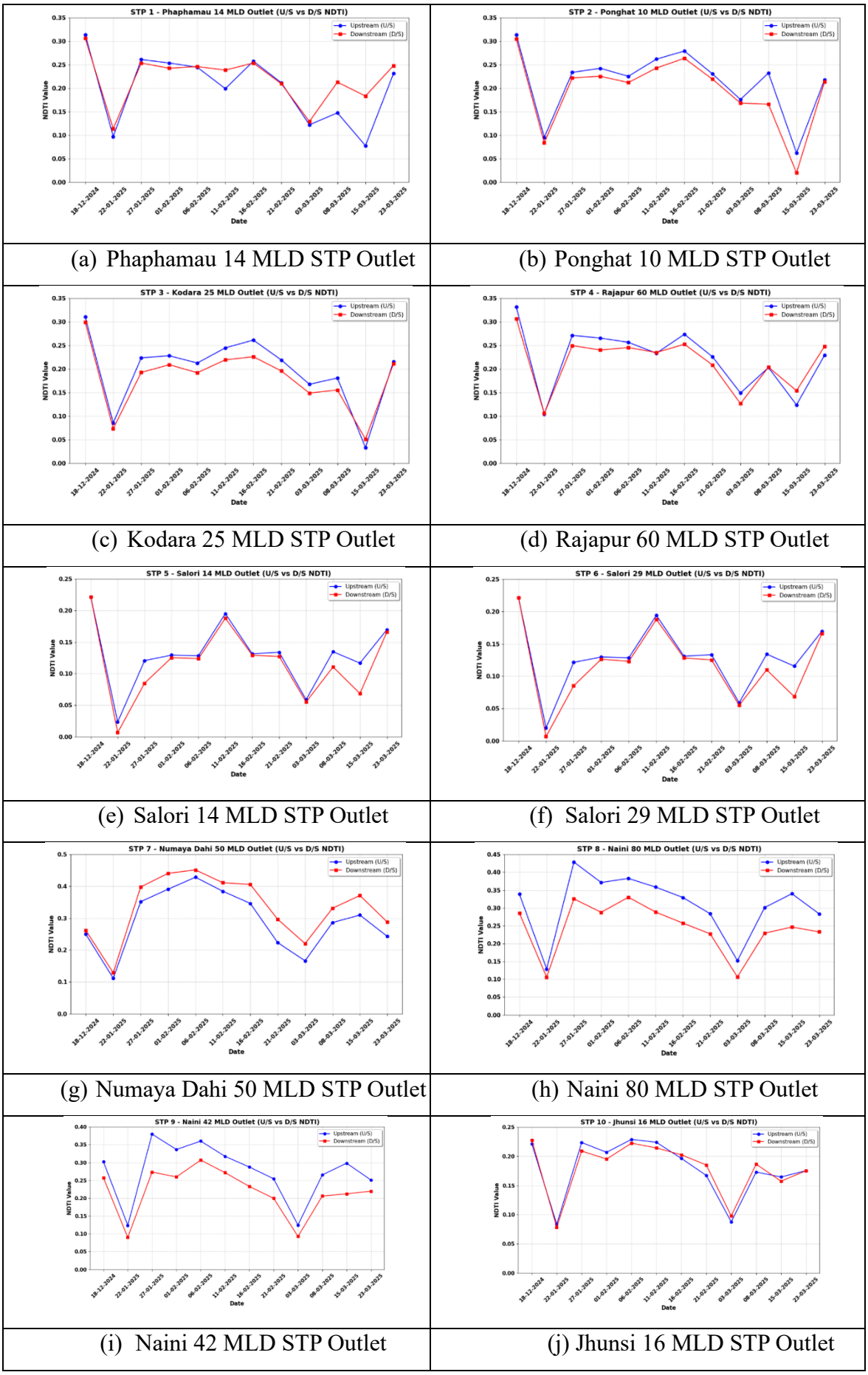
Figure 4.29 Correlation between NDCI versus Chl for all sampling points (R^2=0.01)

4.5.6 Spatial Buffer Analysis Around STPs

To evaluate the localized impact of Sewage Treatment Plants (STPs) on river water quality, spatial buffer analysis was conducted. Buffers were generated upstream and downstream of each STP at predefined intervals of around 3 km radius and 1.5 km buffer from the location of STP to the river stretch to observe any significant variation in water quality indices before and after effluent discharge. In locations where STPs were operational and adequately maintained, a distinct reduction in NDTI values was observed downstream, suggesting effective removal of organic load and suspended solids.

However, in several regions near the Sangam and in the upper Ganga stretch, only a slight impact (about 2%) was observed downstream of the STPs on both the Ganga and Yamuna during the Kumbh. This was quantified by comparing upstream and downstream NDTI values for each STP. Although the STPs near the Sangam did not directly degrade river water quality, they contributed to the overall pattern of higher impacts when considered together with major ghats, drains, and

crowd hotspots. Overall, STPs across the Ganga stretch exhibited a moderate impact, quantified at approximately a 2% increase in downstream NDTI values. However, near the Sangam, sites like the Salori STP showed minimal impact during the Kumbh, suggesting a deliberate reduction in effluent discharge during the event, despite a historically higher discharge count. The analysis of STP in relation to remotely sensed indices highlight their significant role in shaping river water quality. Properly functioning STPs contribute to lowered NDTI values, indicating improved transparency and reduced turbidity levels, while inadequate treatment results in elevated turbidity downstream (Figure 4.13). Overall, comparative assessment suggests that STP, when operating efficiently, exerts a positive impact by lowering NDTI, thus improving river water quality.



(a) Phaphamau 14 MLD STP Outlet

(b) Ponghat 10 MLD STP Outlet

(c) Kodara 25 MLD STP Outlet

(d) Rajapur 60 MLD STP Outlet

(e) Salori 14 MLD STP Outlet

(f) Salori 29 MLD STP Outlet

(g) Numaya Dahi 50 MLD STP Outlet

(h) Naini 80 MLD STP Outlet

(i) Naini 42 MLD STP Outlet

(j) Jhunsi 16 MLD STP Outlet

Figure 4.30 (a)-(j) Impact of STPs on NDTI (Upstream and Downstream)

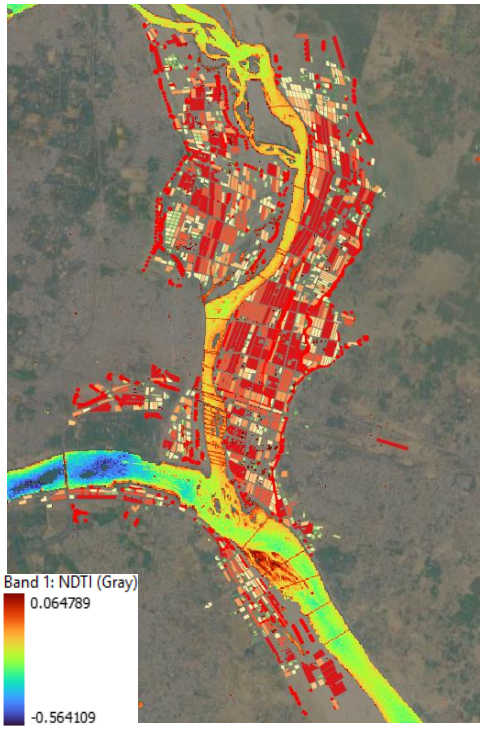
4.5.7 Role of infrastructure on the river

The NDTI maps from 22 January to 15 March 2025 depict temporal variations in suspended sediment and turbidity within the river stretch. On 22 January, low to moderate turbidity is observed, with scattered yellow-green patches along the banks. By 27 January and 1 February, turbidity levels increase, as seen from expanded orange-red zones, suggesting higher suspended sediments, possibly from localized runoff or discharges. On 6 and 16 February, the maps show a shift toward more green-blue areas, indicating a relative reduction in turbidity and improved water clarity, likely due to dilution or settling processes. However, by 15 March, turbidity increases again, with widespread orange-yellow signatures, highlighting renewed sediment influx or anthropogenic activity. Overall, the results indicate fluctuating turbidity levels, with peaks in late January and mid-March, and a reduction around early to mid-February, reflecting dynamic interactions of hydrology, sediment transport, and external inputs.

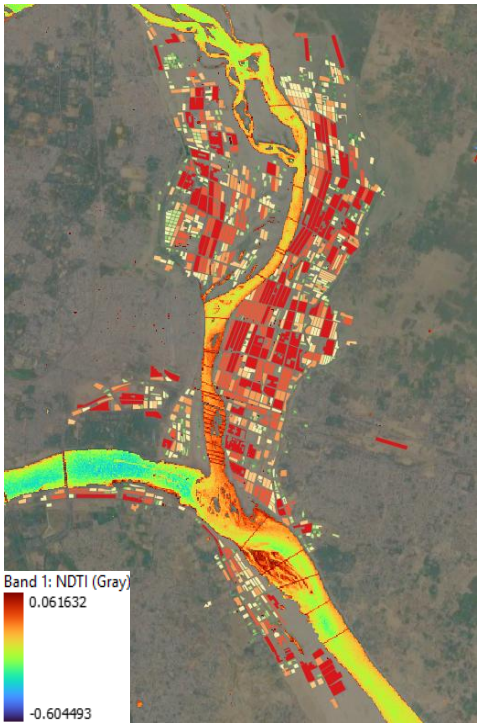
Table 4.6 Influence of Infrastructure and Toilets on Indices.

Date	NDTI Impact (Turbidity)	Reason for the Influence of Temporary Infrastructure/Toilet
22 Jan 2025	Turbidity moderately high	Setup of camps, toilets, and riverbank activities near to Sangam region caused a slight disturbance
27 Jan 2025	Higher turbidity than 22 Jan	Increasing toilet usage and crowd influx elevated organic and suspended matter near Sangam
01 Feb 2025	Significant turbidity spike	Maximum crowd pressure, intense infrastructure use, and waste discharge
06 Feb 2025	Persistently high turbidity	Heavy sanitation uses and gatherings-maintained disturbance
16 Feb 2025	Turbidity reduces but remains elevated	Decreasing crowd load but residual effect of toilets and waste
15 Mar 2025	Lowest turbidity post-event	Minimal influence as infrastructure removed, system recovering

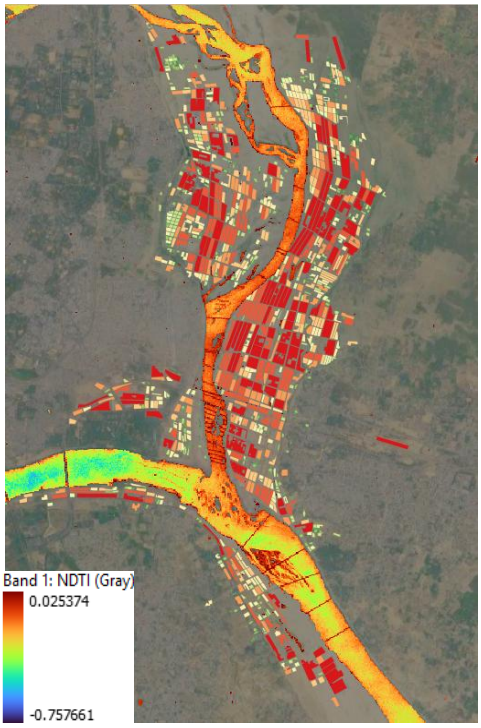
Figure 4.14 represents the influence or impact of temporary infrastructure and toilets during main Snan dates on NDTI excluding the overall imagery computed. We have obtained the impact assessment and have also stated the possible reason which has happened (Table 4.5).



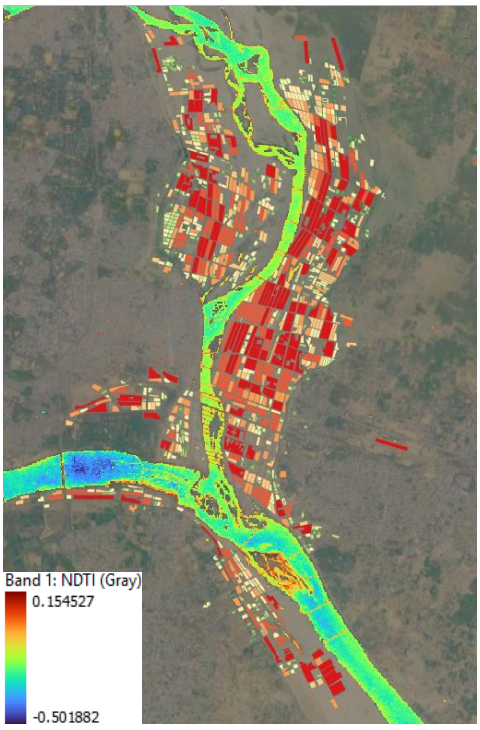
(a) 22 January 2025



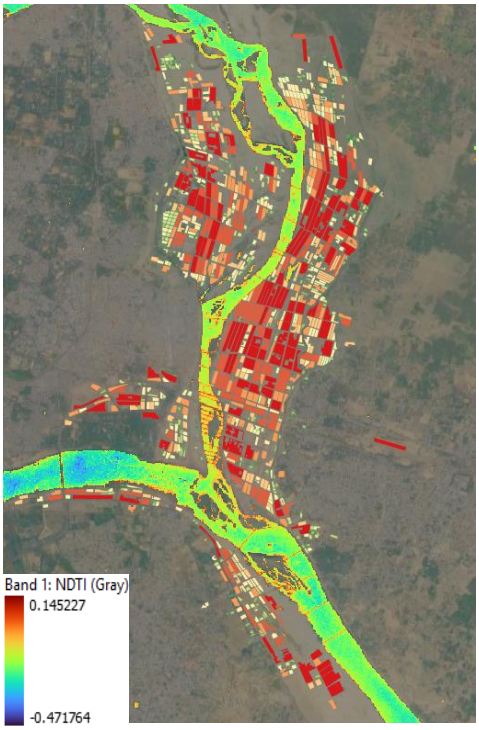
(b) 27 January 2025



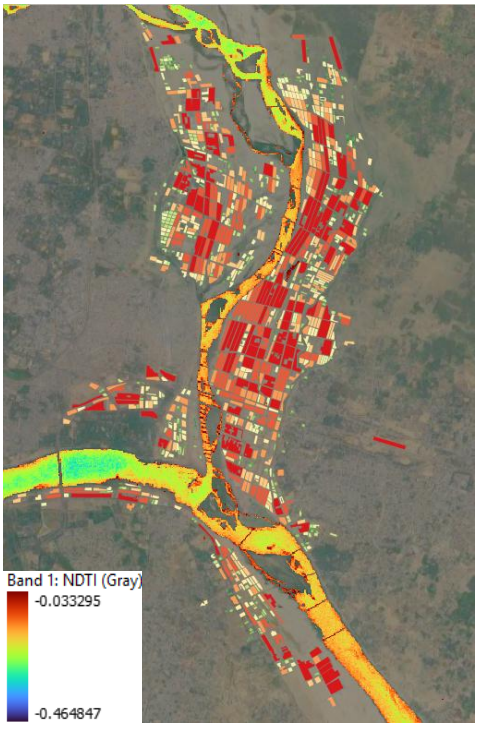
(c) 1 February



(d) 6 February 2025



(e) 16 February 2025



(f) 15 March 2025

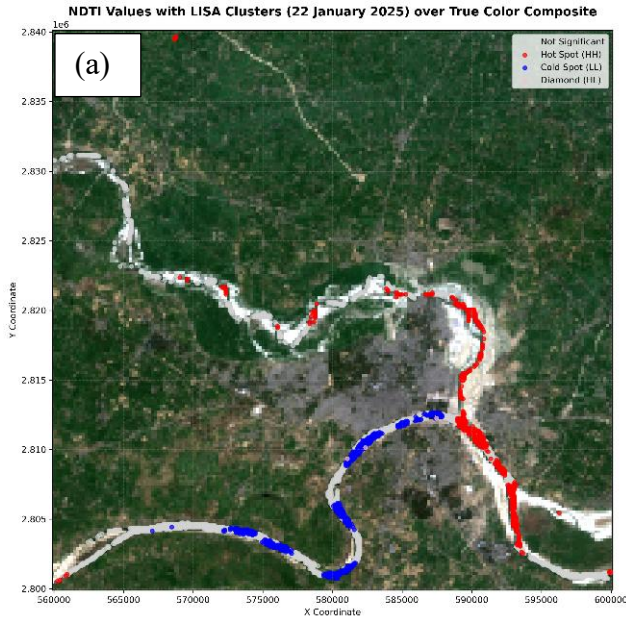
Figure 4.31 Image Interpretation of Influence of Temporary Infrastructure/Toilets on NDTI.

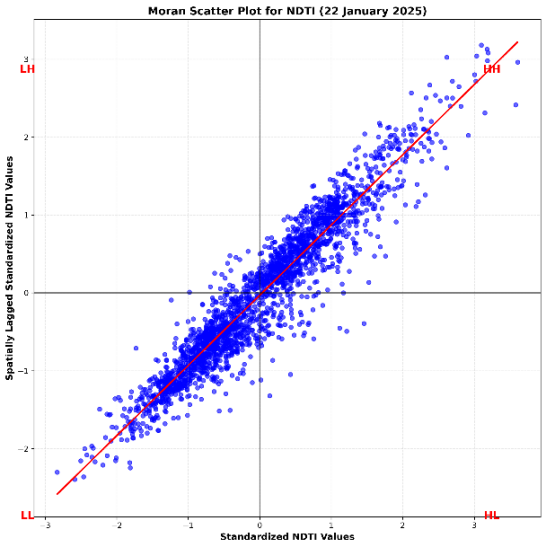
The spatio-temporal variation in NDTI suggests that infrastructure along the river stretch plays a critical role in modulating water quality. The localized spikes in NDTI observed in late January and again in mid-March can be linked to construction-related disturbances, sediment re-suspension near embankments, and untreated discharges from drains or bypassed flows at STPs.

4.5.8 Hotspot Analysis using Moran's I – Spatial Autocorrelation

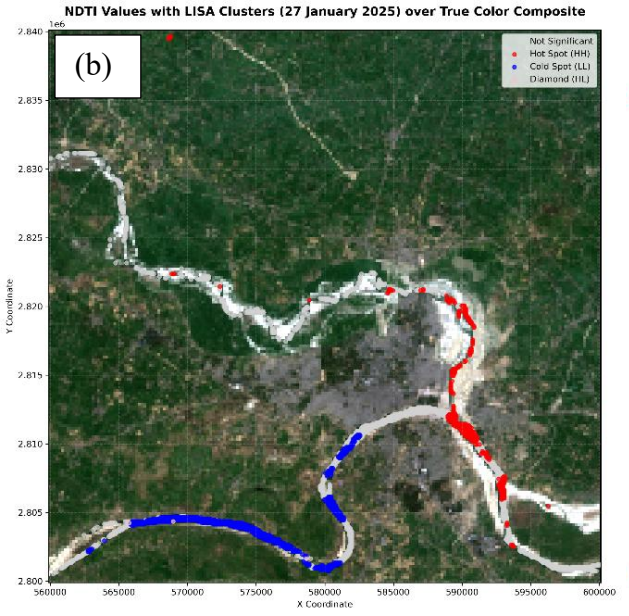
The Spatial Autocorrelation (Global Moran's I) measures spatial autocorrelation based on both feature locations and feature values simultaneously. Given a set of features and an associated attribute, it evaluates whether the pattern expressed is clustered, dispersed, or random. Using this method, the study identified hotspots using NDTI values. Figure 4.15 displays the results of the spatial cluster analysis (hotspots of NDTI values) computed using Global Moran's I during the Kumbh period. The map clearly identified the Sangam region as significant hotspot (red color), implyiong high clustered NDTI values, while the Yamnuna ruver channel exhbits cold spots (blue colour), implying low clustered NDTI values. The scatter plot shows Moran's I values with high values indicating clustered values of NDTI at the Sangam region. The closer the Moran's value is to 1, the more clustered the NDTI values are to each other. On 21st

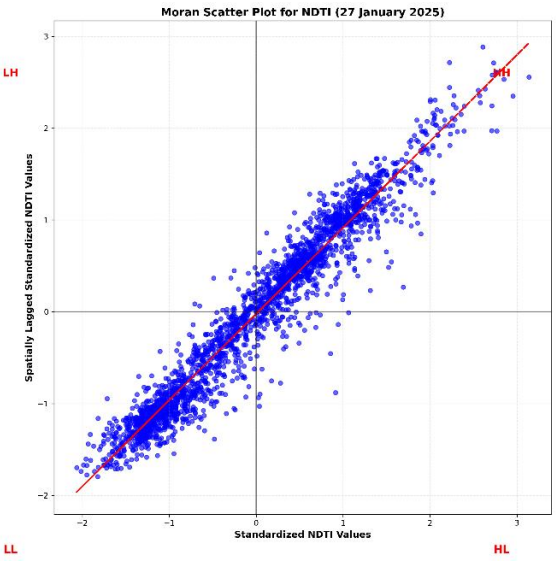
February 2025, the NDTI hotspots are more clustered compared to other previous days indicating high Moran's I (0.96). Thus, proximity of large number of tents and toilets to the Sangam region results in the occurrence of hotspots of water turbidity at the Sangam region.



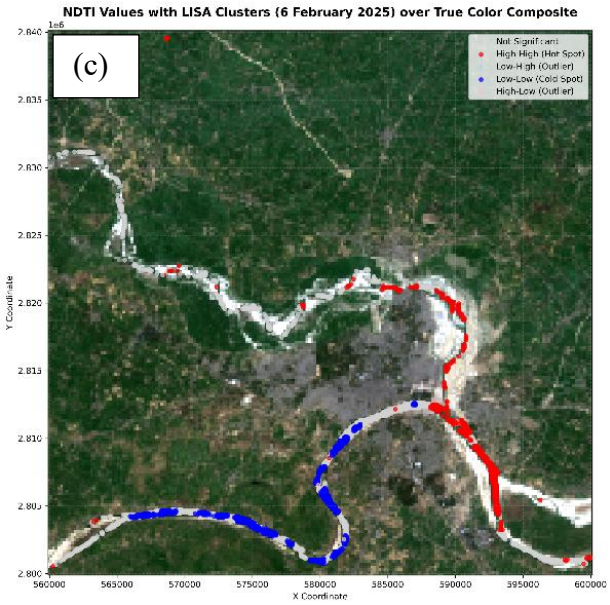


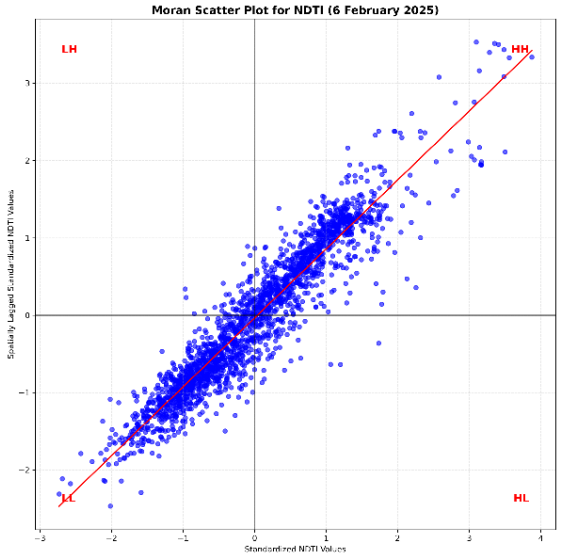
Moran's I value = 0.92



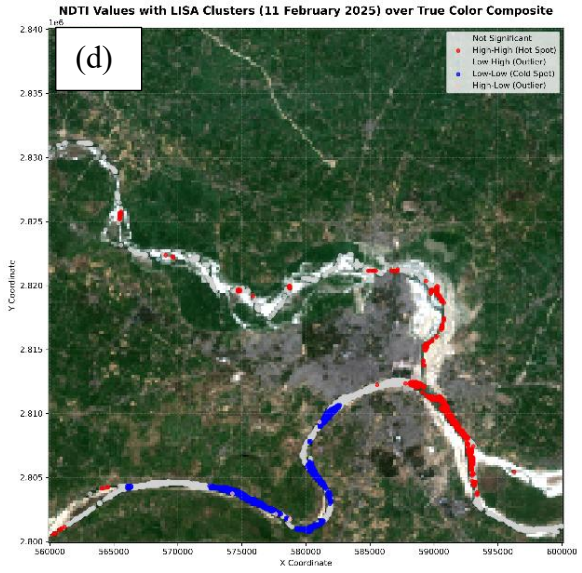


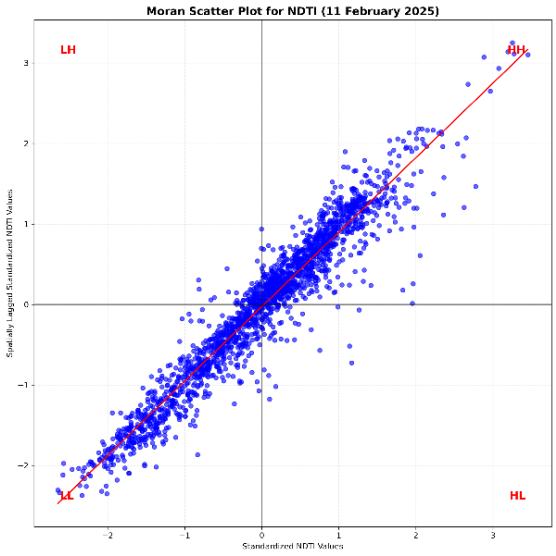
Moran's I value = 0.94





Moran's I value = 0.89





Moran's I value = 0.92

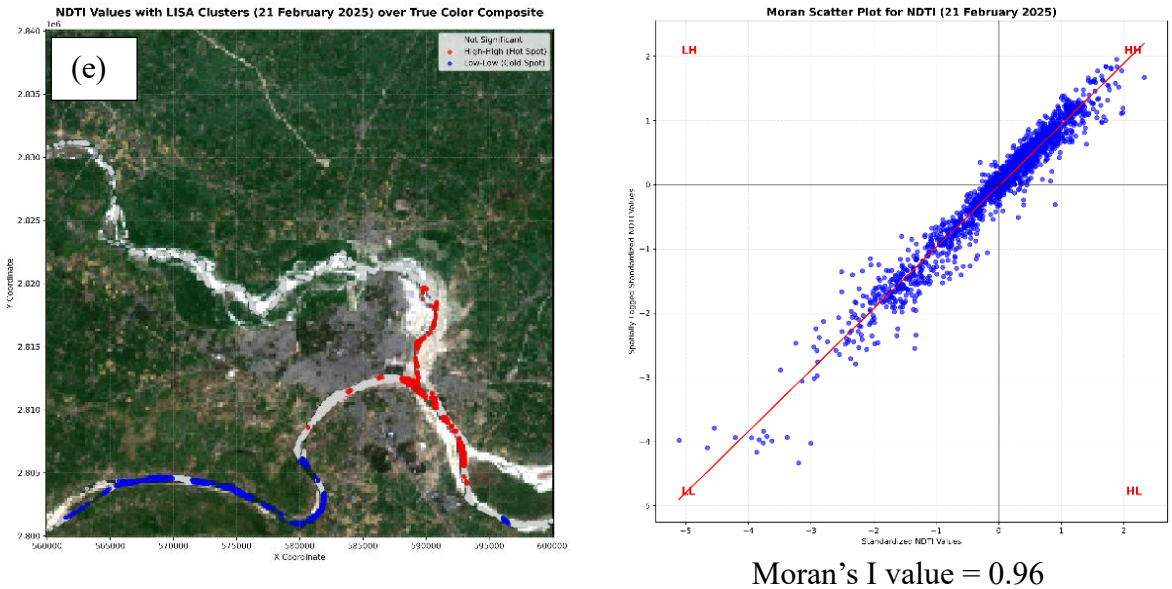


Figure 4.32 Hotspot identification of water turbidity using Moran's I

4.6 Summary

The study investigates how the massive influx of the floating population during Maha Kumbh exerts pressure on the riverine environment through increased sewage generation, nutrient loading, and sediment influx. The integration of spatial indices (NDTI) with non-spatial datasets (BOD, turbidity) provides a comprehensive understanding of upstream and downstream dynamics and the effectiveness of sewage infrastructure. The NDWI Index indicates that surface water coverage was comparatively higher in 2024 compared to 2023, reflecting better water quality on 18 December 2024 (Pre-Kumbh) than during the same period in 2023 which states that initiatives were taken inorder to better water flowing throughout the river during Kumbh.

The correlation between NDCI and chlorophyll (Chl), and between NDCI and BOD showed a weak relationship. This indicates that NDCI alone may not be a reliable indicator for predicting BOD and chlorophyll concentration across the study area during the sampling period. In future studies, hyperspectral data can be used to estimate NDCI for the Ganga and Yamuna rivers by capturing high-resolution spectral reflectance of the water surface. A strong correlation (0.88) was observed between NDTI and turbidity. During 11 and 16 February 2025, high value of NDTI were observed near the Sangam region, primarily due to increased bathing activities. The influence of infrastructure was especially evident at Sangam, where ghats, drains, and nearby STPs collectively shaped the spatio-temporal variations in NDTI. The high spikes in

NDTI corresponded with sediment resuspension linked to bathing activities. These patterns underscore that infrastructure, when strained by crowd surges, can amplify water quality degradation in sensitive zones. The study shows hotspots of water turbidity identified using spatial autocorrelation (Moran's I), which indicates major hotspots near the Sangam region where the major bathing events took place during the Maha Kumbh event.

Overall, study demonstrates the value of combining geospatial tools with field-based measurements for large-scale event-driven water quality assessments such as hotspot identification of water turbidity, statistical correlation between water indices and water quality parameters.

4.7 Takeaway for Stakeholders and Future similar Mega-Events

This pressure of mass inflow of pilgrim translated into intensified water quality degradation, particularly at the Sangam confluence and upper Ganga ghats, where crowd density and ritual activities were highest during main Snan dates such as 22 January 2025. The NDWI Index indicates that the surface water coverage was comparatively higher in 2024 than in 2023, reflecting better water quality on 18 December 2024 (Pre-Kumbh). This difference, compared to the same period in 2023, strongly suggests that successful initiatives were implemented to improve water flow throughout the river prior to the Kumbh event. Sewage Treatment Plants (STPs) played a moderate role in mitigating effluent discharge along the Ganga–Yamuna stretches. However, during peak bathing days on 22 January 2025 and 06 February 2025, infrastructure such as ghats, temporary STP became overloaded alongside the riverbanks, leading to spikes in chlorophyll (NDCI) due to nutrient enrichment and spikes in turbidity (NDTI) linked to sediment resuspension and runoff. The proximity of ghats, drains, and STPs at Sangam made this zone highly sensitive during 03 February 2025(During Kumbh), amplifying spatio-temporal variations in water indices. Spatial autocorrelation (Moran's I) detected crowd hotspots concentrated at Sangam, validating geospatial tools for hotspot identification. Findings demonstrate the value of integrating remote sensing indices (NDTI) with ground datasets for large-scale, event-driven water quality monitoring.

Chapter 5: Hydrodynamic and water quality modelling using HEC-RAS

5.1 Background

The river plays a significant role in fulfilling the freshwater requirements of the world. Therefore, regular monitoring of its physicochemical and microbiological parameters is essential to ensure the suitability of water for various purposes, including domestic, agricultural, and industrial uses. Regular monitoring of water quality helps in controlling disease outbreaks and associated health hazards. Further, it mitigates the deterioration of water quality (Varma et al., 2022). Among the various factors contributing to increased river contamination, mass bathing during religious rituals is one of the most significant causes (Bhasin et al., 2015).

India, with the largest population in the world, is facing severe water pollution problems. Murty & Kumar, (2011) reported water pollution is a serious concern in India. River water quality in India is deteriorating due to human activities, including agricultural runoff, household wastewater discharge, industrial effluents, inadequate sewage treatment, and mass bathing (Ali et al., 2021; Kanaujiya & Tiwari, 2023; Singh et al., 2025). In addition, pollution in the Ganga River rises from untreated industrial waste, tanneries, textile mills, paper and pulp industries, sugar plants, and leather industries, along with organic and non-biodegradable waste from religious and cultural practices, such as flower offerings (Mohamad Noor et al., 2025; Raju & Singh, 2017; Sinha et al., 2020; Varma et al., 2022). Further, previous studies reported that the state of Indian rivers is critical, with the Ganga and its tributaries being severely affected by mass bathing events (Bhatnagar & Sangwan, (2009); Dwivedi et al., (2020); Varma et al., (2022)). Mass ritual bathing and other religious activities along the banks of the Ganga river significantly contribute to water pollution (Dwivedi et al., 2018). Recent report, National Environmental Engineering and Research Institute (NEERI, 2017) and Central Pollution Control Board (CPCB, 2018) further supported the Ganga contains a remarkably higher number of bacteriophages compared to the Yamuna river.

The Ganga River is believed to offer salvation through ritual bathing with mass gatherings occurring at many locations along its course (Arora et al., 2013). Among these, the Maha Kumbh at Prayagraj holds special significance. However, the river water quality has severely deteriorated due to multiple point and non-point pollution sources (Dwivedi et al., 2020). While several studies have examined the river's physicochemical properties, limited research has

focused on hydrodynamic and water quality modeling (Arora et al., 2013; Bhatnagar et al., 2016; Varma et al., 2022). Since mass ritualistic bathing is a periodic and major event along the Ganga, it is crucial to evaluate its impact on river water quality. In this regard, the present study aimed to evaluate hydrodynamic and water quality modeling under different discharge scenarios during the Maha-Kumbh.

Hydrodynamics and water quality are two fundamental characteristics of river water environments. This study utilized modeling tools to examine the influence of hydraulic conditions on water quality, and subsequently developed a coupled hydrodynamic water quality model to predict water environmental conditions.

The models QUAL2Kw, QUAL2E-UNCAS, QUAL2E, and QUAL2K have been widely applied across various watersheds to simulate water quality parameters and develop various management scenarios (Fang et al., 2008; Pelletier et al., 2006; Zehra et al., 2023). Parmar & Keshari, (2012) assessed the water quality of the Yamuna River in the Delhi stretch using the QUAL2E model. They demonstrated that the model has worldwide applicability and provides valuable insights for water quality assessment even with limited datasets. Verma et al., (2024) highlights the critical deterioration of the Yamuna water quality due to drains and limited self-purification capacity. Modeling with QUAL2kw indicates that higher treatment efficiency is essential, as flow augmentation alone is insufficient. They also state that External aeration and improved wastewater treatment are vital to maintain desired DO levels. Each river has a different self-purification capacity, making it essential to determine the pollutant loads from various sources that can be integrated without degrading its natural characteristics. Mathematical modeling serves as an effective tool to validate pollutant load estimations and to establish relationships between pollution sources and water quality (Oliveira et al., 2012). The simulation results provide a valuable management tool to assist policymakers in formulating realistic strategies that account for basin-specific conditions. This study aims to evaluate the applicability of a water quality model in an 18 km stretch of the Ganga River and to analyze the variations and trends in water quality across major bathing dates during the Maha Kumbh.

In the past, research on river systems largely focused on addressing specific water quality issues in specific regions. However, a significant research gap remained that highlights the need for a more integrated approach. The present study addresses this gap by exploring the effectiveness of combining hydrodynamic and water quality modeling for better understanding of river water dynamics during large-scale events. A review of existing literature indicates that no prior

research has extensively simulated hydrodynamic and water quality conditions for rivers during a mega event such as the Maha Kumbh. Since Maha Kumbh involves mass bathing, there is a critical need to predict and simulate water quality to ensure safe bathing conditions. Although several studies have focused only on water quality sampling, a significant gap remains in the integrated applications of models such as HEC-RAS and QUAL2Kw, along with GIS-based approaches. The present study focuses on simulating flow behavior and assessing the impacts of wastewater loadings on the water quality of the Ganga and Yamuna rivers using HEC-RAS and QUAL2Kw models.

5.2 Description of the Study Area

The study was conducted across the Prayagraj stretch of the rivers Ganga and Yamuna (Figure 5.1), which includes two (2) months periods (13 January 2025 to 26 February 2025). The model was calibrated for three (3) CPCB monitoring stations, namely Lord Curzon Bridge (CPCB-1), Near pontoon bridge No. 15 (CPCB-2), and Sangam (CPCB-3), as shown in Figure 6.1. CPCB-1 is 2.41 km upstream (u/s) near the Lord Curzon Bridge. Thereafter, two other locations were chosen, namely CPCB-2 (approximately 1.09 km d/s near Nagvasuki Temple), and CPCB-3 (approximately 0.5 km u/s Jhunsi STP), to assess the spatial and temporal distribution of water quality.

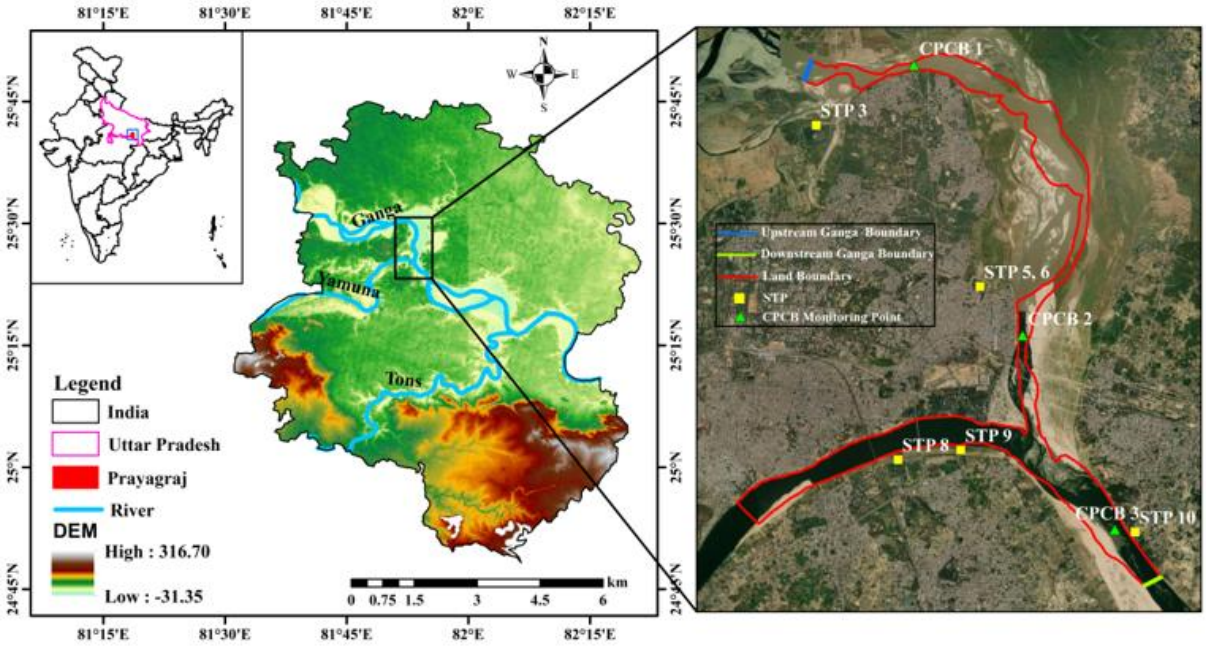
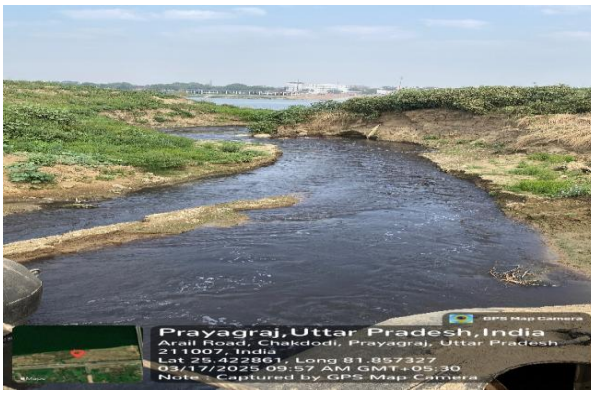


Figure 5.133 The location of the study area.

5.2.1 Field Visit and ArcGIS Story Maps

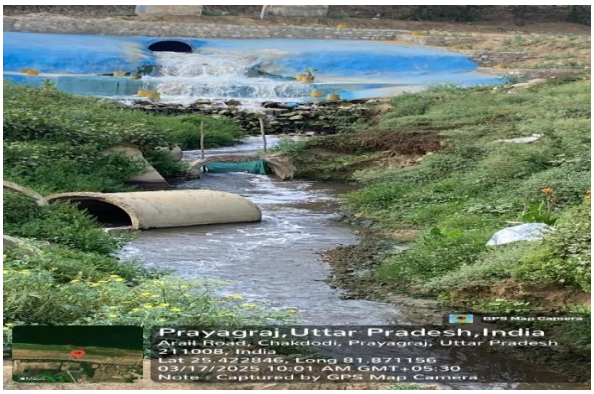
Extensive field visits were conducted during and after the Kumbh period. The objective was to collect on-ground observations and validate existing STP, drain, and river information. Key locations, including major Ghats, drain outlets, and STP discharge points, were visited. ArcGIS Story Maps were developed to present a visual narrative of the study area, highlighting key locations of infrastructure and pollution hotspots. The story map integrates field observations and photographic evidence to communicate environmental conditions during and after the Kumbh. Annexure D depicts the status of drain, STPs, Ghats, temporary toilets during the Maha Kumbh area. Figure 5.2 (a-e). represents the characteristics of the existing STPs and major drains in Prayagraj. Full story map and details are available at: https://storymaps.arcgis.com/stories/b0a72939c6404b3384ed210730dc568d (during Kumbh), https://storymaps.arcgis.com/stories/8c0084432e9048a08502524dab1bc755 (after Kumbh).



(a) The discharge from the Naini-I 80 MLD STP.



(b) A parallel channel runs alongside the mainstream of the River Ganga.



(c) The presence of foam, color, or foul odor in the discharged water.



(d) A view of city drainage channel carrying household wastewater.



(e) Geotube installed in Maha Kumbh area in Praygraj.

Figure 5.2. (a-e). Characteristics of the existing STPs, Geotubes and major drains in Prayagraj.

5.2.2 Sewage Treatment Plants (STPs)

The Prayagraj region has a total of ten STPs to treat the wastewater generated from different areas. These treatment facilities play an important role in reducing the pollution load on the Ganga and Yamuna rivers by handling both domestic and municipal wastewater. Table 5.1 presents the details of these STPs, along with their respective treatment capacities.

Table 5.7 Details of Sewage Treatment Plants located at Prayagraj (CPCB Report).

Sr. No.	Name	Treatment Technology	Designed Capacity (MLD)
1	Ponghat	Improved Bio-tower	10
2	Kodra	Improved Bio-tower	25
3	Rajapur	Up flow Anaerobic Sludge Blanket (UASB)	60
4	Phaphamau	Fluidized Catalyst Reactor (FCR)	14
5	Salori, Old	Fluidized Aerobic Biofilm (FAB) reactor	29
6	Salori, New	Sequencing Batch Reactor (SBR)	14
7	Numayadahi	Improved Bio-tower	50
8	Naini, Old	Activated Sludge Process (ASP)	80
9	Naini, New	Fluidized Catalyst Reactor (FCR)	42
10	Jhunsi	Fluidized Catalyst Reactor (FCR)	16
		Total capacity	340

5.3 Materials and Methods

The main aim of the present study is to simulate flow behavior and assess the impacts of wastewater loading on the water quality of the Ganga and Yamuna Rivers in the Prayagraj region of Uttar Pradesh state. The study includes sample analyses and descriptions of the HECRAS and QUAL2Kw model. The methodology used in this study is summarized in Figure 5.3.

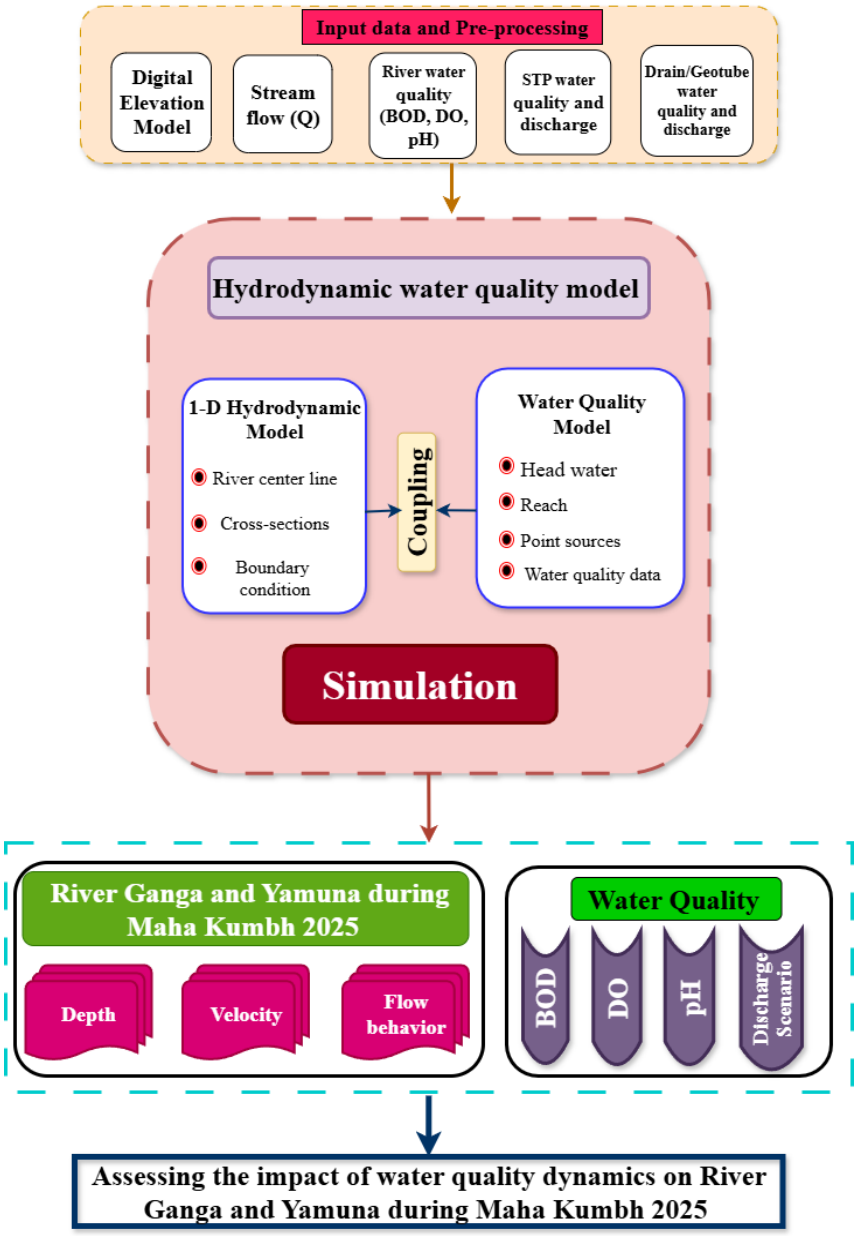


Figure 5.34 Flowchart of the developed methodology.

5.3.1 Description of HEC-RAS

HEC-RAS is a hydraulic modeling software developed by the US Army Corps of Engineers for simulating river flow, floodplains, and sediment transport (Fan et al., 2009; Kim et al., 2023;

N. Kumar et al., 2017). It is an integrated hydraulic modeling program designed to calculate velocity, water depth, and water surface profiles based on the principles of energy conservation. The governing equation applied in the model is the energy equation (Brunner, 2016).

$$Y_1 + \frac{\alpha V_1^2}{2g} + Z_1 = Y_2 + \frac{\alpha V_2^2}{2g} + Z_2 + h_e \quad (5.1)$$

Where, Y = water depth (m), Z = channel bed elevation (m), V = average velocity (m/s), α = velocity weighting coefficient, h_e= energy head loss (m), g = gravitational acceleration (9.81 m/s^2), subscripts 1 and 2 = upstream and downstream cross-sections, respectively. To execute the model, detailed cross-sectional geometry of the river channel and upstream flow data (discharge) are essential inputs. Using the energy conservation equation, the model iteratively computes the velocity and water depth at each cross-section.

5.3.2 Data required for HEC-RAS

(a) River centerline

The river centerline represents the main flow path of the river. This used to define the length of the river. In this study, the river centerline was digitized from high-resolution satellite imagery of 29th Jan, 2025 and Copernicus DEM map, ensuring proper alignment with the actual flow direction. The centerline provides the baseline for assigning cross-sections, flow data, and boundary conditions within the model.

(b) Cross-section of the River

The cross-section of a river, denoted as X–X′, represents its depth profile. These cross-sections are drawn perpendicular to the river's flow to capture variations in depth across the channel. In the present study, a total of 55 cross-sections were drawn along Reach 1 (Ganga River before Sangam), 30 cross-sections along Reach 2 (Yamuna River), and 16 cross-sections along Reach 3 (Ganga River after Sangam). The interval between successive cross-sections ranges from 200 to 300 m, ensuring adequate representation of channel geometry within each reach. Figure 5.4 shows the river flow direction and cross-section map of rivers Ganga and Yamuna.

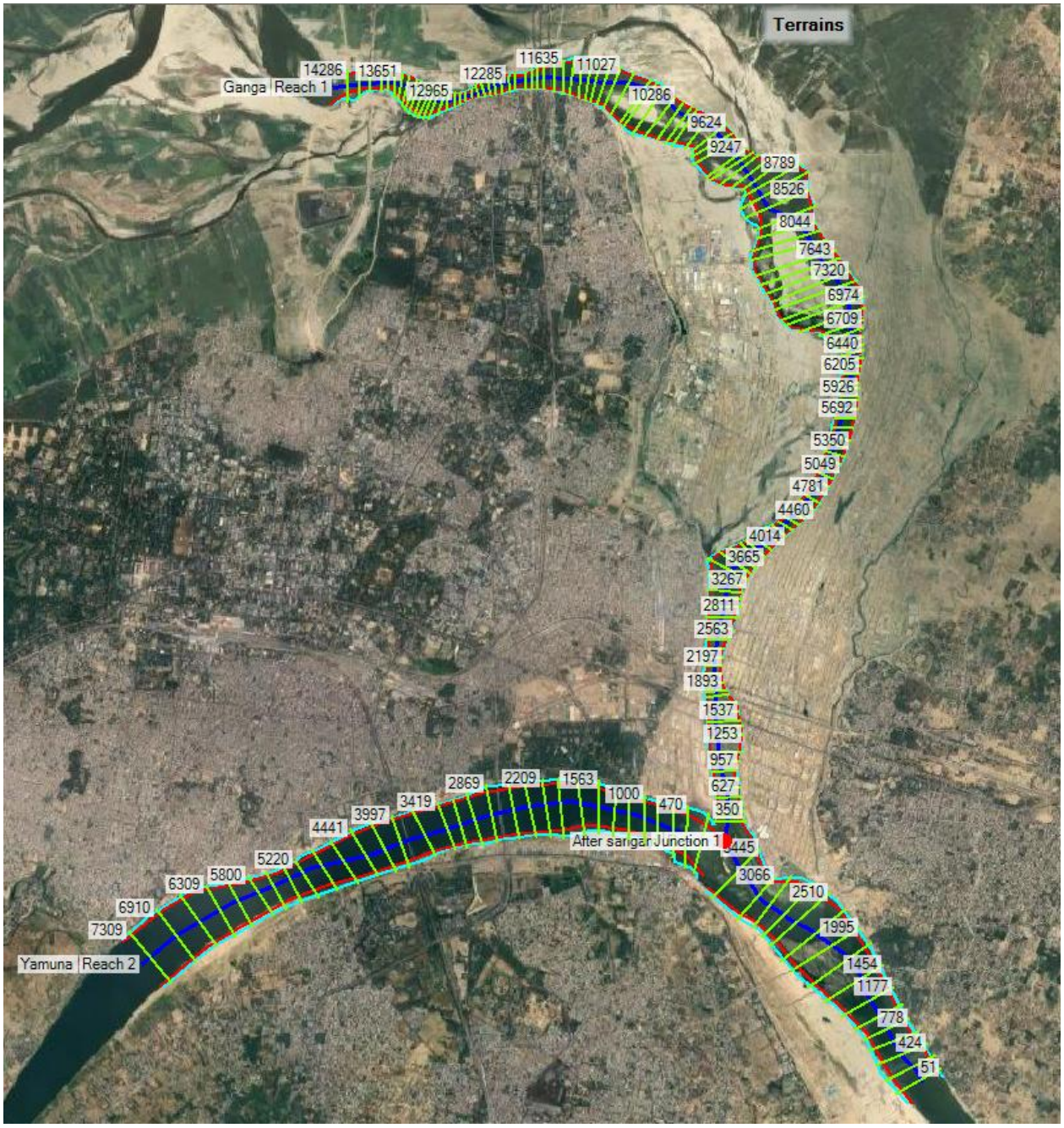


Figure 5.4 Geometric layout of the river network.

(c) River Discharge

River discharge is one of the most important input parameters in HEC-RAS modelling. In this study, the discharge data for the Ganga River were obtained from NMCG. For the Yamuna River, discharge values were assumed based on estimates reported in the existing literature. Annexure E presents the discharge data of the Ganga River, which was utilized for hydrodynamic and water quality modeling in this study.

(d) Manning's Roughness Coefficient

The Manning's roughness coefficient used for this study has taken from the (Jarrett, 1985). Two types of coefficients were considered, one for the riverbed (0.030) and another for the riverbanks (0.035). These values were applied in the model to represent bed roughness within the study area. The details of the various parameters used in the model for this study are presented in Table 5.2.

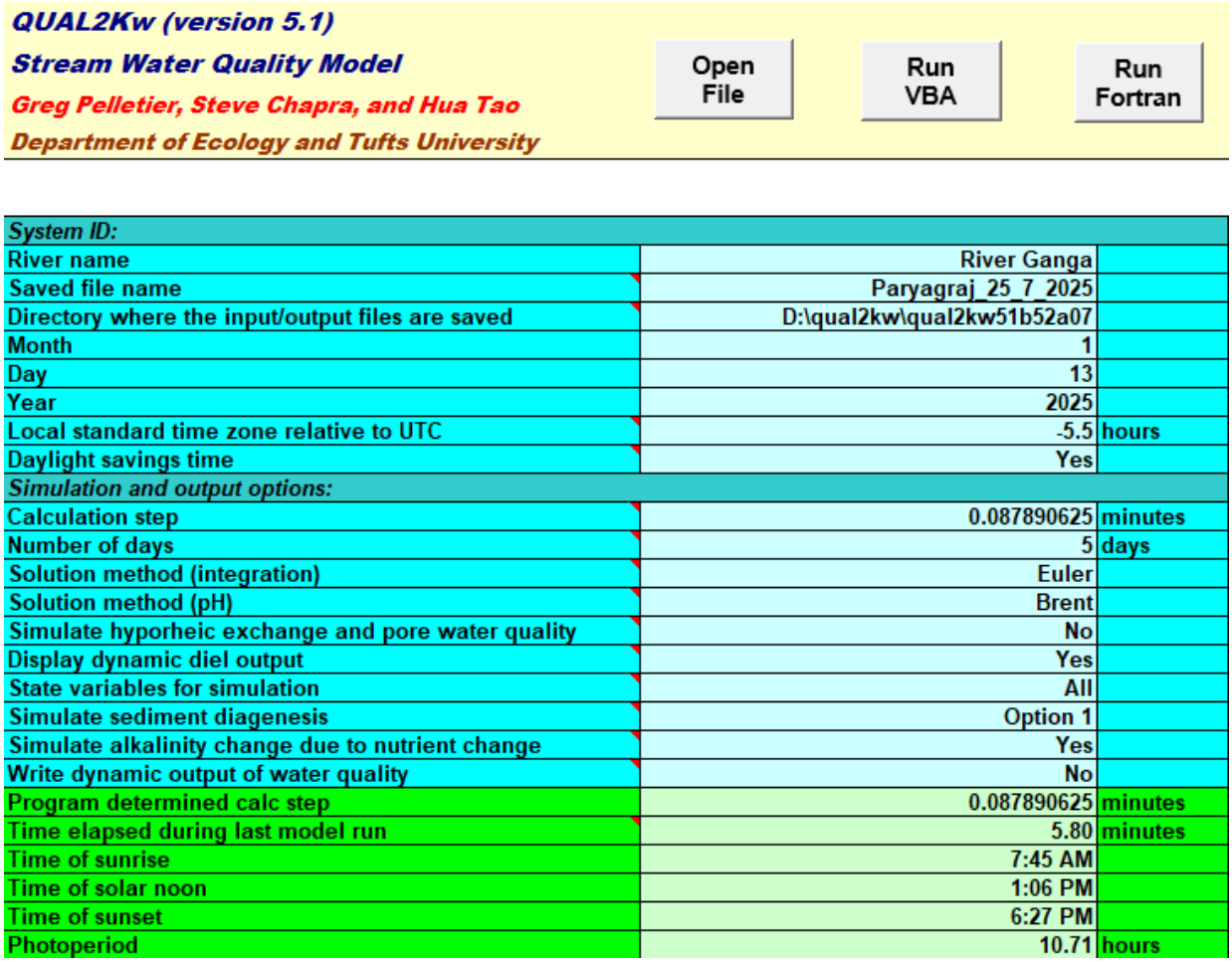
Table 5.8 Parameters used in the study (Brunner, 2016; Jarrett, 1985)

Input parameter	River (Ganga and Yamuna)	L. H. S side of river	R. H. S side of river
Manning's Coefficient	0.030	0.035	0.035
Boundary Condition	Normal Depth	Upstream 0.001	Downstream 0.001

5.3.3 QUAL2Kw

The QUAL2Kw model is a one-dimensional (1D) river water quality model designed for systems with relatively steady flow and consistent pollution loads (Goodarzi et al., 2023; Sarafaraz et al., 2024). The model simulates changes within the daily cycle with a user-selected time step of less than 1 hour (Zou & Lung, 2004).

QUAL2Kw is integrated within the Microsoft Excel environment and developed using Visual Basic for Applications (VBA). The process of numerical integration during model simulations is performed by a compiled Fortran 95 program, which is executed through the Excel VBA framework. The model provides a unique capability, including multiple abstraction and loading point input data. As shown in Figure 5.5, the graphical user interface illustrates stream water quality simulation and variable storage functions, clearly indicating the locations of abstraction and loading points along the upstream and downstream reaches within the study area.



QUAL2Kw (version 5.1)
Stream Water Quality Model
Greg Pelletier, Steve Chapra, and Hua Tao
Department of Ecology and Tufts University

Open File | Run VBA | Run Fortran

System ID:		
River name	River Ganga	
Saved file name	Paryagraj_25_7_2025	
Directory where the input/output files are saved	D:\qual2kw\qual2kw51b52a07	
Month	1	
Day	13	
Year	2025	
Local standard time zone relative to UTC	-5.5	hours
Daylight savings time	Yes	
Simulation and output options:		
Calculation step	0.087890625	minutes
Number of days	5	days
Solution method (integration)	Euler	
Solution method (pH)	Brent	
Simulate hyporheic exchange and pore water quality	No	
Display dynamic diel output	Yes	
State variables for simulation	All	
Simulate sediment diagenesis	Option 1	
Simulate alkalinity change due to nutrient change	Yes	
Write dynamic output of water quality	No	
Program determined calc step	0.087890625	minutes
Time elapsed during last model run	5.80	minutes
Time of sunrise	7:45 AM	
Time of solar noon	1:06 PM	
Time of sunset	6:27 PM	
Photoperiod	10.71	hours

Figure 5.5 Graphical user interface of QUAL2Kw depicting the simulation of Ganga River water quality, including variable storage and sampling functions.

The general mass balance equation for a constituent concentration (c_i) in the water column of a river reach (excluding hyporheic exchange) can be expressed as follows in Figure 5.6.

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_i}{V_i}c_i - \frac{Q_{ab,i}}{V_i}c_i + \frac{E'_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E'_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \qquad (5.2)$$

Where Q_i denotes the flow (m^3/d) (with Q_{ab} representing abstraction), V_i is the volume of the reach i (m^3), E'_i is the bulk dispersion coefficient between reaches i and $i+1$, W_i represents the external loading of the constituent to reach i, and S_i denotes sources and sinks of the constituent resulting from reactions and mass transfer processes. For bottom algae in the water column, the transport and loading terms are excluded from the mass balance differential equations.

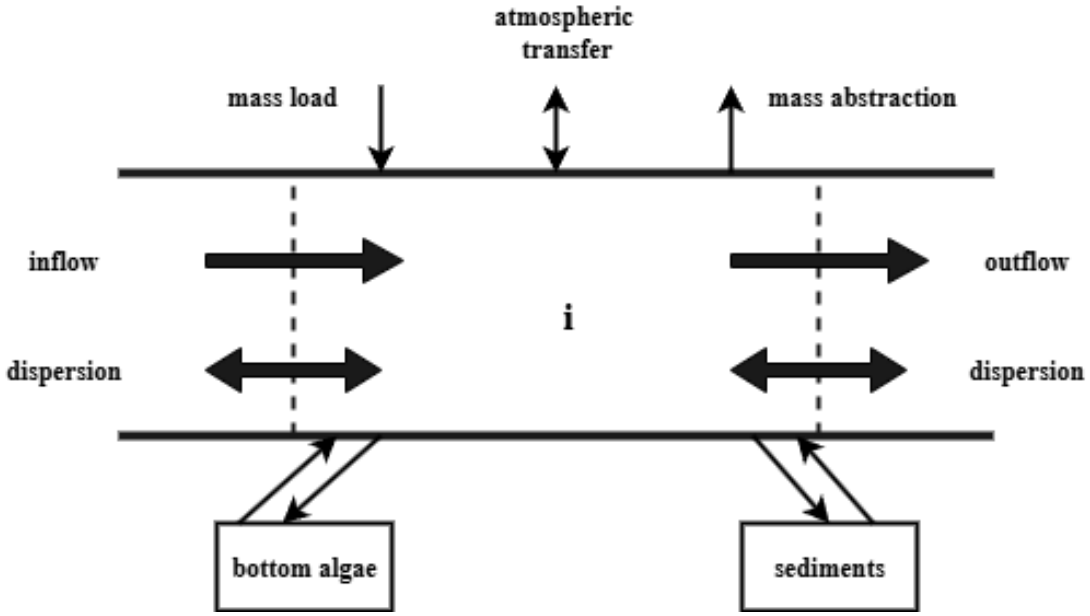


Figure 5.6 Mass balance for constituents in a reach segment (i).

The source/sink term (S_i) used in Equation 5.2 requires the specification of several parameters for each state variable (e.g., the maximum growth rate of bottom algae). The model allows the user to define which parameters are to be held constant and which are to be optimized using the genetic algorithm (GA). A comprehensive description of the model can be found at this link (https://ecology.wa.gov/research-data/data-resources/models-spreadsheets).

5.3.3.1 Limitations and Assumptions

The flow is assumed to be in a steady state during the study period. The data used in this study were taken from published CPCB reports (water quality sampling in the River and STP) during Maha Kumbh. The discharge data for the study area was acquired through published reports and literature. The STP discharge values were assumed according to their installed treatment capacities, and the outlet water quality parameters were acquired from the CPCB-published reports. In cases where data for certain dates were missing, the values were estimated using available temporal data and supported by reasonable assumptions derived from earlier studies and reports.

5.3.3.2 Point source Pollution Inventory

The model was calibrated using data from three CPCB monitoring stations (CPCB 1-3). The study incorporated the influence of ten sewage treatment plants, namely Ponghat, Kodara, Rajapur, Phaphamau, Salori New, Salori Old, Numaya Dahi, Naini I, Naini II, and Jhunsi STP, and seven major drains, specifically Sadar Bazar, Rajapur, Ganga Puri, Jondhwal, Shiv kuti, Saori, Sasur Khaderi, have been considered in the study. The river was divided into nine

reaches, starting from near the steel bridge at the Kumbh Mela (headwater point) and ending near the Jhunsi STP downstream (Ending point). The river segmentation is based on making divisions at points of major changes, such as confluence with the Yamuna tributary. QUAL2Kw is not constrained to uniform reach sizes, and therefore, variable reach sizes have been selected as appropriate based on major changes, such as locations of large inflows and outflows. Figure 5.7 shows a schematic diagram of the study area. The figure illustrates the flow profile of the River Ganga, featuring various STPs, drains, and the Yamuna tributary. The river, STP, and drain water quality data, including pH, DO, BOD, and COD data, were used from the Central Pollution Control Board (CPCB) during the Kumbh period. Table 5.3 shows the reach-wise average of the flow, length, and water quality parameters (pH, DO, BOD, and COD). The table gives the average characteristics of the entire river reach. The details of STP 1-10 and the Yamuna river are given.

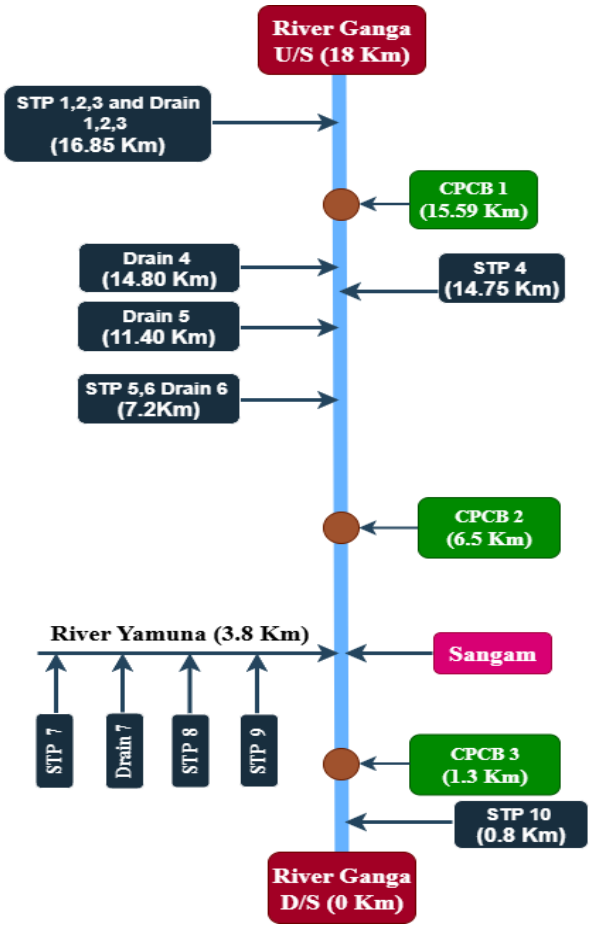


Figure 5.7 Schematic diagram of the river Ganga along with monitoring stations, river Yamuna, and point sources (STPs, Drains) in Prayagraj.

Table 5.9 Average characteristics of various pollution loads during Maha Kumbh (CPCB report)

STP	Station Name	Location (Km)	Discharge (m^3/sec)	Length (Km)	pH	BOD	COD
STP 1	Ponghat	16.85	0.116	1.15	7.79	14.75	34.51
STP 2	Kodara	16.85	0.289	1.15	7.21	37.27	12.7
STP 3	Rajapur	16.85	0.694	1.15	7.7	41.33	18.87
Drain 1	Sadar bazar	16.85	0.064	1.15	7.54	27	87
Drain 2	Rajapur	16.85	0.381	1.15	7.46	25	87
Drain 3	Ganga Puri	16.85	0.064	1.15	-	-	-
Drain 4	Jondhwal	15.9	0.064	0.95	7.38	27	89
STP 4	Phaphamau	14.75	0.162	2.15	7.6	21.85	43.74
Drain 5	Shiv Kuti	11.4	0.064	3.35	7.51	28	86
STP 5	Salori New	7.2	0.336	4.2	8.05	22.95	38.28
STP 6	Salori Old	7.2	0.162	4.2	7.67	7.82	25.68
Drain 6	Salori	7.2	0.51	4.2	7.44	24	49
River Yamuna	-	3.8	80	3.4	7.87	4.52	12.8
STP 7	Numaya Dahi	3.8	0.579	3.4	7.6	15.95	39.49
STP 8	Naini I	3.8	0.926	3.4	7.34	20.25	43.8
STP 9	Naini II	3.8	0.486	3.4	7.5	19.11	33.53
Drain 7	Sasur Khaderi	3.8	0.064	3.4	7.72	29	96
STP 10	Jhunsi	0.8	0.185	3.0	7.95	16.03	42.97

5.3.3.3 Water quality and discharge data

The data were collected from various government agencies, including the Central Pollution Control Board (CPCB), Motilal Nehru National Institute of Technology (MNNIT), Allahabad, and published reports which included measurements for pH, BOD, DO, COD, and water temperature. Air temperature, dew temperature, wind speed, cloud cover, and shade for the study period were obtained from the India Meteorological Department (IMD) and the Central Water Commission (CWC). The data for river width were taken from the very-high-resolution (VHR) satellite imagery (30 cm). The imagery was acquired by the WorldView Legion satellite operated by Maxar Technologies on January 29, 2025. The river discharge data were collected from the report, and the other STPs/Drains/Geotube discharge was assumed as per their installed capacity. Global values for the rate parameters, such as hydrolysis rate, oxidation rate, hydrolysis, settling velocity, transfer coefficient, pathogen decay rate, sediment porosity, and hyporheic exchange flow, were obtained from the QUAL2Kw user manual (Pelletier et al.,

2006). Table 5.4 provides the location details and water quality of three CPCB monitoring stations during the Kumbh period.

Table 5.10 Average characteristics of monitoring stations during Maha Kumbh (CPCB report)

Name	Location (Km)	Discharge (m^3/sec)	pH	DO	BOD
Ganga u/s (Headwater)	18	288.8	7.97	9328	2.76
CPCB 1 (Curzon bridge)	15.59	N.A.	8.04	8.9	5.18
CPCB 2 (Pontoon 15)	6.5	N.A.	8.06	8.88	2.76
CPCB 3 (Sangam)	1.3	N.A.	8.14	8.56	2.63
Ganga d/s (Ending point)	0	N.A.	8.13	8.52	3.47
Note: N.A. implies 'Not Available'					

5.2.4 Model Evaluation and Comparison

Three statistical metrics were used to evaluate the model quantitatively. They included root mean square error (RMSE), mean absolute error (MAE), and percentage of bias coefficient (PBIAS). These metrics are calculated as follows:

(a) Root mean square error (RMSE)

The Root mean square error (RMSE) is a commonly applied statistical indicator used to evaluate the performance of water quality simulation models (Raheja et al., 2024; Zehra et al., 2023). The RMSE is calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(M_v - S_v)^2} \tag{5.3}$$

(b) Mean absolute error (MAE)

The Mean absolute error (MAE) is another widely used statistical metric for evaluating model performance in water quality simulations. The MAE is expressed as:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|M_v - S_v| \tag{5.4}$$

(c) Percentage bias coefficient (PBIAS)

The Percentage bias coefficient (PBIAS) is widely used to evaluate the accuracy of water quality simulation results (Aslam et al., 2022; Bui et al., 2020; Wei et al., 2024). The PBIAS is expressed as follows:

$$PBIAS = \left| \frac{\sum_{i=1}^{n}(M_v - S_v)}{\sum_{i=1}^{n} M_v} \right| \quad (5.5)$$

Where M_v = measured value, S_v = simulated value, and n = total number of measured data points. Typically, in water quality simulations, PBIAS ≤ 25% is generally considered to indicate excellent model performance, 25% < PBIAS ≤ 40% reflects good performance, while values beyond these ranges suggest fair or less reliable results.

5.4 Results and Discussions

5.3.1 Hydrodynamic characteristics of the Ganga and Yamuna rivers

The model parameters were calibrated and optimized specifically for the Kumbh period, and a detailed description of the discharge used is provided in Annexure E. The model was executed for the simulation period from 31 Jan 2024 to 27 Feb 2025, covering the major bathing events. Figure 5.8 illustrates the flow behavior of the Ganga and Yamuna Rivers during this period. This figure clearly represents that the model reproduced the hydraulic conditions with reasonable accuracy. In contrast, the velocity in the Yamuna river ranges between 0.5 m/s and 1.5 m/s. The Yamuna channel exhibits a smoother geometry than the Ganga river. The width of the Yamuna river remains relatively uniform from the upstream reach to confluence at the Sangam region, varying between 500 m and 650 m. However, the Ganga river shows considerable variability in channel geometry. Upstream, the width ranges from 300 m to 400 m, in the middle reach it fluctuates between 100 m and 400 m, and near the Sangam it stabilizes again between 300 m and 400 m. Further, Figure 5.9 presents the simulated velocity distribution. A clear observation is that the velocity increases significantly in the upstream region near the Nagvasuki Temple, where the river cross-sectional area contracts. In this reach, the velocity varies from 2.5 m/s to 5.5 m/s. The width of the channel is smaller compared to the upstream and downstream. Velocity becomes high in this region, and bathing activities are relatively limited. Therefore, the water quality here is comparatively better than in other stretches where lower velocities stimulate pollutant accumulation.



Figure 5.8 Flow behavior of rivers Ganga and Yamuna during the Maha Kumbh.

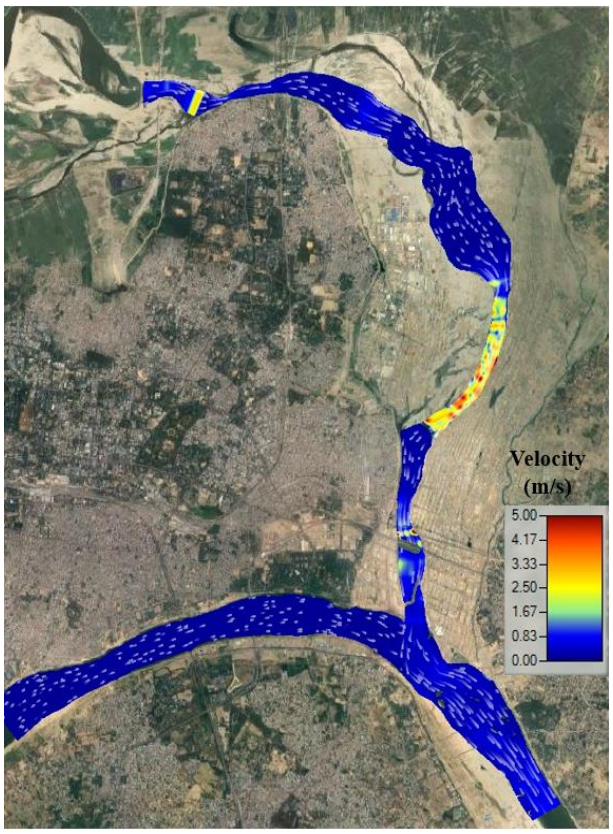
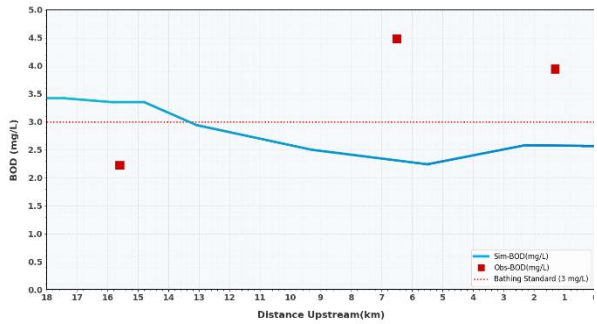


Figure 5.9 Velocity of rivers Ganga and Yamuna during Maha Kumbh.

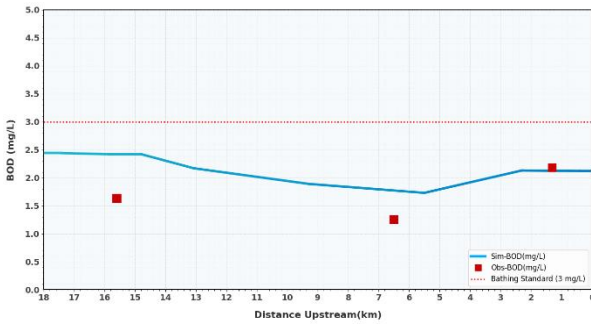
5.3.2 QUAL2KW water quality assessment

a) Biological Oxygen Demand (BOD)

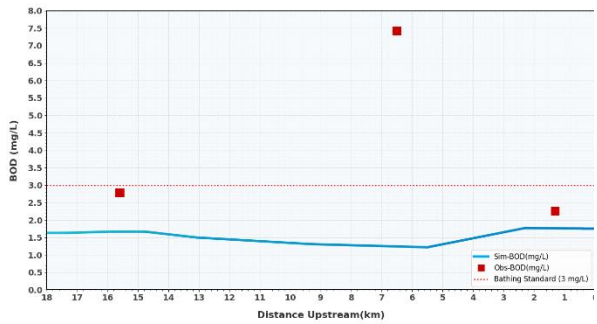
The model effectively simulates the behavior of the river water BOD parameter, as illustrated in Figures 5.10. The BOD values ranged from 1.21 mg/L to 3.42 mg/L, with a mean of 2.25 mg/L. A notable decline in BOD concentration is observed between the Phaphamau and Salori stations. However, following the confluence with the Yamuna River and the discharge from three STPs into the Ganga River, the BOD levels start to increase. This rise is primarily attributed to mass bathing activities in the area and the contaminants from the STPs. Particularly, the BOD concentration exceeds the CPCB recommended bathing water limit of 3 mg/L only during the first major bathing event on January 13 and the third on January 29. On the remaining four dates of observation, the BOD levels remained well within the permissible limits, indicating effective dilution and self-purification capacity of the river.



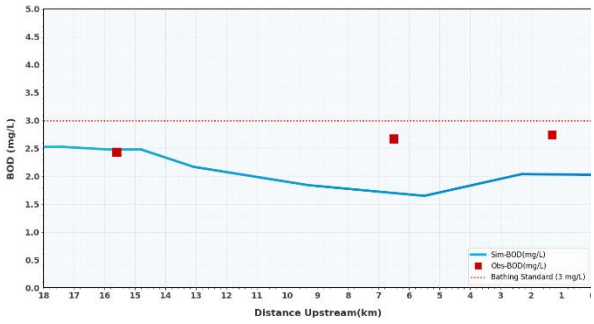
(a) 13 Jan 2025



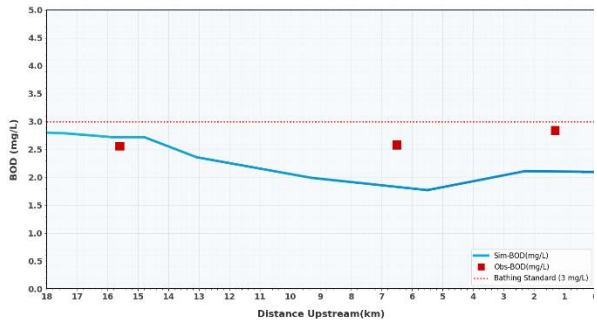
(b) 14 Jan 2025



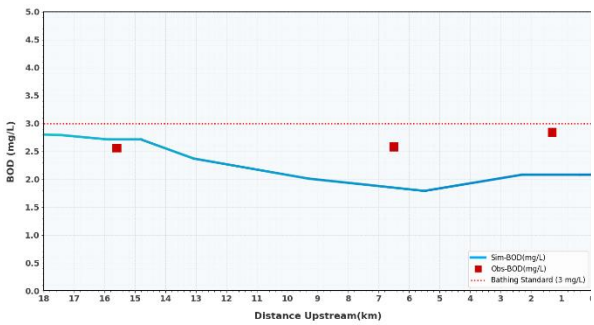
(c) 29 Jan 2025



(d) 03 Feb 2025



(e) 12 Feb 2025

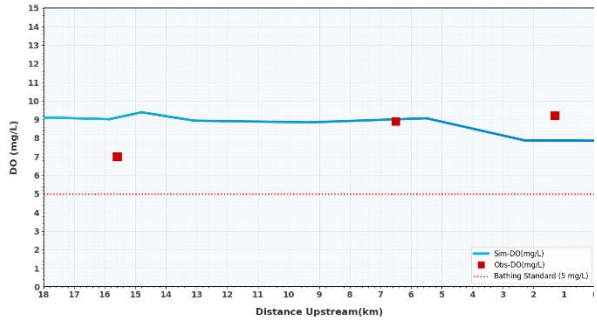


(f) 26 Feb 2025

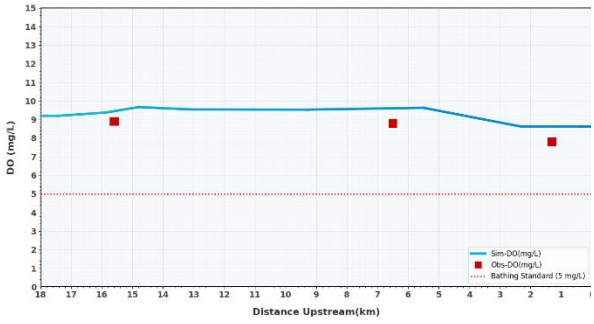
Figure 5.10 (a-f). Simulation of Ganga River water quality BOD parameter during Maha Kumbh.

b) Dissolved Oxygen (DO)

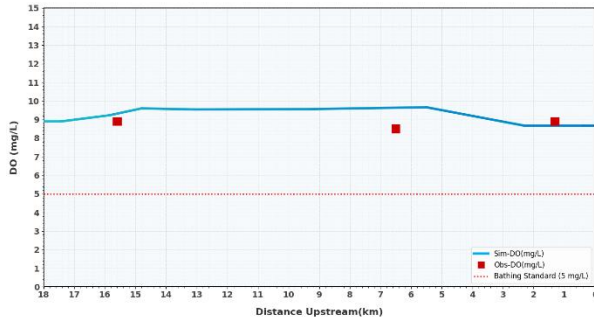
The comparison between the measured points and the simulated points reveals that the dissolved oxygen (DO) data demonstrates an acceptable level of accuracy, as shown in Figures 5.11 (a-f). The DO value ranged from 7.02 mg/L to 9.67 mg/L with a mean of 8.55 mg/L. The concentrations are well above the CPCB-recommended minimum of 5 mg/L for bathing criteria, indicating that DO levels remained consistently within the desirable range to support bathing water quality. The DO concentrations remain relatively stable between the Phaphamau and Salori stations due to insignificant anthropogenic activity in this stretch of the river. However, a rapid decline in DO levels is observed almost 5 km downstream, which signifies localized water quality deterioration. This drop is primarily due to the impact of mass bathing during the Kumbh Mela and the discharge of wastewater from nearby sewage treatment plants (STPs). Such inputs increase the organic load and microbial activity, thereby increasing oxygen demand and reducing DO concentrations in the affected zone (Sinha et al., 2020; Varma et al., 2022).



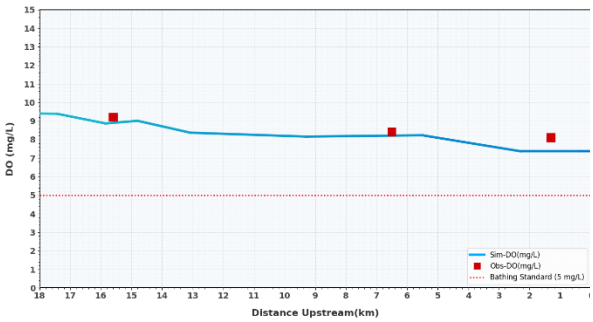
(a) 13 Jan 2025



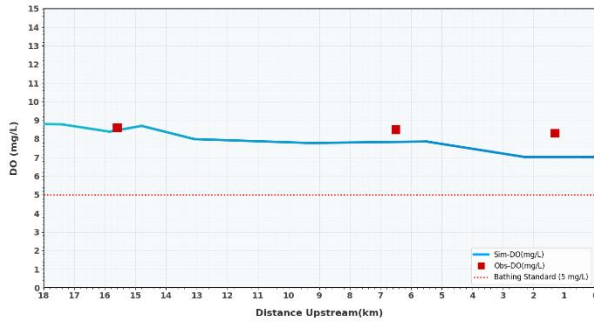
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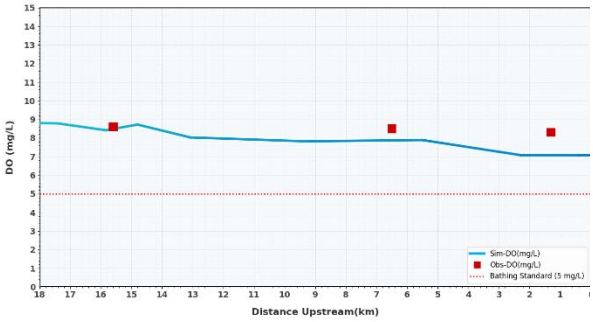
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(d) 03 Feb 2025



(f) 12 Feb 2025

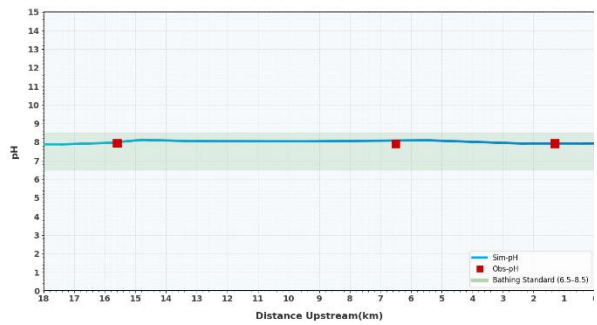


(e) 26 Feb 2025

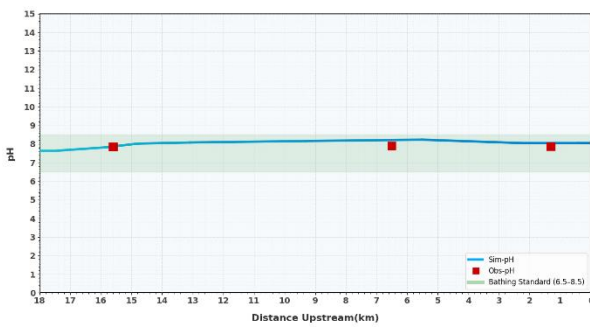
Figure 5.11 (a-f). Simulation of Ganga River water quality DO parameter during Maha Kumbh.

c) pH

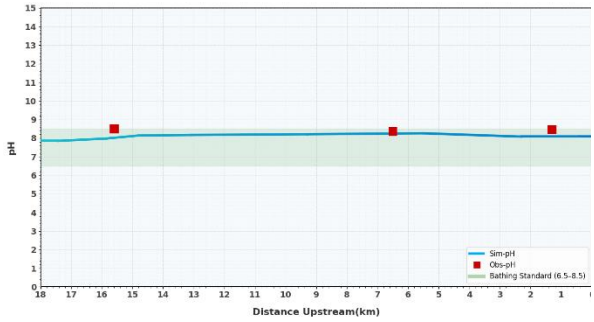
Figure 5.12 (a–f) illustrates the pH concentration along the river stretch during the six major bathing events of the Maha Kumbh period. The values of pH during the six major bathing days of Maha Kumbh vary from 7.64 to 8.47 with mean of 8.03. Throughout these events, pH values remained relatively stable, consistently falling within the standard permissible range (6.5 – 8.5) as specified by the CPCB bathing standards. Moreover, the simulated results closely align with the measured data, demonstrating the model's acceptable level of accuracy.



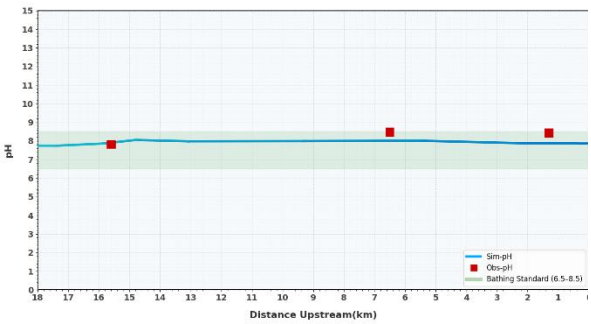
(a) 13 Jan 2025



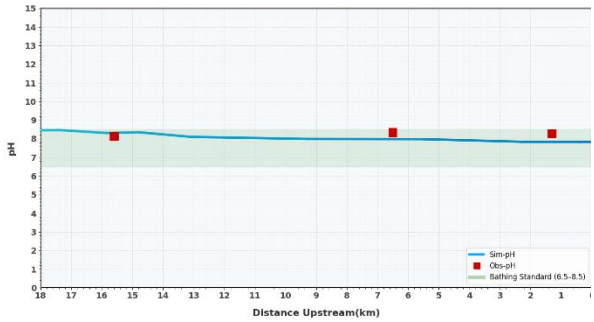
(b) 14 Jan 2025



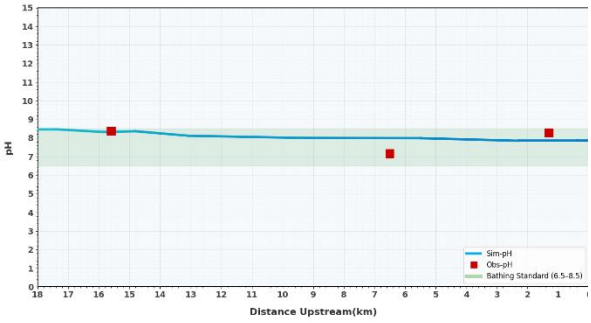
(c) 29 Jan 2025



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Figure 5.12 (a-f). Simulation of Ganga River water quality pH parameter during Maha Kumbh.

d) Assessment of Results

The simulation results in terms of RMSE, MAE, and PBIAS for predicting the water quality parameters BOD, DO, and pH using the QUAL2Kw model are reported in Table 5.5. For the BOD parameter, the model yielded RMSE of 1.695 mg/L, MAE of 1.302 mg/L, and PBIAS of 24.96%, all of which fall within the acceptable range and indicate good model performance. For DO, the predicted results showed RMSE of 0.876 mg/L, MAE of 0.654 mg/L, and PBIAS of 0.81%, reflecting excellent agreement between the observed and simulated values. Similarly, for pH, the model achieved an RMSE of 0.346, an MAE of 0.245, and a PBIAS of 0.16%, further demonstrating the high accuracy of the simulations. Overall, the low RMSE and MAE values, along with the PBIAS percentages well within acceptable limits, indicate that the QUAL2Kw model is reliable for simulating and predicting key water quality parameters in the study area during the Maha Kumbh period.

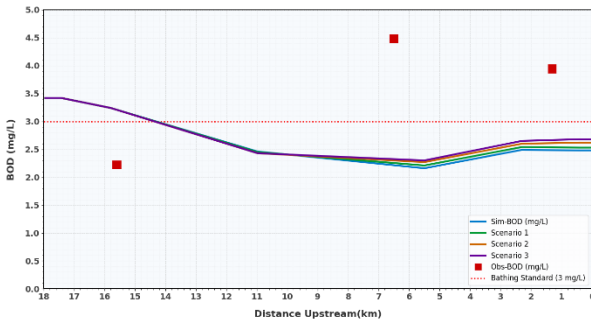
Table 5.11 Assessment results of the water quality during Maha Kumbh

Parameters	RMSE (mg/L)	MAE (mg/L)	PBIAS (%)
BOD	1.695	1.032	24.96%
DO	0.876	0.654	0.81%
pH	0.346	0.245	0.16%

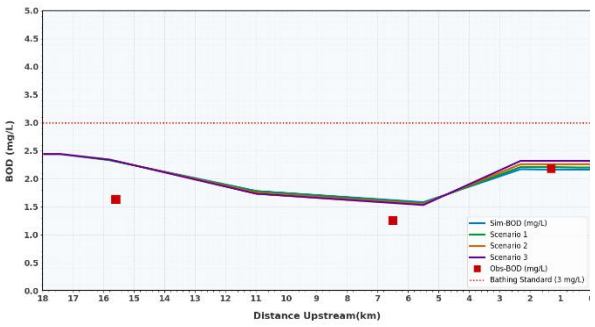
e) Scenario analysis of BOD response to discharge

Figure 5.13 (a–f) illustrates the simulation results of the BOD parameter under varying discharge scenarios. The three discharge scenarios were considered to evaluate the impact of flow reduction on river water quality: Scenario 1 (10% discharge reduction), Scenario 2 (20% discharge reduction), and Scenario 3 (30% discharge reduction). The results obtained from these three scenarios clearly indicate a noticeable change in BOD levels along the downstream reaches of the river. As the discharge decreases, the natural dilution capacity of the river is gradually reduced, which in turn leads to higher BOD concentrations. The majority of changes in BOD concentration are observed near the Sangam region of the study area, because of extreme mass bathing activities during the Kumbh Mela. Finally, after 30% reduction of discharge, the simulation results reveal a significant deterioration, with BOD levels increasing by approximately 8% compared to the baseline condition.

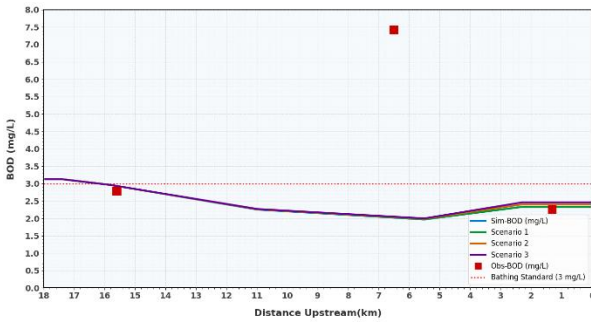
Overall, these findings highlight the importance of maintaining adequate upstream discharge, particularly during large-scale events such as the Kumbh Mela, to safeguard the river's self-purification capacity and to minimize the deterioration of water quality in the Sangam stretch.



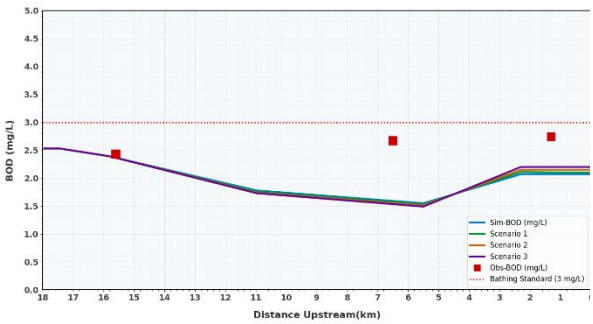
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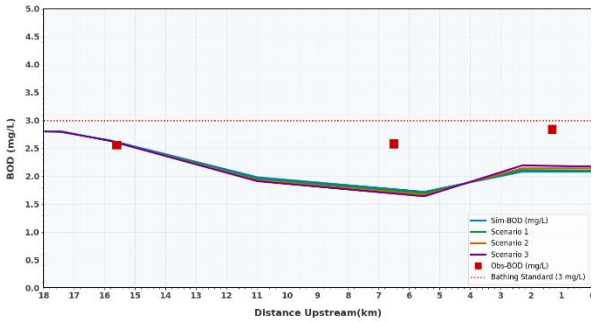
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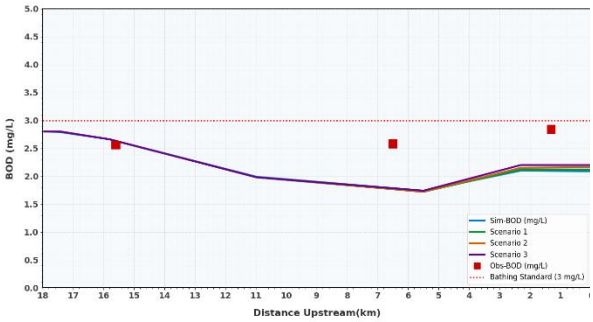
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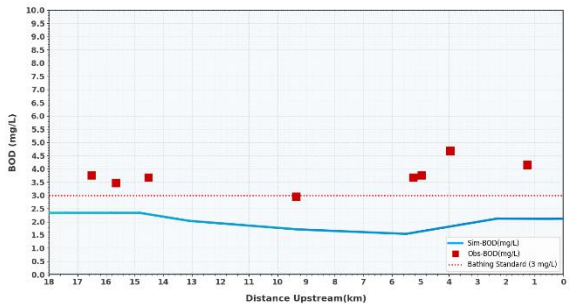
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Figure 5.13 (a-f). Simulation of river water quality under the discharge reduction scenario.

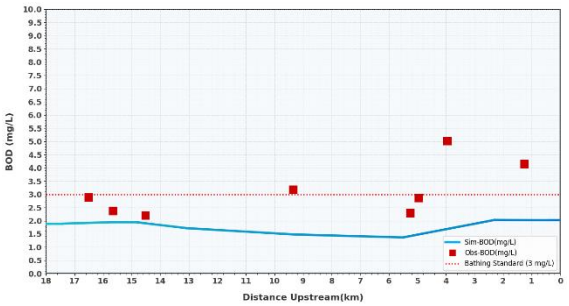
f) Assessment with IIT BHU Sampling data

In this study, QUAL2Kw simulations were also carried out on the water samples collected by the IIT BHU team. A total of 16 sampling sites were selected across the Ganga and Yamuna rivers, of which 9 sites fell within our 18 km study reach. The simulation results are presented in Figures 5.14 (BOD), 5.15 (DO), and 5.16 (pH). From Figure 5.14 (a-f), it is evident that the BOD values consistently exceeded the bathing water quality guidelines prescribed by CPCB across all six major bathing dates.

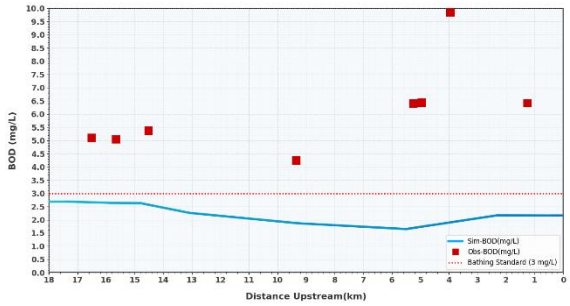
The DO parameter performed well in the simulation, with the model showing good agreement between observed and simulated values, as illustrated in Figure 5.15 (a-f). The only exception was on the major bathing dates of 03 Feb and 12 Feb 2025, where noticeable deviations were observed. Similarly, the pH results, shown in Figure 5.16 (a-f), indicate that both simulated and observed values for all sampling points remained within the CPCB bathing water quality range of 6.5–8.5, thereby meeting the prescribed standards.



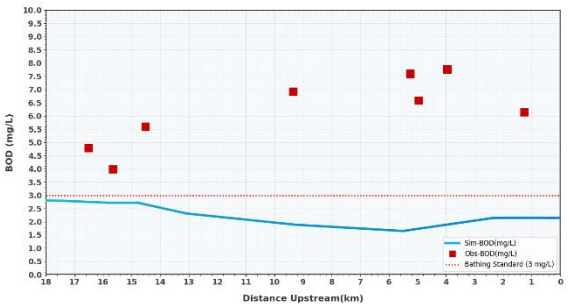
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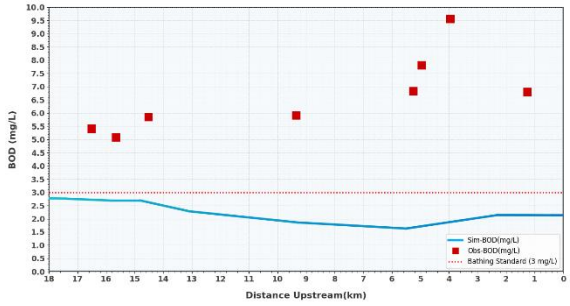
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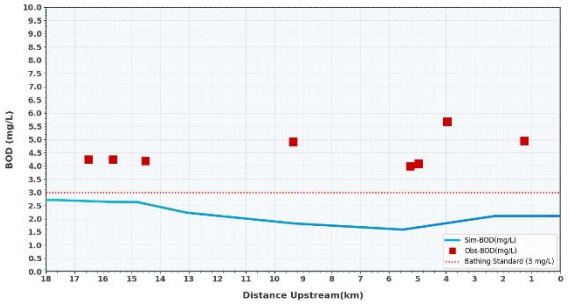
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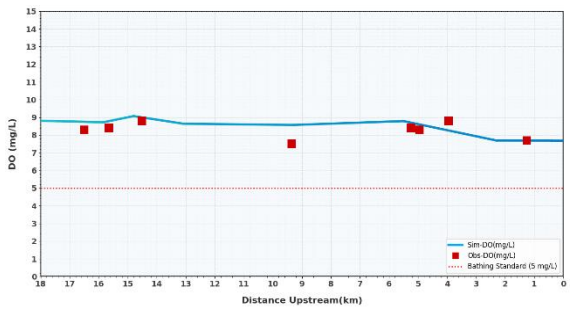


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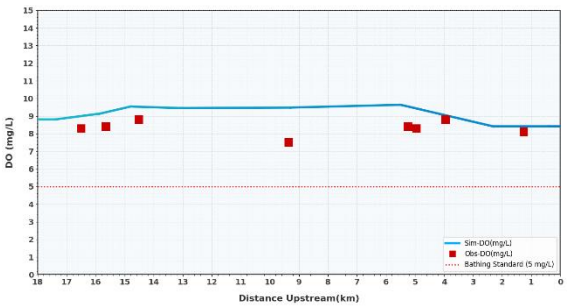


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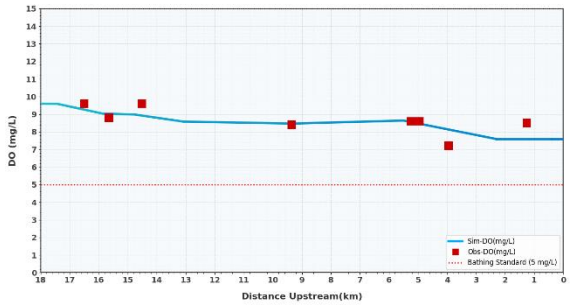
Figure 5.14 (a-f). Simulation results with IIT BHU sampling data for the BOD parameter.



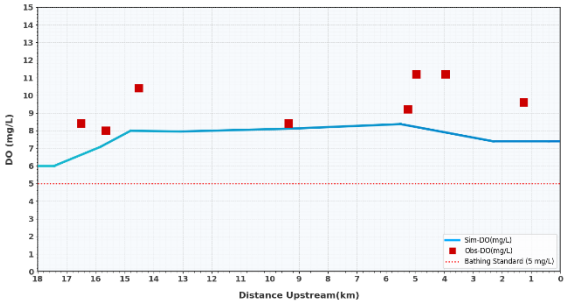
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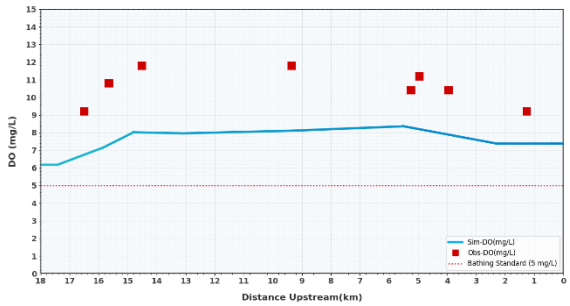
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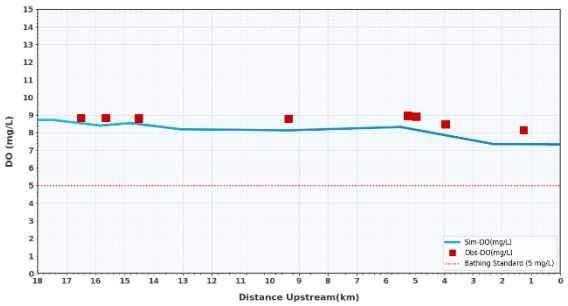
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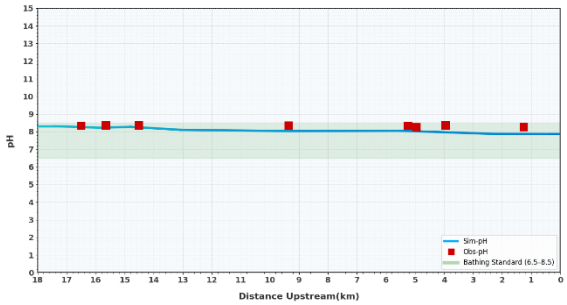


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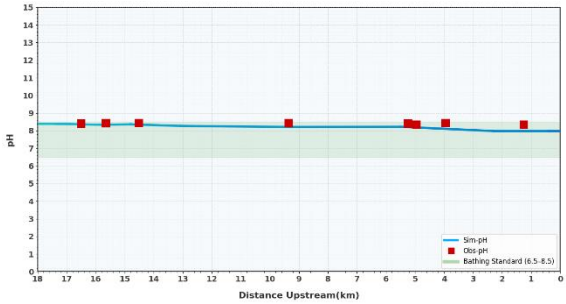


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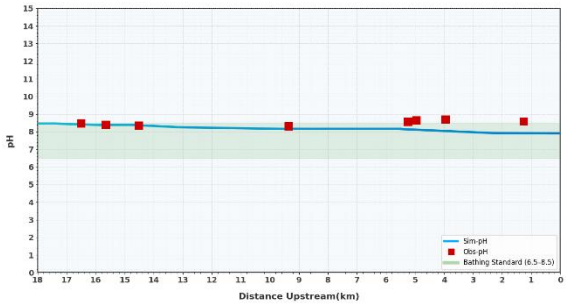
Figure 5.15 (a-f). Simulation results with IIT BHU sampling data for the DO parameter.



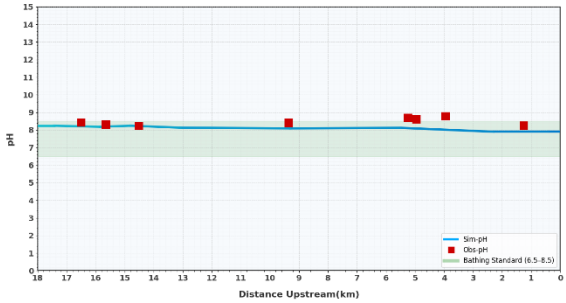
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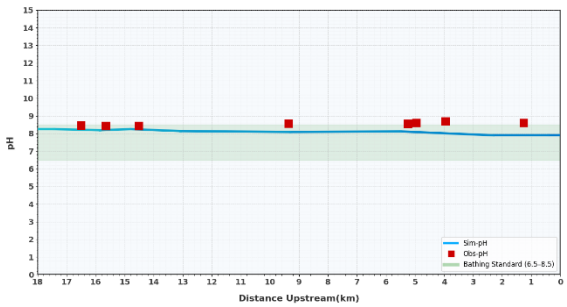
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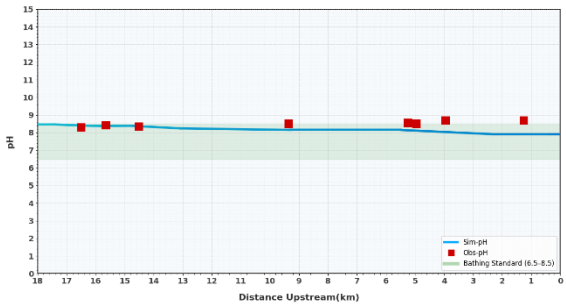
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Figure 5.16 (a-f). Simulation results with IIT BHU sampling data for the pH parameter.

5.5 Summary

The study analyzed variations in both water quantity and quality during the Maha Kumbh period. It developed a couple hydrodynamic water quality model using HEC-RAS and QUAL2Kw to make the model simulation results more reliable. The main conclusions are as follows:

1. The HEC-RAS model effectively simulated flow dynamics of the Ganga and Yamuna during the Kumbh period and shows reliable performance. Higher velocities near the Nagvasuki temple due to the channel reduction contributed to improving water quality in this stretch.
2. The QUAL2Kw model demonstrated good accuracy and applicability for simulating and predicting water environments under similar conditions. The model yielded RMSE values of 1.695 mg/L, 0.876 mg/L, and 0.346, MAE values of 1.032 mg/L, 0.654 mg/L, and 0.245, and PBIAS values of 24.96%, 0.81%, and 0.16% for BOD, DO, and pH, respectively.
3. Simulation results indicated that water quality of the Ganga river was better in the lower reaches, primarily due to the dilution effect of higher flows. However, a localized increase in BOD concentrations was observed near the Sangam region and after the Sangam region.
4. Notably, the overall BOD concentration during the Kumbh period remained within the permissible limits specified by the CPCB bathing water quality standards, except at certain locations on January 13 (Paush Purnima) and January 29 (Mauni Amavasya), due to increased organic load from mass bathing. In the three (3) discharge scenarios, a decrease in discharge gradually reduced the natural dilution capacity of the river, which in turn leads to higher BOD concentrations.

5. Using the IIT BHU sampling data, the QUAL2Kw simulations indicate that DO and pH levels largely fulfilled CPCB bathing water quality standards across the study reach. However, BOD values consistently exceeded the permissible limits, indicating persistent organic pollution loads.

Based on the above conclusions, the study confirmed that HEC-RAS and QUAL2Kw models can reliably simulate flow and water quality dynamics in the Ganga and Yamuna rivers during the Maha Kumbh.

5.6 Scope for Future Work

Based on the above findings, further research can significantly strengthen the understanding and management of river water quality during mega-events such as the Maha Kumbh.

1. Beyond BOD, DO, and pH, future studies may include nutrients (phosphate), microbial indicators (total coliforms), and heavy metals to obtain a holistic assessment.
2. Modeling under different discharge scenarios influenced by climate change, rainfall variability, and upstream water abstraction will help assess long-term resilience.
3. Testing alternative interventions, such as STP efficiency and effluent regulation during peak bathing days, can guide policy and event planning.
4. Future studies could include the non-steady flow to capture the hydrological variation more accurately.

5.7 Takeaway for Stakeholders and Future Mega-Events

The present study provides important insights for stakeholders involved in managing river water quality during future mega-events such as the Maha Kumbh. The application of HEC-RAS and QUAL2Kw models demonstrated reliable performance in simulating river flow and water quality dynamics. The findings investigate proper flow regulation, particularly maintaining higher velocities in some selected stretches that can maintain water quality by reducing pollutant accumulation during peak bathing activities. Although overall BOD levels remained within CPCB bathing standards, a localized increase in BOD level has been observed near the Sangam region, which revealed the need for continuous water monitoring and increased water sampling frequency. These results confirm that predictive modeling can serve as an effective planning tool for identifying susceptible locations and supporting actions such as regulated discharges and improved STP capacities.

Chapter 6: Water, Sanitation and Hygiene (WASH) at Maha Kumbh Mela 2025

6.1 Background

Mass gathering events, especially religious gatherings like Maha Kumbh and Hajj, pose complex challenges in managing WaSH (Water, Sanitation, and Hygiene) services while catering to the needs of pilgrims (Almehmadi & Alqahtani, 2023). These gatherings are considered vulnerable, which pose risks to public health safety, such as the transmission of travel-related infectious diseases, personal hygiene and the dignity of the pilgrims (Sphere Handbook, 2018). As the influx of pilgrims cannot be regulated, as shown in Figure 6.1, issues with WaSH might arise from infrastructural, governance and management challenges, and due to people's religious sentiments and personal behaviour.



Figure 6.1 Mass gathering of pilgrims in the Maha Kumbh Mela 2025

Thus, in this chapter, we examine the current 'Status' of Water, Sanitation, and Hygiene (WaSH) services at the Maha Kumbh Mela and assess how these services are 'Impacted' by the massive influx of millions of floating populations into the catchment area. We also explore

the key drivers that enable the effective delivery of WaSH services, along with the pressures these systems face while meeting the needs of both the floating population and the residents of Prayagraj. The objective was to understand how human activities and associated factors influence the outcome of WaSH services delivery in the Kumbh Mela using a DPSIR framework especially designed for addressing the needs of the Kumbh Mela.

The challenges that arise due to these gaps can be significant, given the scale of the event and the diverse needs of the attendees. For example, the number of persons per toilet can be notably high. Based on the Kumbh Mela of 2013, (Baranwal et al., 2015) reported that 42% of Akharas had 11-15 persons per toilet and 30% had more than 15. This can lead to inadequate sanitation facilities and increased health risks. In addition, they noticed that there were no separate toilets for males and females, which may affect privacy and hygiene, particularly for women. Previous studies indicate that there are chances of spread of infectious diseases such as Cholera through contaminated water in the Kumbh Mela, which was prevalent before the mid-20th Century (David & Roy, 2016). However, no deadly spread of infectious diseases has been reported since then (Almehmadi & Alqahtani, 2023; Vortmann et al., 2015). Retrospectively, detecting such incidences can be difficult as infectious diseases usually take approximately 48 hours to manifest after infection. Research on previous Kumbh Mela has indicated that drinking river water had been the main avenue for the spread of infectious diseases in the Mela (Karampourian et al., 2019). The sheer number of populations attending Kumbh itself creates changes due to their mobility, density, and limited exposure to sustained hygiene interventions.

In 2013, drainage was another major challenge observed in 45% of Akharas, leading to potential health hazards and unsanitary conditions, as effective drainage systems are crucial to manage waste and prevent flooding, especially during heavy rains (Baranwal et al., 2015). One of the core reasons is the temporary nature of the Mela city (site), which is usually developed two and a half months before the event, resulting in a constrained time frame to support the WaSH services for the massive influx of population. The Mela site is submerged predominantly during the months of monsoon. The time allotted for the development of the temporary infrastructure is thus limited (Maclean, 2001).

Other challenges arise due to individual awareness gaps, cultural norms, and long-standing behavioural patterns (John & Ajibade, 2024). Previous editions of Kumbh Mela have had instances of open defecation and ritual bathing without sanitation safeguards. These incidents occurred due to a gap in evidence-based, and easily accessible information on sanitation and

hygiene, compounded by deeply rooted cultural beliefs and traditional practices that may inadvertently lead to unsafe hygiene behaviours (Almehmadi & Alqahtani, 2023).

In recent years, Government Authorities have moved in support of improved sanitation and water services and increasing access to quality medical services through compulsory inoculation. Previous reports on the event's budget show that a greater portion is marked for health and sanitation and has seen an increase over the years. For example, compared to 1966, 2013 had a 25% higher allocation, and the incidence rate of diseases spread that was last accounted for was at 5% (Vortmann et al., 2015). In 2019, telemedicine and tele-consultation services were introduced to facilitate the management of complex medical conditions at the Kumbh Mela through real-time support from tertiary hospitals located hundreds of miles away (Raghav et al., 2020). Owing to such proactive measures and consistent commitment over successive editions, the Kumbh Mela has successfully averted large-scale medical crises, ensuring that no major emergencies escalated into public health havoc.

Over the years, many good practices have been undertaken by the authorities for Kumbh Mela, but some challenges still persist in completely addressing the issue. For example, in the context of Maha Kumbh 2025, our research indicates that strengthening the floating population's behaviour, awareness, and knowledge is as important as the infrastructure provided by the authorities. Thus, to aid the Kumbh Mela Authorities, such as Prayagraj Mela Authority (PMA), in assessing, mapping, reporting, and responding to the dynamic needs of WaSH services at Kumbh Mela, we have developed a framework. K-WaSH consolidates best practices and introduces indicators for status, impacts, and pressures, enabling evidence-based decisions for future editions and long-term interventions using lessons from previous Kumbh Melas and stakeholder experience.

The need for this framework stems from limited availability of structured protocols to monitor, assess, and report WaSH at mega gatherings, especially pilgrimages, requiring culturally sensitive approaches. It was developed using on-ground experience from Maha Kumbh Mela 2025, Prayagraj and serves as a reporting structure to evaluate multi-dimensional factors affecting WaSH services:

- The psychosocial dimensions that influence WaSH, e.g., socio-cultural, behavioural, and belief systems.
- The infrastructure and technological dimensions, e.g., septic tank infrastructure, toilet infrastructure, and hand-washing facilities.

- The institutional support and governance dimensions required for installing, operating, and managing the WaSH services.

To develop the framework, we used the Driver-Pressure-State-Impact-Response (DPSIR) model to identify the indicators, as shown in Figure 7.2 (Kristensen, 2004) . This framework facilitates the structuring of complex human-environment relations into logical categories, which helps in screening indicators for relevance and avoiding redundancy while maintaining representativeness of all system-dynamics dimensions of selected indicators of distinct values (Vila-Guilera et al., 2021). For example, a high influx of pilgrim population for Kumbh Mela, which is a human activity (Driver), might create 'Pressures' on accessing clean drinking water sources for all pilgrims. Thus, 'lack of clean drinking water' can be a State of the WaSH services leading to various 'Impacts' such as health impacts and economic impacts. Using this example, we can establish indicators such as 'Population Influx" for Drivers, "lack of clean drinking water" as an indicator of the State, etc.

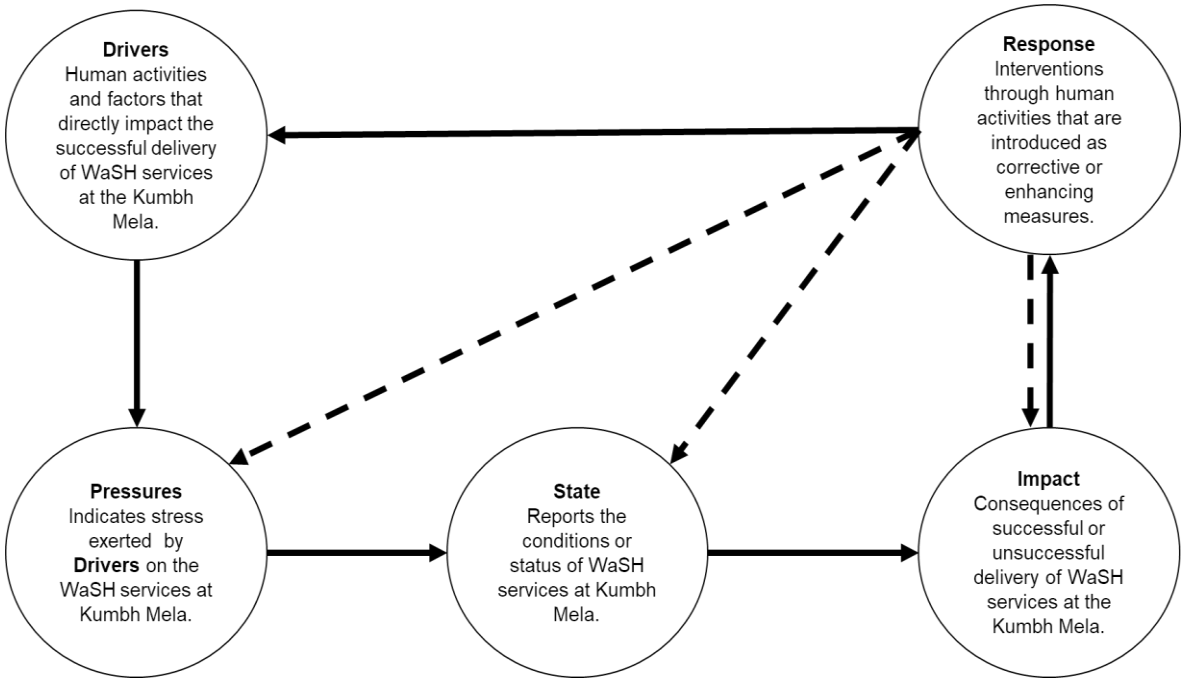


Figure 6.2. Conceptual diagram of K-WaSH services using the DPSIR framework

To identify indicators, we reviewed existing frameworks, reports, research papers, and national/international WaSH guidelines (Figure 6.3). For Kumbh-specific insights, we conducted primary data collection in three phases: Pre-Kumbh, During-Kumbh, and Post-Kumbh, across 25 sectors from 15 Dec 2024 to 31 Mar 2025**.** Data included stakeholder surveys, consultations, and observational records of sanitation infrastructure and technologies, supported by field notes, photos, videos, maps, and corroborative data from earlier chapters.

The framework development procedure has been explained in detail in sections 6.1.1, 6.1.2 and 6.2. In section 6.3 and 6.4, we have analysed the data collected from Maha Kumbh Mela 2025 and validated the K-WaSH framework, along with reporting the 'State' and 'Impacts' of the WaSH services provided for this year's Kumbh Mela. Section 6.5 discusses the causes for the successful WaSH services in this year's Kumbh Mela, along with recommendations for future events.

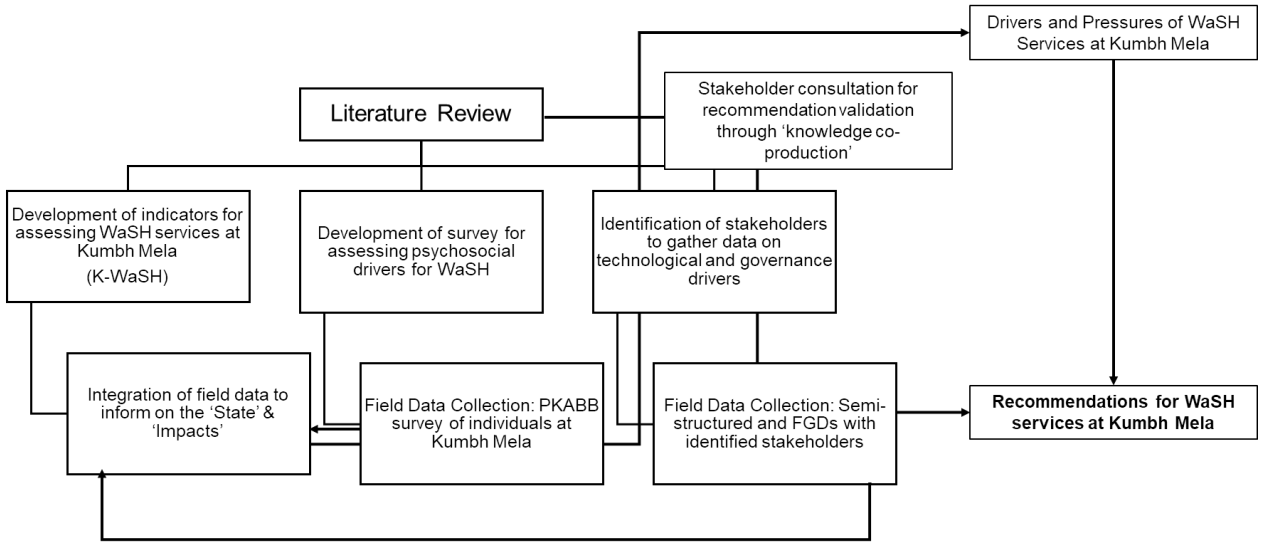


Figure 6.3. K-WaSH framework development for improved WaSH services at religious mass gatherings (PKABB - Pilgrim Knowledge, Attitude, Behaviour & Beliefs Survey)

6.1.1. Development of the K-WaSH framework

The methodology adopted for developing the framework comprised two key components: (i) a literature review and (ii) a validation process employing field-based techniques. For the literature review, a para-systematic approach was undertaken to ensure both breadth and depth of coverage. Relevant academic and grey literature were identified using predefined search terms, as outlined in Table 6.1. The search strategy included combinations of the following keywords: 'WaSH', 'Water', 'Sanitation', 'Hygiene', 'Mass Gathering', and 'Kumbh Mela', applied across Google Scholar and Google Web Search platforms. Analysis was done based on the screening of abstracts and executive summaries from available secondary literature (Figure 6.4),

Table 6.1. Definitions of WaSH for mass gathering events were used to identify relevant literature.

WaSH: In the Kumbh Mela context, WaSH refers to integrated systems and practices ensuring equitable, affordable, and sustainable access to safe drinking water, adequate sanitation, and effective hygiene for public health, disease prevention, and dignity (WaSH in the New UNICEF Strategic Plan, 2022).
Water: Continuous access to safe, acceptable, and sufficient potable water for personal and domestic use, located nearby and managed by human rights standards (World Health Organization, 2024).
Sanitation: Safe, dignified management of human excreta, solid waste, and wastewater through accessible, functional facilities with proper disposal/treatment and environmental safeguards (World Health Organization, 2024; Hermann, 2005).
Hygiene: Availability and promotion of hygiene infrastructure and practices, e.g., hand hygiene, menstrual/incontinence management, vector control, and cleanliness that empowers communities to maintain health (De Wit et al., 2024; Karmacharya, 2022; UNICEF Report, 2022).
Mass Gathering: A planned or spontaneous congregation that may exceed local/national operational capacity, straining planning, coordination, and emergency response (Almehmadi & Alqahtani, 2023; Johansson et al., 2012; Karampourian et al., 2019).

All 41 selected reports and academic publications were uploaded to the web-based platform ATLAS.ti, a qualitative data analysis software designed to facilitate the identification and categorisation of relevant textual segments through a process known as coding. The literature review employed an inductive coding approach, systematically guided by the DPSIR (Drivers, Pressures, State, Impact, Response) framework to ensure analytical rigour and thematic coherence. The following reports and protocols were the core literature for deriving our framework: WaSH4WORK; WaSH in health care facilities by WHO; IndiaKit; Sphere Handbook 2018; Joint Monitoring Report by WHO/UNICEF.

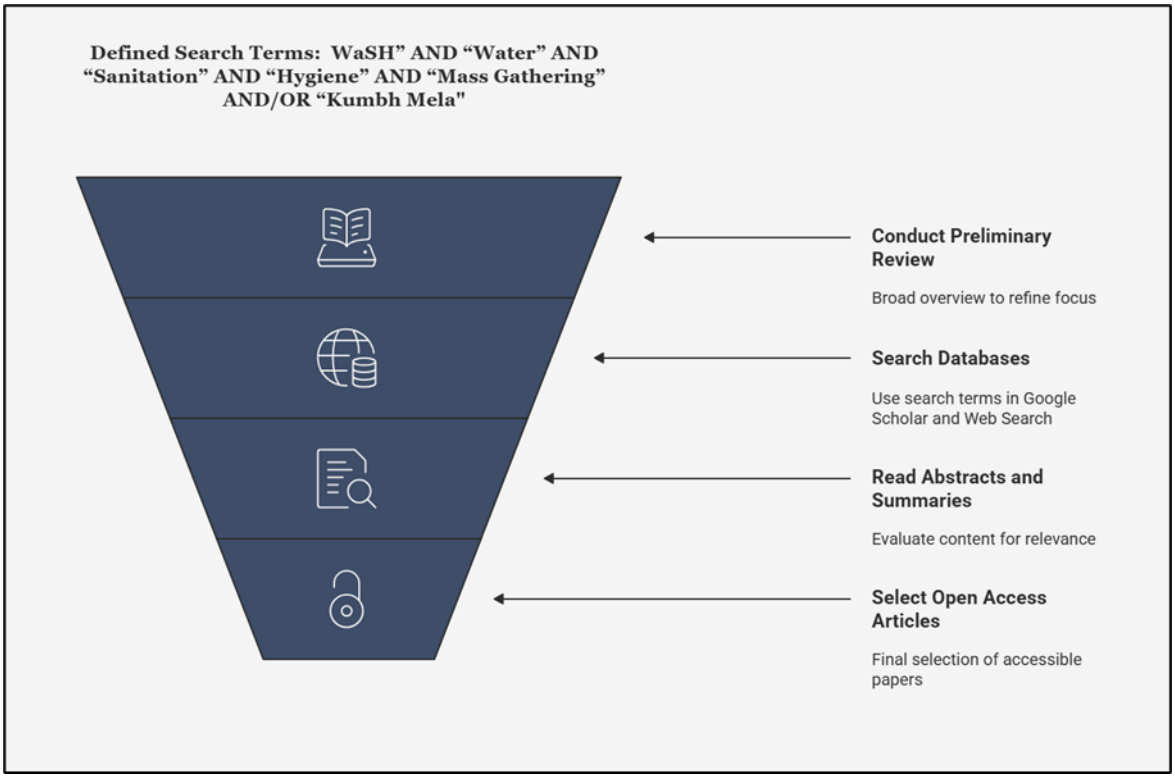


Figure 6.4. Flow diagram of literature review

6.1.2. Using DPSIR for the identification of K-WaSH indicators

The Drivers-Pressures-State-Impact-Pressure Framework (DPSIR) serves as a structured analytical tool for tracing chains of causality originating from driving forces such as economic and other anthropogenic activities that generate pressures, alter environmental states, and result in impacts on ecosystems, human health, or functional systems (Kristensen, 2004). Given the complexity of these causal linkages, the framework simplifies the analysis into sub-components, such as examining the Pressure and State relationships. (Kristensen, 2004). In the context of this study, the DPSIR framework was instrumental in establishing the analytical objectives and guiding the relevance of our inductive coding approach. To operationalise the framework to identify indicators, we formulated the following questions:

a. What are the service delivery requirements of WaSH services?

b. What factors influence or hinder the delivery of WaSH services?

c. How can the service delivery requirements of WaSH services be effectively measured?

d. What are the consequences of gaps or shortfalls in WaSH services delivery?

Through the application of these guiding questions, we first identified the service delivery requirements of WaSH services at Kumbh Mela. The services were divided into Water, Sanitation and Hygiene with the following service delivery requirements.

Through the application of these guiding questions, we first identified the service delivery requirements of WaSH services at Kumbh Mela. The services were divided into Water, Sanitation and Hygiene with the following service delivery requirements.

6.1.2.1. Water Supply Services Expected Requirements for Mega Religious Gatherings

- **Availability & Proximity:** Ensuring that the floating population can locate a drinking water source within 20 minutes or 500 meters (World Health Organization, 2024).
- **Equitable & Affordable Access**: Ensuring everyone at the Kumbh Mela site has fair access to safe drinking water sources, regardless of their socioeconomic status, within a span of 10 minutes (Sphere Handbook, 2004).
- **Quality & Acceptability:** Ensuring that the drinking water supplied at the Kumbh Mela site is clean, potable, and free from contaminants (faecal and chemical); and is culturally and personally acceptable by the floating population in terms of taste, odour, and appearance (WHO, 2011).
- **Quantity & Continuity:** Ensuring that sufficient safe water is separately available for the floating population for drinking and other personal and domestic uses, consistently and reliably without disruptions at the Kumbh Mela site, and without impacting the resident population (IRC WaSH, 2016; Rahut et al., 2022).
- **Safety:** Any form of water and its sources, storage, and distribution systems must not pose health risks to the floating population and the resident population (UNICEF Report, 2016).

6.1.2.2. Sanitation Services Expected Requirements for Mega Religious Gatherings

- **Equitable & Affordable Sanitation Facility:** Ensuring equitable and affordable access (1 facility to 50 people) to sanitation facilities such as handwashing stations, latrines, toilets, and bathrooms across the sectors within the Kumbh Mela site (Nagla, 2020; UNFCCC, 2023)
- **Accessibility, inclusivity, proximity, and functionality:** Ensuring that sanitation facilities are usable by all, including children and persons with disabilities, and they are easily accessible within <100m (WHO Report, 2023; WHO Report, 2018).
- **Safety, Privacy & Dignity:** Ensuring that sanitation facilities are hygienic, afford adequate privacy, and safeguard human dignity constitutes a fundamental human right and an essential component of equitable public health infrastructure (Coffey et al., 2015; De Wit et al., 2024)

- **Safe Disposal of Waste:** Ensure the safe and scientifically robust management of biomedical waste, solid waste, and wastewater- either through treatment on site or via appropriately designed off-site treatment systems, which is critical for protecting public health (EPA, 1980).
- **Environmental Sanitation:** Ensure that the floating population has access to a clean and safe environment, free from biomedical waste, solid waste, and untreated wastewater, while controlling potential environmental factors that may pose risks to human health and preventing direct exposure to hazardous waste (Cronk et al., 2015; Wisner & Adams, 2003).

6.1.2.3. Hygiene Practices Expected Requirements for Mega Religious Gatherings

- **Health Hygiene:** Ensure that all stakeholders residing and visiting Kumbh Mela have access to safe water, sanitation facilities, and secure accommodation to maintain their health and well-being (Almehmadi & Alqahtani, 2023).
- **Menstrual Hygiene:** Implement measures to guarantee access to appropriate menstrual hygiene products and safe, private facilities that enable women to manage their health with dignity. The Kumbh site should prioritise creating an inclusive and respectful environment that acknowledges and supports women's biological needs as an essential aspect of public health and gender equity (Carrard et al., 2022).
- **Vector and Communicable Disease Control:** Implement comprehensive measures to prevent the proliferation of disease-carrying vectors and to control the transmission of water-borne and other communicable diseases at the Kumbh site, thereby significantly reducing the risk of outbreaks among the large congregating population (Karampourian et al., 2019).
- **Awareness & Promotion**: Measures to encourage and promote personal and community hygiene practices in the population visiting Kumbh Mela (De Wit et al., 2024).
- **Environmental Hygiene:** Measures to ensure that the Kumbh Mela site is overall clean, litter-free, and pathogens-free; and that no environmental factors affect access to Water and Sanitation Services (Cronk et al., 2015).

Using these service requirements as objectives, we identified four indicators for 'State', four for 'Impacts', and three for 'Drivers' (Figure 6.5). Each indicator was further divided into sub-indicators addressing specific pillars of service delivery. Literature review shows that 'Pressures' are highly variable and evolve, making them identifiable only through the causal

linkage framework within DPSIR for each scenario. The K-WaSH indicators derived from this review are as follows:

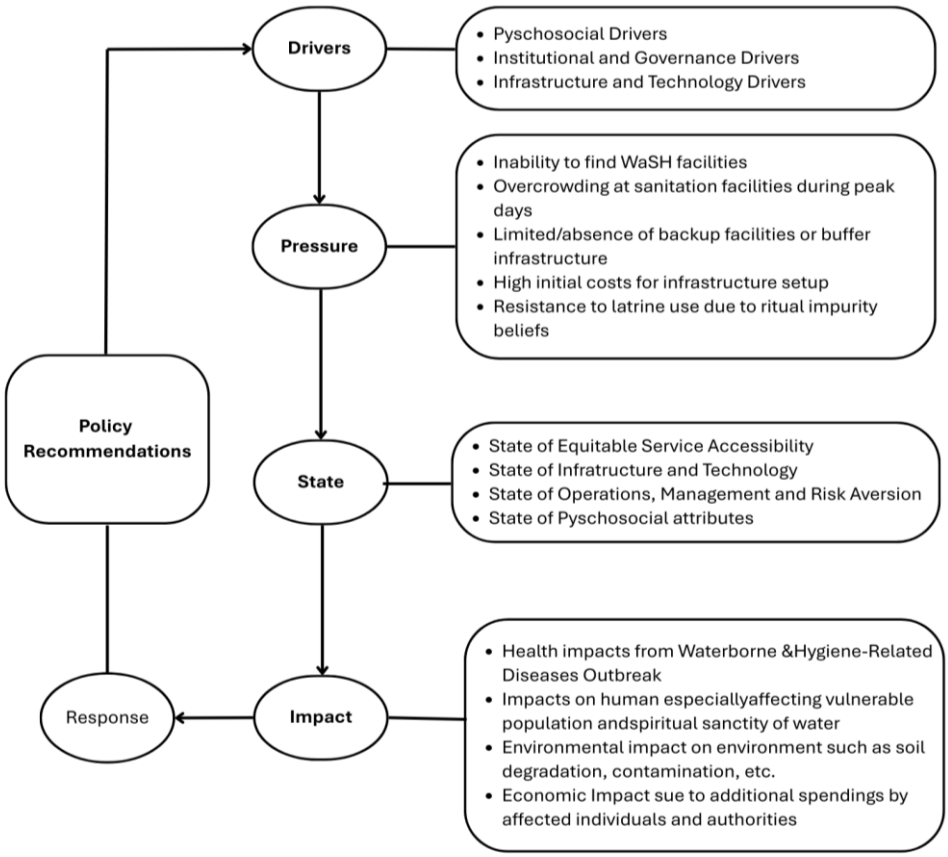


Figure 6.5. Broader Indicators of 'Driver', 'Pressure', 'State' and 'Impact' dimensions of the DPSIR framework

6.1.2.4. Framework Indicators of K-WaSH: "State"

a. **State of Equitable Service Accessibility:** The State of equitable access to WaSH service indicates the status of all individuals at the Mela Site accessibility to clean and safely managed WaSH services, regardless of their socioeconomic status, gender, caste, creed, distance, health, etc (Caruso et al., 2021; Sphere-Handbook, 2018). The state can be observed and recorded using the following dimensions:

- **Accessibility Metrics to water and sanitation facilities:** The percentage of the stakeholders with access to basic WaSH facilities (age, gender, socio-economic) (Madikizela et al., 2024).
- **Affinity for hygiene practices:** Hygiene practices observed by the floating population at the Kumbh Mela Site (Kumar Kanaujiya & Tiwari, 2021).
- **Affordability:** Economically accessible WaSH service by the floating population at the site, regardless of their socioeconomic status (Rhodes-Dicker, 2024).

- **Quality of the WaSH services:** Water should be clean, potable, and free from contaminants (faecal and chemical) (The Sphere Handbook: 2018).
- **Quantity of WaSH services:** Sufficient amount of water, toilets, and hand washing stations should be available for all personal and domestic uses at the site (UNICEF, 2022).

b. **State of Infrastructure & Technology**: Improved infrastructure and technology mean the availability of improved WaSH facilities such as flush/pour flush to piped sewer system, septic tank, pit latrine, RO fitted water access points, soaps, etc. at Kumbh Mela Site (Curtis, 2019; Kumar et al., 2024).

- **Types of improved infrastructure and technology:** Types of infrastructure provided, such as ROs and filters for clean water, standpoints and tube wells for accessing water, toilets, hand washing stations, etc., for sanitation (Coffey et al., 2015).
- **Availability of improved infrastructure and technology**: Sufficient availability of infrastructure and technology required for maintaining safety and hygiene, such as dustbins, smart-bins, handwashing stations, Water ATMs, etc. (Baranwal et al., 2015; John & Ajibade, 2024).
- **Availability of Improved Support Infrastructure**: Ensure the provision of adequate support infrastructure, such as reliable electricity, transportation, and related utilities, to enable the continuous supply of clean water and the effective operation of sanitation facilities at the Kumbh site. Robust supporting infrastructure is essential, as interruptions in power supply can directly disrupt water distribution and sanitation services, while inadequate transportation systems can hinder timely waste collection and disposal (Krishnan, 2019).

c. **State of Operations, Management and Risk aversion:** Operations, Management and Risk aversion means providing safe, continuous and managed WaSH services to avert public health risks at the Kumbh Mela. This dimension is indicated by the following:

- **Safely managed water and sanitation facilities:** The water and other sanitation facilities provided at the site should not pose a health risk to the users of the services (The Sphere Handbook: 2018).
- **Hygienic Environment:** Maintain a local environment that is free from human and animal faecal matter, litter, garbage, and stagnant water pools, thereby reducing

potential health hazards and ensuring a safe and sanitary setting for the congregation (Pigeon et al., 2025).

- **Health Risk from River Water:** Ensure that river water quality meets established public health standards, eliminating or minimising contaminants so that it does not pose any risk to human health (Palo et al., 2021).
- **Continuity of WaSH Services:** Ensure that WaSH services are consistent, reliable, and seamlessly maintained throughout all three phases: pre-event setup, the duration of the event, and post-event dismantling without leaving behind any unhealthy residues or environmental contaminants (Kmentt et al., 2021).
- **Public Health Risk Management:** Prevent disease outbreaks and ensure safe operations through trained sanitation personnel equipped with PPE (gloves, boots, masks) and essential first-aid resources (Chakraborty et al., 2022).
- **Promotion of WaSH awareness:** Cultivate community cognisance regarding water, sanitation, and hygiene practices, fostering behavioural adherence through targeted education and participatory engagement (Sphere Handbook, 2011).

d. **State of Psychosocial Dimension of WaSH:** This indicator measures how social dimensions such as age, gender, economic group, education, etc., influence Knowledge, Awareness and Perception towards WaSH practices. Literature shows that income levels, education, and gender play an important role in acquiring knowledge, awareness and developing a perception towards WaSH services in communities. Thus, using this idea and based on our current understanding, we have introduced the following indicators for assessing this State (Sphere Handbook, 2018).

- **Affinity for Hygiene Practices:** Demonstrate intrinsic adherence to hygienic routines, reflecting internalised behavioural norms that mitigate pathogen transmission and promote public health resilience (Consumer Drivers and Barriers of WaSH Products Use in Rural Ethiopia, 2016).
- **Knowledge and Awareness on WaSH Practices**: Evidence-based understanding and situational awareness regarding standardised WaSH practices enabling informed decisions that reduce health risks and optimise community well-being (Miller-Petrie et al., 2025).

- **Satisfaction on WaSH services at the event:** Perceived adequacy and effectiveness of WaSH facilities, reflecting user confidence in service quality and accessibility during the event (Roy et al., 2023).

6.1.2.5. Framework Indicators of K-WaSH: "Drivers"

Within the DPSIR framework, drivers represent stakeholder behaviours and decisions influencing WaSH service delivery. Literature shows these are shaped by three key factors: psychosocial determinants, institutional/governance protocols, and infrastructure/technology availability. Each category was subdivided for detailed analysis of actions impacting WaSH during the event.

a. Psychosocial Drivers of K-WaSH

- **Knowledge and Awareness of Stakeholders:** Both management (e.g., PMA, PWD) and the floating population require knowledge to access and maintain clean water, handwashing stations, and latrines, reducing waterborne disease risks (Caruso et al., 2021; John & Ajibade, 2024; Vortmann et al., 2015; WaSH in the New UNICEF Strategic Plan, 2022) . This driver includes:
- **Pilgrims' Knowledge and Behaviour:** Intrinsic knowledge stems from socio-economic background—households with latrines are 90% more likely to understand WaSH benefits (Coffey et al., 2015). Wealthier, educated groups use latrines more, while marginalised groups show higher open defecation (Rahut et al., 2022). Extrinsic knowledge includes Mela-based information signage, water ATMs, hygiene stations and campaigns via hoardings, street plays, and announcements. Hygiene education reduces open defecation (David & Roy, 2016); public interest improves water access (Madikizela et al., 2024).
- **Provision of Information in Kumbh Mela Management:** For Kumbh Mela Management, knowledge and awareness refer to access to timely, relevant information about target groups (pilgrims, sanitation workers, floating population), communication channels, and emergency protocols. This information supports effective WaSH service delivery and adoption of best practices (Almehmadi & Alqahtani, 2023; Vortmann et al., 2015). Achieving this requires a well-trained workforce and clear protocols to handle issues like water leaks, septic overflow, and waste mismanagement.
- **Cultural and Religious Norms (Belief):** Cultural and religious beliefs play a critical role in shaping WaSH behaviours (Alexander 2016, n.d.; Sphere-Handbook, 2018; Caruso et al., 2021; Hutton et al., 2018). In Hinduism, notions of purity and pollution

strongly influence defecation practices. Many consider defecating near living areas impure, leading to reluctance in using latrines even when available (Alexander, 2016.; Coffey et al., 2015). Additionally, the reverence of rivers as sacred entities further impacts sanitation behaviours, as open defecation near water bodies is often avoided or regulated, demonstrating how deeply spiritual beliefs can both support and constrain WaSH adoption, particularly in sacred settings like the Kumbh Mela.

b. **Institutional Support and Governance Drivers of K-WaSH:** Institutional and governance factors strongly influence WaSH delivery at Kumbh Mela. Key drivers include:

- **Best Practices Protocols:** Adoption of frameworks like *Sanitation Safety Planning* ensures timely installation and infection control (WHO, 2018).
- **Integration of National Strategies:** Aligning WaSH services with initiatives such as *Swachh Bharat Mission,* similar to Saudi Arabia's SDG alignment for Hajj, sets benchmarks for service delivery (Madikizela et al., 2024).
- **Workforce Motivation:** Staff under Swachh Bharat often view their work as a social mission, driving strong commitment (Curtis, 2019).
- **Accountability:** Senior officials adopting campaign-style approaches accelerate sanitation progress, shifting district staff from routine administration to mission-driven action (Curtis, 2019)
- **Networks and Coalitions:** Multi-actor coalitions strengthen advocacy and resource mobilization for sanitation.
- **Monitoring Framework:** Flexible, context-specific systems with clear roles enable data-driven policy and timely interventions (Cronk et al., 2015).

c. **Infrastructure & Technology (I&T) Drivers:** Assesses the extent to which innovative technologies are integrated into WaSH service delivery to enhance efficiency, responsiveness, and scalability. This includes the deployment of IoT-based systems for real-time monitoring of water quality, toilet fill levels, and hygiene supplies; AI-driven crowd management tools for dynamic facility allocation; and mobile health platforms for hygiene education and early outbreak alerts. The indicator also captures the use of drone-based remote sensing and real-time analytics to track infrastructure usage and optimise service planning (Armitage, 2013; Chowdury et al., 2019)

6.1.2.6. Framework Indicators of K-WaSH: "Impact"

a. Environmental Impact:

- **Water sources and rivers contamination:** Untreated sewage that is released into rivers from sanitary facilities can contaminate the water used for bathing. Additionally, it can damage communities downstream and aquatic life.
- **Chemical Pollution from Bathing:** Soaps, laundry detergent, and household items contribute significantly to chemical pollution during mass ritual bathing. According to studies, dissolved cleaning chemicals have raised the amounts of sodium (90–180 mg/L) and chloride (88.04 mg/L).
- **Overloaded Waste Systems:** Inadequate sludge removal results in open dumping; poorly managed waste drains, causing septic malfunctions and hazardous environments.
- **Disruption of Local Ecology and Biodiversity:** The accumulation of untreated sludge, plastic waste, and ritual waste compromises ecological integrity and endangers riverine biodiversity over the long run.

b. Economic Impacts:

- **Superfluous Financial Expenditure:** Inefficiencies in WaSH service delivery can lead to increased operational costs and potential regulatory challenges. For example, the National Green Tribunal and courts can hold them accountable for preventable environmental pollution and associated public health impacts.
- **Reputation and future investment loss:** Negative media coverage and public dissatisfaction can harm the event's image nationally and internationally, which can deter future investments in the Mela. For example, perceived lapses in cleanliness may affect the willingness of pilgrims to return.
- **Post-event Cleanup Expenses:** Post-event river and land cleanup costs can reach hundreds of crores; pilgrims may face treatment costs and lost workdays.

c. Health Impacts from Waterborne & Hygiene-Related Diseases Outbreak:

- **Risk of spread of diseases:** Contaminated drinking water and inadequate sanitation lead to gastrointestinal illness, skin infections, and eye diseases, or an outbreak of communicable diseases such as Cholera, reflecting a direct link between unhygienic surroundings and inadequate WaSH infrastructure.

- **Hand hygiene facilities and practices:** Lack of safe sanitation facilities and hygiene practices can increase the risk of faecal-oral transmission during food preparation and eating in communal spaces.

  Strain on Local Healthcare Systems: The spread of infections can place sustained pressure on local healthcare infrastructure, with demands persisting even after the conclusion of the event.

d. Impacts on humans, especially affecting the vulnerable population and the spiritual sanctity of water

- **Impact on Women's Health and Hygiene:** Female pilgrims can face disproportionate risks of compromised dignity, safety, and health in the absence of menstrual hygiene facilities.
- **Conflict and Inequities within the Mela Site:** Competition for scarce resources fosters inequities and occasional conflicts, undermining both social cohesion and water security (Sphere Handbook, 2018).
- **Psychological impacts of vulnerable groups:** WaSH conditions can sometimes increase stress, anxiety, and social marginalisation among vulnerable groups, exacerbating mental health challenges linked to inadequate sanitation and hygiene.
- **Justice concerns:** Distribution of WaSH services may sometimes intersect with existing socio-economic stratification.
- **Perception of impurity from unclean surroundings affecting spiritual experience**: Pollution of sacred river water impacts religious bathing rituals and public trust in event management.

6.1.2.7. Identifying Pressures on WaSH Services Using Causal Linkage

Pressures within the DPSIR framework can be defined as the immediate stresses that Drivers place on Kumbh Mela's WaSH system. Building on the prior analysis of Drivers (psychosocial, infrastructure and technology; governance and institutional), we can identify emergent 'Pressures' as the observable pathways through which those Drivers translate stress on WaSH service delivery, showcasing a causal linkage. In practice, some pressures are attributable to a single Driver (e.g., an information gap that hampers safe water use), while many are composite, arising from the interaction of multiple underlying Drivers. For analytical clarity in this section, emergent pressures have been classified into four thematic brackets: (i) operational and management pressures; (ii) pressures linked to behavioural and cultural norms; (iii) pressures

from financial and economic burden; (iv) pressures from infrastructure and service gaps, as shown in Figure 6.6. Together, these pressures play a vital role in shaping the State of WaSH during the Mela and help provide some insights into the perceived impacts.

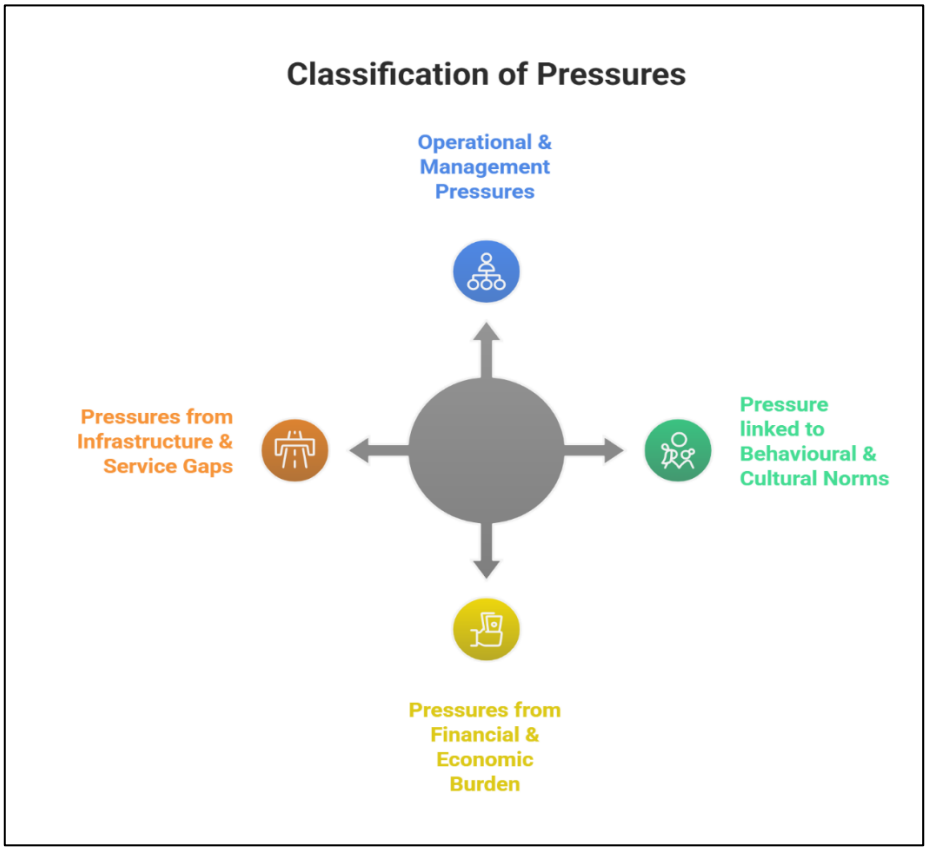


Figure 6.6. Key thematic brackets of 'Pressure' identified in the context of Kumbh Mela 2025

To identify the Pressures through a causal link, one can draw on the Drivers of WaSH services identified above (Figure 6.6). A brief illustration may help understand the above-mentioned causal logic between drivers and pressures. For instance, following the 29 January 2025 overcrowding at Kumbh Mela, where officials confirmed multiple injuries, authorities responded promptly due to heightened public attention and safety concerns. Immediate governance responses included cancellation of VIP protocols, declaring no-vehicle zones in fair areas, and enforcing one-way traffic flows to decongest routes. These measures aimed at crowd safety also created second-order pressures on WaSH operations: tanker routing and sludge logistics had to be re-planned, on-ground communication and data dashboards reprioritised, and manpower reallocated to high-risk nodes, all under heightened public scrutiny. In this illustration, a crisis-triggered governance and institutional Driver (accountability and risk management), interacting with psychosocial dynamics (risk

perception, trust), exerted multi-bracket pressures such as operational, infrastructural, information and management on WaSH service delivery.

Another example, the inability to locate WaSH facilities can be due to human activities or conditions such as the absence of accurate population estimates leading to inadequate facilities, limited knowledge and awareness among the floating population, and insufficient or unclear signage.

6.2 Methodological approach for assessing WaSH services at Kumbh Mela using the K-WaSH framework: A case study of Maha Kumbh Mela 2025

6.2.1 Data Collection

To test the conceptual K-WaSH framework, data were collected over 3 months, covering **Pre-Phase:** 15th – 21st December 2024 and 9th - 12th January 2025; **During Phase:** 13th January 2025- 26th February 202; and **Post Phase:** 27th February 2025 to 31st March 2025. Primary data included qualitative and quantitative inputs through surveys, stakeholder consultations, and focus group discussions. This was supplemented by secondary research conducted during the same period to address gaps due to the fixed event timeline.

6.2.1.1 About the Study Area

The study encompassed 25 sectors of the Maha Kumbh Mela 2025 (Figure 6.7), covering approximately 4,000 hectares on the Ganges-Yamuna floodplains, with a total attendance of 660 million over 45 days. Sanitation infrastructure included mobile toilets, waste collection units, and sewage management. Hygiene facilities included more than 5,000 handwashing stations and menstrual hygiene kiosks. Public-private partnerships, like Reckitt's Dettol campaign, helped with these facilities. The Jal Jeevan Mission led the way in making sure that people had access to safe water. The Ministry of Jal Shakti and the Ministry of Health and Family Welfare worked together to create standard operating procedures (SOPs) for things like testing water in communities, keeping an eye on diseases, and responding to emergencies. This temporary urbanization, known as Uttar Pradesh's 76th district, is an example of ephemeral urbanism. It teaches us about scalable infrastructure, how to work together with other agencies, and how to get people involved in mass level religious gatherings.

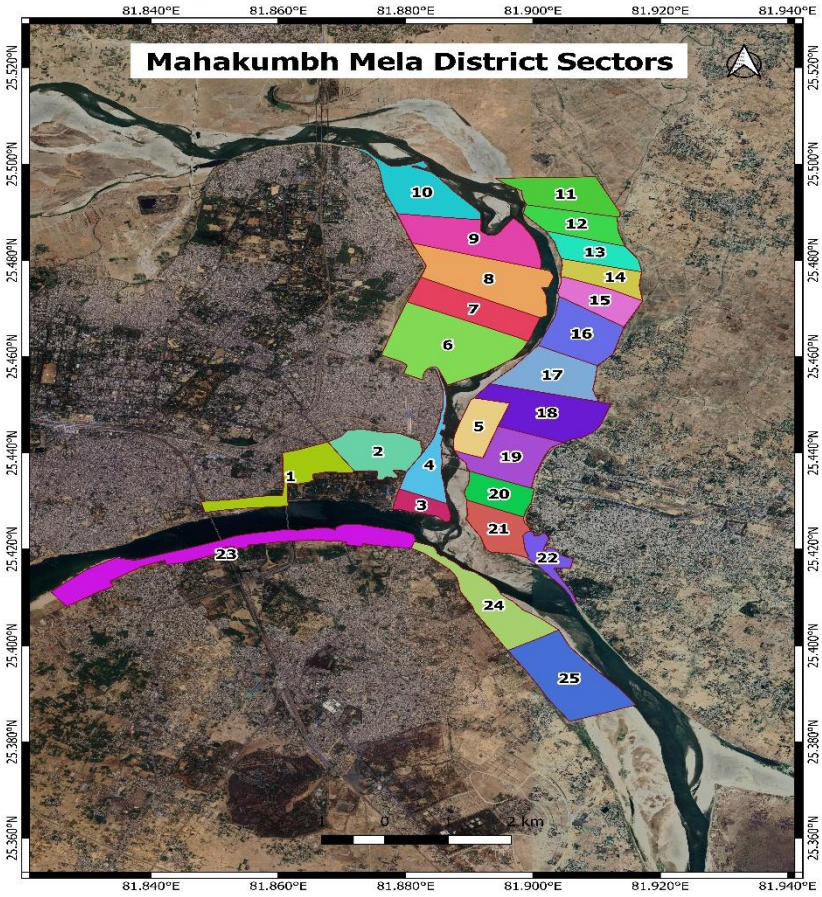


Figure 6.7. Study Area: 25 sectors of Maha Kumbh Mela 2025

To collect primary data, we adopted a mixed-method approach (qualitative and quantitative) and engaged stakeholders directly influencing WaSH service delivery at Kumbh Mela (Freeman & McVea, 2005). Based on literature from previous events (Case Study of Making of Kumbh 2019, 2019), six stakeholder categories were identified, grouped as institutional and individual:

1. **Institutional Stakeholders:** Government agencies, CSOs, academic/research bodies, and businesses.
2. **Individual Stakeholders:** Local population and floating population (Kalpvasis, religious/spiritual groups).

After framework development, select institutional stakeholders validated the K-WaSH framework and recommendations (refer to Annexures F, G, and H for more information). Key stakeholders included:

- **Government:** Prayagraj Mela Authority (PMA), SDMs, sanitation heads, sector magistrates, medical officers, EY consultants, frontline workers; UP Jal Nigam (Urban) engineers and sanitation staff.

- **Academic/Research:** UPPCB, IIT Roorkee, IIT BHU, IIIT Prayagraj, MNNIT Prayagraj, University of Allahabad, ICFRE Prayagraj, CIFRI Prayagraj.
- **CSOs/NGOs:** Global Interfaith WaSH Alliance (Paramarth Niketan), Dettol India, Ganga Praharis (Wildlife Institute of India), Lions International, Sant Nirankari Charitable Foundation.
- **Businesses/Vendors (**Providers of goods, services, and infrastructure**)**: Ecostan Infra Pvt. Ltd., Hari Bhari Pvt. Ltd., Pankhudiyaan, Lallooji and Sons.
- **Floating Population:** ISKCON, religious akharas (e.g., Juna Akhara, Baba Bageshwar Dham), sadhus, Kalpvasis.
- **Local Population:** Residents directly impacted by Mela arrangements.

6.2.1.2. Qualitative data collection

Qualitative data included stakeholder discussions (video recordings, interviews), on-site observations, and photo documentation. A total of 52 discussions (n) were conducted: 24 before the event (n1), 26 during (n2), and 12 after (n3). During Maha Kumbh Mela 2025, more than 2,000 photos were taken and used for this research. In August 2025, stakeholder consultations were held with top government officials along with academics from the institutions mentioned above to improve and confirm the draft K-WaSH Framework. This was done by using a knowledge co-production approach to make sure that the framework was relevant to the context, possible to implement, and in line with the views of all stakeholders.

A bilingual survey was used to gather quantitative data during each of the three stages. The survey was divided into two sections: (i) demographic information and (ii) WaSH knowledge, awareness, and perceptions (Annexure G). Random sampling, which is occasionally non-representative, was employed to guarantee collective safety because of the high volume of attendees. The survey was created to be flexible while staying succinct, and it was updated throughout the Mela to correspond with indicators.

In addition to open-ended questions, the survey was designed to include Likert-scale assessments, such as the Kuppuswamy Scale for socioeconomic standing, the New Environmental Paradigm for attitudes, and the WaSH stressors. The objective was to evaluate six stakeholder groups' attitudes and practices regarding water use, disposal of waste, and hygiene as well as the accessibility and availability of WaSH facilities. Pre-phase (n1=479), during-phase (n2=2,323), and final phase (n3=548) surveys totaling n=3,350 were conducted. We collaborated with Vidaksh Technology Pvt. Ltd. to administer the survey over the 4,000-hectare site.

To examine the Drivers affecting WaSH state and its effects:

- **Psychosocial drivers** were evaluated using survey data, focusing on floating population responses.
- **Institutional/Governance and Infrastructure/Technology drivers** were examined through secondary literature, news articles, field observations, and stakeholder consultations.

These drivers were then analysed individually to understand their impact on WaSH service delivery at Kumbh Mela.

6.2.1.3 Secondary data

Secondary data was obtained from reports, articles, and research studies, particularly the most recent ones on Maha Kumbh Mela 2025 and WaSH structures to support findings and fill in gaps in field data. The triangulation of institutes involved in the making of this report made assessment of the following data possible:

- Demographic profiles (age, gender, origin of respondents).
- Pilgrims' perceptions, religious and cultural practices influencing WaSH
- WaSH service status across pre-, during-, and post-Kumbh phases.
- Stakeholder expectations from administrative authorities.
- Areas where service delivery could be further strengthened relative to demand and sustainability requirements.

6.2.2 Data Analysis

As data was collected in two different forms, two different approaches were taken for the data analysis. Firstly, the data collected was used to report on the 'State' and 'Impacts' of WaSH services in Kumbh Mela using the K-WaSH framework. Next, using correlation, we tried to find associations of 'State' with the Drivers and inferred the relation with the 'Pressures' on the WaSH services at Maha Kumbh Mela 2025.

6.3.2.1 Qualitative data analysis

Stakeholder Consultations, field observations of various research team members and open-ended responses from the survey were analysed using qualitative data software ATLAS.ti. ATLAS.ti is an AI-based software that helps with processing Natural Languages. We used pre-determined themes based on the K-WaSH framework as deductive codes to identify relevant sequences of text segments.

The collected data through video records, interviews and field data were transcribed using OneNote, and noises were manually cleaned. All interview data were then imported as .docx to ATLAS.ti for processing. Photographic evidence captured during the data collection period was manually screened, service-wise and then thematic (code) wise. They were then collated and blind reviewed on thematic coding.

6.3.2.2 Quantitative data analysis

For quantitative analysis, descriptive analysis was done using Likert-type scale questions to present the findings. To analyse the Likert-type scales of questions, 'Mode' was used to reflect how the majority of the population perceived, had knowledge of, and were aware of.

The quantitative data analysis was conducted using MS Excel and Python. The findings, discussions and recommendations gathered after the stakeholder validation process are elaborated in the subsequent sections of this chapter.

6.2.3 Limitations of the survey

Across the phases, we encountered several limitations in our data collection process. Most dominantly, there was a low response rate of pilgrims as they wanted to disperse as soon as possible. This was dominant post 29th January. Secondly, only limited government representatives in the pre- and during phases of the Mela, primarily due to the intense work pressures faced by officials during this period. Thirdly, there were logistical issues in capturing data due to a huge influx of population, which created logistical challenges at the site. As the indicators were fine-tuned, different questions for different phases were floated, which led to the difficulty in mapping out the questions under the same indicators. These circumstances arose as the theory was developed in parallel to the survey.

6.3 The 'State' of WaSH Services and the 'Impacts' of the floating population on it in Maha Kumbh Mela 2025

In this section, the 'State' of the WaSH services of Maha Kumbh Mela 2025 were presented three phases, i.e., pre, during and post Kumbh Mela; and three service areas of WaSH, i.e., Water, Sanitation and Hygiene. The section covers: firstly, the demography of the surveyed floating population, secondly, the state of the WaSH services observed and inferred, and lastly, the 'Impacts' observed from the State of the WaSH services.

6.3.1 Demography and influx of the floating population surveyed at Maha Kumbh Mela 2025

The results presented for this section are based on a limited sample size of the population surveyed for the study and may not be fully representative of the entire population for Maha Kumbh 2025.

6.3.1.1 Influx pattern of the surveyed population in Kumbh Mela 2025

Pre-phase: The surveyed population in the pre-Kumbh Mela phase was predominantly originating from Uttar Pradesh and neighbouring states (Figure 6.8). The data indicates a clear geographic concentration, with the largest share of respondents (85%) belonging to Uttar Pradesh, the host state of the event. The remaining respondents were from other neighbouring states, like Madhya Pradesh, Uttarakhand, and Bihar, with Bihar indicating the smallest proportion of about merely 3%. This suggests that proximity to the Mela location was a primary determinant of attendance. Thus, the composition of the surveyed population consisted of primarily individuals from the nearest regional settings.

During Phase: In the “during Phase” of the Kumbh Mela, the surveyed population's demographic profile illustrated some shift from the pre-Mela phase, showing a wider geographical representation. (Figure 6.9). However, Uttar Pradesh remained the largest source of the surveyed population, representing nearly 60% of the share. Subsequently, Madhya Pradesh contributed to 11% of the respondents. All other states, were represented in much smaller proportions, including the states from India’s southern and eastern belts. This data indicates that Kumbh Mela is a national event attracting attendees from across the country with the population from the host and neighbouring states being the focal point.

Post Phase: In the “post” phase of the Mela, the state-wise representation of the surveyed population reduced significantly, mirroring a demographic profile like the pre-Mela phase, as shown in Figure 6.10. The data indicates a sharp upward trend in the proportion of people from Uttar Pradesh, surging to 91%, highlighting that a large majority who stayed back were from the host state. The remaining states were represented in very small numbers, even though in the during phase their representation was higher as indicated earlier. This post-Mela data highlights strong evidence backed pattern of attendees returning to their home states after the Mela, with the majority population remaining only from the nearby states, particularly Uttar Pradesh.

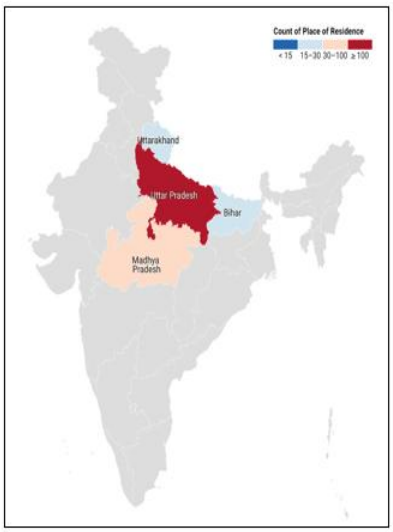


Figure 6.8 State wise influx o pilgrims in the Pre phase of Kumbh Mela

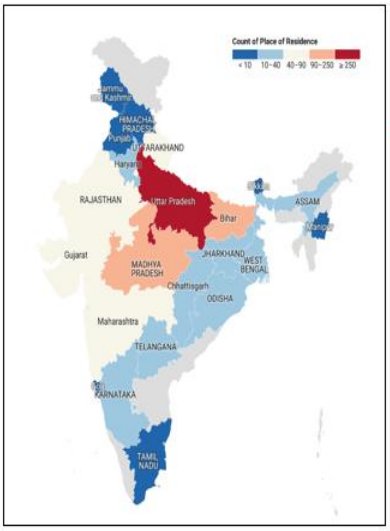


Figure 6.9 State wise influx of pilgrims in the During phase of Kumbh Mela

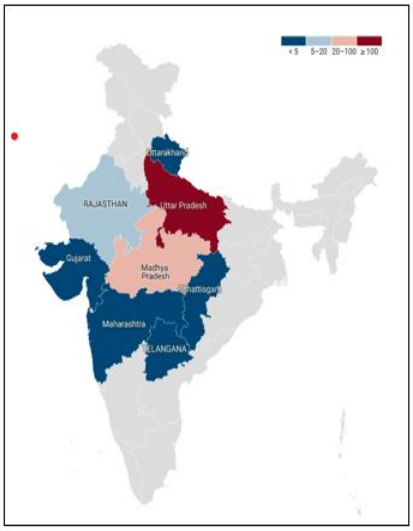


Figure 6.10 State wise influx of pilgrims in Post phase of Kumbh Mela

6.3.1.2 Age distribution of surveyed demography at Kumbh Mela 2025

Pre-phase*:* In the pre-phase, we mostly had respondents from the middle-aged group, with minimal representation from younger and older populations (Figure 6.11). 39% of the respondents were from the age bracket of 40-49 years, making it the most prominent set of respondents. Subsequently, 21% of the respondents belonged to the 35-39 age group with other age brackets showing minimal representation. Only 6% belonged to the 15-24 age group (youngest) whereas 50 and above age group were only 14%. It was seen that, none of the respondents in this phase were over the age of 70 illustrating unwillingness to attend the event due to logistical challenges related to their age and physical inabilities as they require more support and prefer to attend during the main event when a more extensive infrastructure is in place.

During Phase: During the Mela, the age distribution shifted towards a more younger population group and a diverse bracket. 23% of the surveyed population belonged to 25-29 age bracket, making it the most prominent group (Figure 6.11). The 35-39 age group (21%) was the second largest set, while the 20-24 age group saw an increase to 10%. The older population remained largely similar to the Pre-phase at 16% (50 and above). This indicates a trend of higher attendance by young adults, a pattern further corroborated by observational studies and stakeholder consultations.

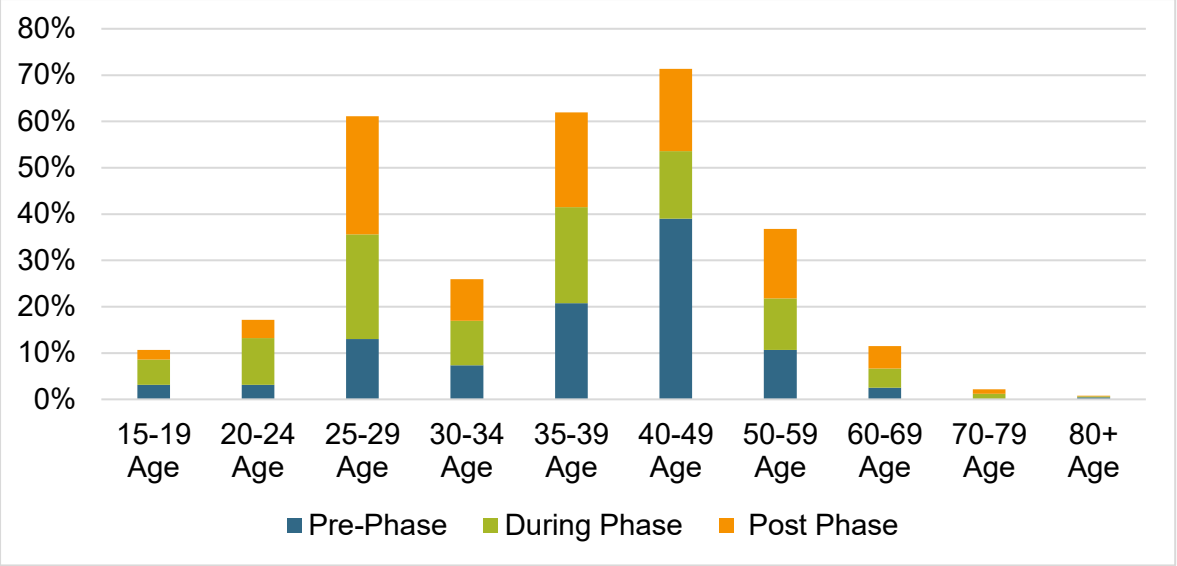


Figure 6.11. Age distribution of surveyed population across three phases of the study

This influx of younger participants can be attributed to several factors. The improvements made towards infrastructure and accessibility of WaSH (Water, Sanitation, and Hygiene) facilities and enhanced social media outreach are believed to have played a crucial role in attracting a younger population, who are more receptive to modern communication and improved infrastructure.

Post Phase: The post-Mela phase age distribution of the surveyed population shows a noticeable shift in the representation of older age groups, but a persistent emphasis on a younger adult demographic. The 25–29 age group makes up a significant 26% of the population in the post-phase, making them the largest single group of attendees (Figure 6.11). With the majority of participants still in their 20s to 40s, youth continue to predominate in attendance. Interestingly, 15% more people in the 50–59 age range attended, whereas very few people in the 60–79 age range did.

6.3.1.3 Gender distribution of the surveyed demography at Kumbh Mela 2025

The survey population of Kumbh Mela attendees consisted of three gender groups: Female, Male, and Other. A clear demographic trend emerged from the representation of the surveyed population throughout the event's various stages.

The gender split in the Pre-Mela phase was 42% female and 58% male, suggesting a notable but less extreme imbalance. But as the event progressed into its main phase, the percentage of men represented rose significantly to 72%, while the percentage of women represented fell to 28%. As seen in Figure 6.12, this pattern persisted into the post-Mela phase, when men made up an even greater 76% of the population surveyed, while women made up 24%.

According to this data, although both sexes attend the Mela, men are more likely to stay for the duration of the main bathing days and the closing stages of the celebration. Numerous factors could be responsible for the rising male-to-female ratio. These could include the nature of the pilgrimage itself, logistical issues that might disproportionately affect female attendees, or sociocultural norms surrounding travel and participation in sizable public gatherings. A high level of gender conformity within the surveyed population is indicated by the "Others" category's low representation.

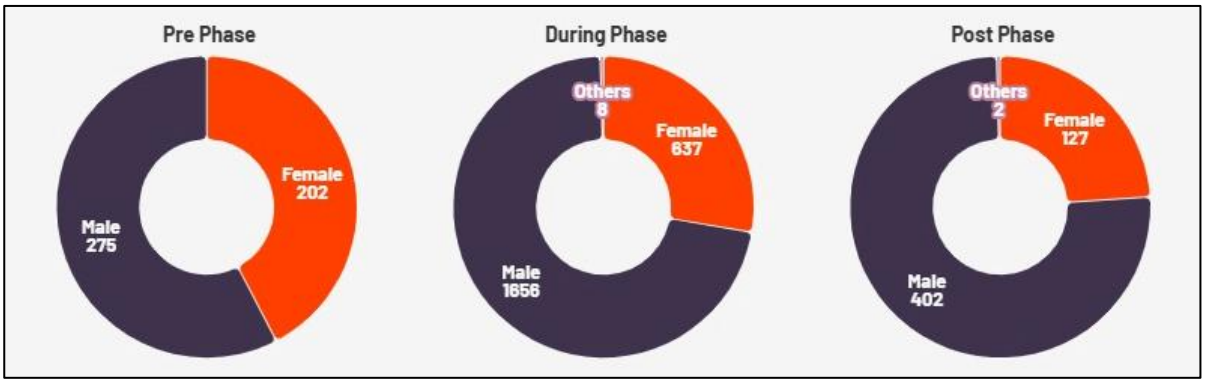


Figure 6.12. Gender distribution of floating population at Kumbh Mela 2025

6.3.1.4 Socio-economic characteristics of the surveyed demography at Kumbh Mela 2025

The socio-economic characteristics of the surveyed population were analysed using the Kuppaswamy Scale, on three parameters: *educational qualification, professional qualification, and Income group.*

a) Educational Qualification

Pre-phase: The analysis regarding the educational qualifications of the surveyed population in the pre-Kumbh phase showed that the majority of respondents possessed higher education degrees with either a Graduate degree (46%) or a Professional/Honours degree (34%). On the contrary, the representation of individuals with lower educational qualifications was minimal as shown in Figure 6.13.

The findings contest the prevailing narrative that the pilgrimage attracts a homogeneous demographic, rather indicating that the initial phase of the Kumbh Mela was attended by a comparatively more educated and potentially affluent pilgrims. The educational profile critically shapes pilgrims' motivations, information seeking and WASH management, revealing links between socio-cognitive factors and public health in mass gatherings.

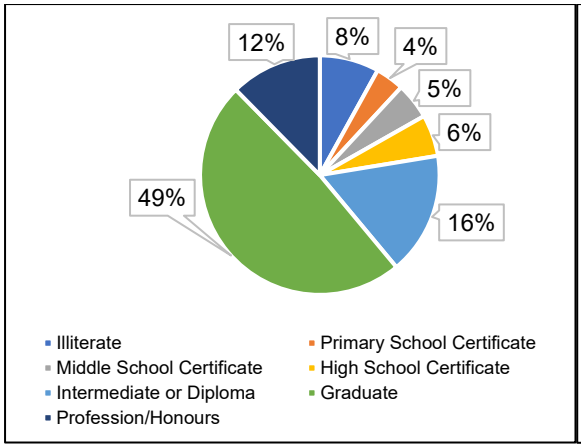


Figure 6.13. Educational Qualifications of Floating Population in the Pre Phase of Kumbh Mela 2025

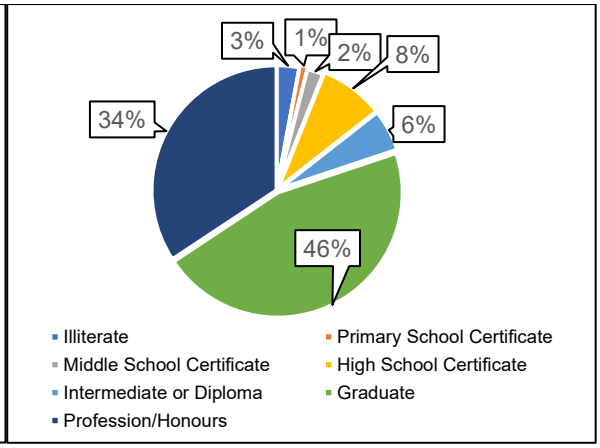


Figure 6.14. Educational Qualifications of Floating Population in the During Phase of Kumbh Mela 2025

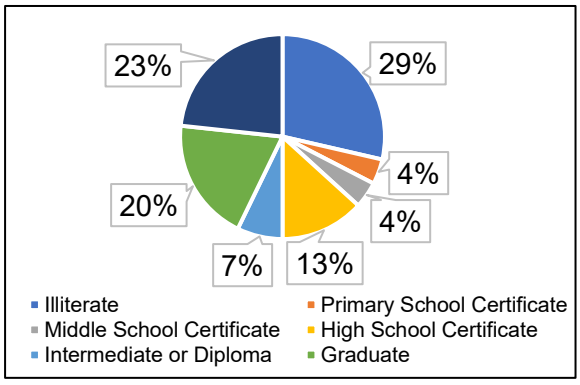


Figure 6.15. Education qualification of floating population in Post Phase of Kumbh Mela 2025

During Phase: In the during phase of the Mela, pilgrims with a higher level of educational attainment remained a prominent feature, which was consistent with the earlier phase. Graduate degree holders constituted the single largest group at 49%. However, the data also reveals an expansion in the diversity of educational backgrounds, with the number of respondents from other states rising in survey numbers. This shift suggests that while the core group of highly educated individuals remains, Mela's major bathing days seem to draw a more inclusive mix of participants from various educational and, by extension, socioeconomic backgrounds (Figure 6.14).

Post Phase: The proportion of highly educated attendees dropped significantly in the post-phase, with Graduate and Professional/Honours forming a smaller segment of the respondents surveyed, while the majority fell under the illiterate category**,** accounting for a substantial **29%** of the population. This finding underscores the dynamic and stratified composition of the Kumbh Mela's attendees, with distinct demographic groups prevailing in each phase of the event. (Figure 6.15).

b) Profession

Pre-Phase: While field observation and stakeholder consultations on site indicate a diverse range of professional backgrounds of the attendees, the survey data provides a more definitive account for this trend by underscoring the dominant demographic. During the pre-Kumbh phase, the respondent profile was notably skewed towards the "Professionals" category, comprising 60% of the surveyed population. The remaining participants were primarily categorised as "Clerks" and "Unemployed", each accounting for a significant 15%, as illustrated in Figure 6.16.

The relatively high level of education and knowledge within this demographic composition may create a conducive environment for adopting improved WASH services during the Mela. Their ability to understand and respond to new information could support the acceptance of public health measures and use of upgraded infrastructure.

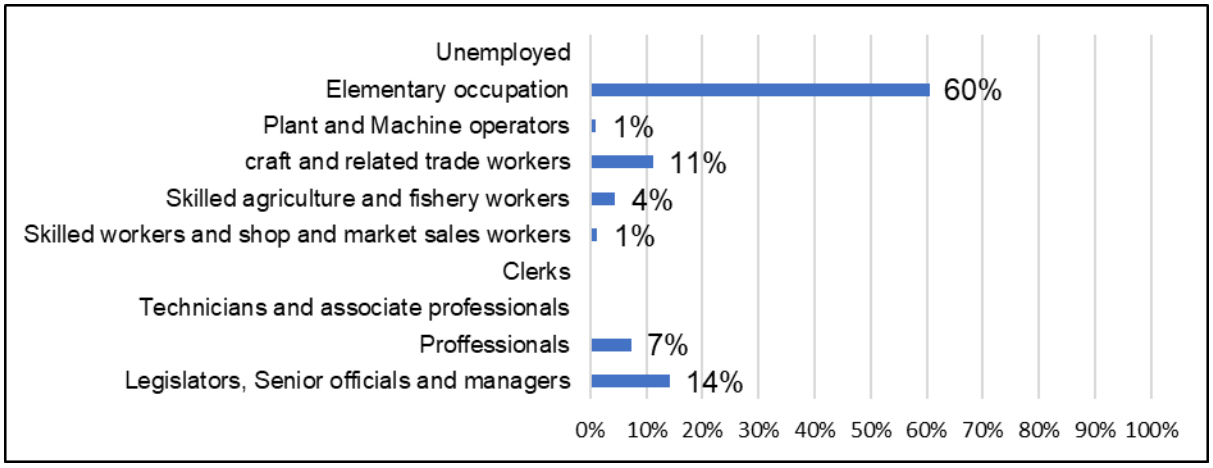


Figure 6.16. Professional backgrounds of the surveyed population in the pre-phase of the Kumbh Mela

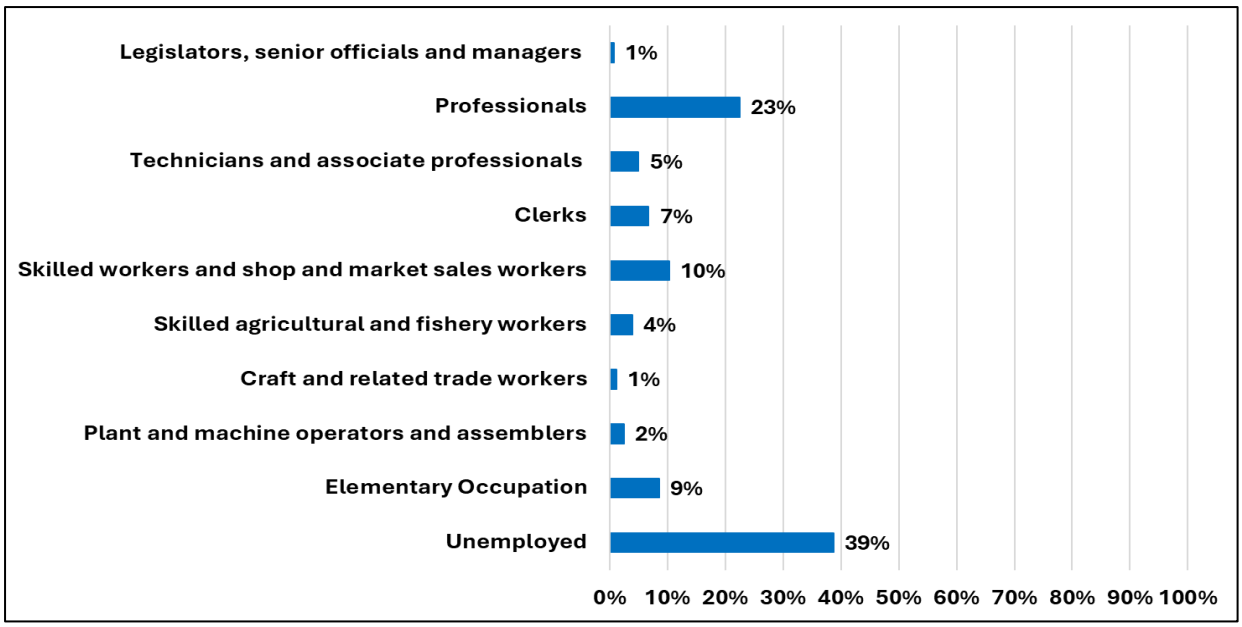


Figure 6.17. Professional backgrounds of the surveyed population in During phase of Kumbh Mela 2025

During Phase: In the 'During phase', a substantial number of surveyed populations consisted of legislators, senior officials, and managers (40%). This professional concentration, however, does not preclude inclusivity. The second most common professional group is "Elementary occupation" at a notable 20%, followed by other categories in smaller proportions, which confirms Mela's broad appeal across various socioeconomic strata, as shown in Figure 6.17. The presence of a high-ranking professional cohort during the critical phase of the Mela is a crucial asset for event management. The authority and decision-making capacity of these officials can be strategically leveraged to streamline the implementation of WaSH interventions.

Post-Phase: Post-Mela survey data indicate a shift in the occupational composition of attendees. "Legislators, Senior officials and managers" remain the largest group (30%), suggesting sustained administrative presence for post-event operations. Simultaneously, there is a marked rise in essential service workers, with "Skilled agriculture and fishery workers" comprising 20% and "Craft and related trade workers" 15% (Figure 6.18). This distribution reflects a coordinated post-Kumbh strategy, combining managerial oversight with specialized labour to ensure the systematic dismantling of temporary infrastructure and effective site restoration.

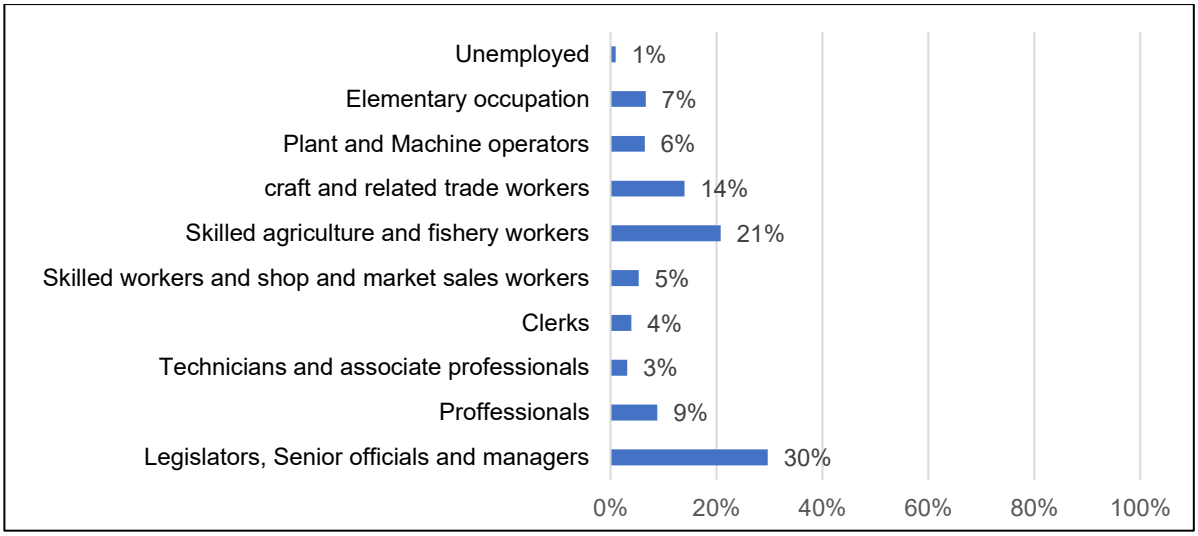


Figure 6.18. Professional backgrounds of the surveyed population in Post phase of Kumbh Mela 2025

c) Socioeconomic

Based on the graph, the income distribution of the surveyed population went through a significant transformation across the three phases of the Mela. The findings suggest a clear demographic shift, with the event transitioning from an upper-middle-class presence in its early stages to a dominance by lower-income groups towards its conclusion (Figure 6.19a, b, c).

Pre-Phase: The pre-phase of the Mela was characterized by a highly concentrated income demographic. The survey captured mainly respondents from the 'Upper Middle-Income' (70%) (Figure 6.19-A). The presence of all other income groups was negligible.

During Phase: In the during-Mela phase, there was a significant diversification of the floating population. The proportion of Upper Middle-Income attendees dropped sharply to around 34% (Figure 6.19-B). This shift suggests that the most spiritually significant days of the Mela attracted a much broader cross-section of society, including a larger number of individuals from lower income brackets.

Post-Phase: In the post-Mela phase, the demographic trend reversed completely. The Upper Middle Income group's representation continues to decline to approximately 25%, while the Upper Lower Income group became the dominant category, rising to nearly 45% (Figure 6.19-C).

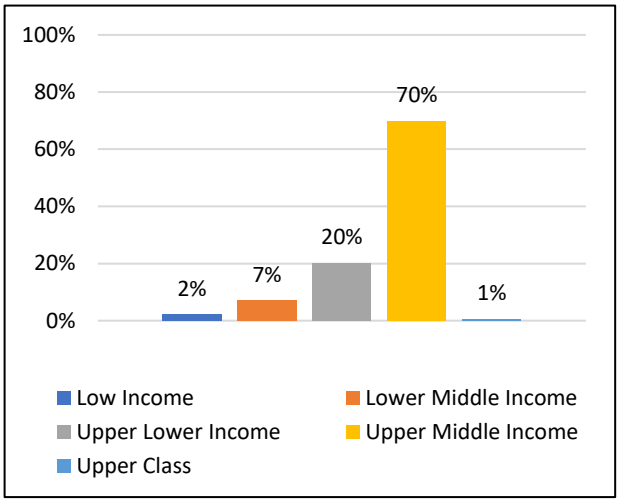


Figure 6.19-A

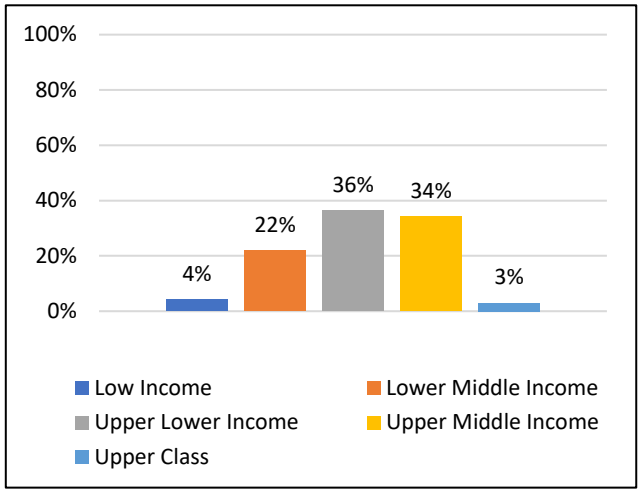


Figure 6.19-B

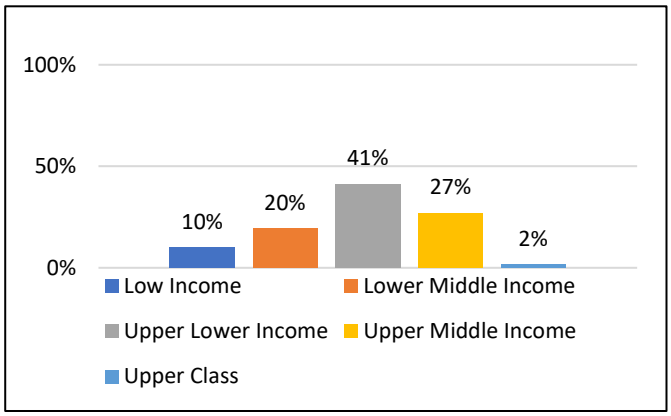


Figure 6.19C

Figure 6.19. Income distribution of surveyed population in Pre-phase (Figure 6.19-A), During Phase (Figure 6.19-B) and Post Phase (Figure 6.19-C) of Kumbh Mela 2025.

6.2. State of WaSH Services of Maha Kumbh Mela 2025

The 'State' of WaSH services at the Maha Kumbh Mela 2025 was assessed as the status of water, sanitation, and hygiene service delivery across the pre-event, during, and post-phases of the Mela. The assessment involved application of the K-WaSH framework developed in Section 6.2, which revolves around 4 key indicators- (A) State of Infrastructure and Technology, capturing the infrastructural and technological provisions made by government authorities; (B) State of Equitable Service Accessibility, documenting how WaSH services were

accessed by different groups of pilgrims in the Kumbh site; (C) State of Operations, Management, and Risk Aversion, examining how WASH services were managed and risks mitigated during the event; and (D) State of Psychosocial Factors, reflecting the behaviours, beliefs, and perceptions of pilgrims regarding water, sanitation and hygiene. Each indicator was supported by a set of sub-indicators, developed through a review of existing literature on WaSH and mass gatherings (Section 6.2). Data was integrated from relevant sources (Section 6.3) and validated through stakeholder consultations ensured contextual relevance and analytical robustness.

6.2.1. Pre-phase

6.4.1.1. State of Infrastructure & Technology

A. Service-Water Supply

- **Types and number of water access points:** This indicator displays the diversity and distribution of water supply infrastructure available during Maha Kumbh Mela 2025. Such water access points include: - Water ATMs, standposts and tap connections. The water supply infrastructure was ongoing, due to which not all water supply facilities were not in place in the phase. The pipelines were being laid in pre-phase (Observation, Figure 6.20). An extensive drinking water supply infrastructure was concentrated primarily at the major hotspots within the Kumbh area in pre-phase (Observation, Figure 6.21). An increased demand for bottled water was observed, potentially reflecting ongoing limitations in infrastructure provision.



Figure 6.20. Picture showing the ongoing infrastructure provision at Sangam in Pre phase.



Figure 6.21. Placement of water taps at Sangam (periphery of mela)

- **Types and number of water extraction systems (tubewells/borewells):** This indicator displays the diversity and distribution of water extraction systems available during Maha Kumbh Mela 2025. According to planning conducted by the PMA in

coordination with the Uttar Pradesh Jal Nigam, the Kumbh Mela site featured 85 water extraction points (tubewells and borewells), encompassing both existing and newly installed tubewells. These tubewells sourced water directly from the river floodplains underlying the site.

- **Delivery of water into water access points (piped water/tanker-truck/through vendors):** The delivery of water was done by water supply pipelines in Maha Kumbh Mela 2025. During the pre-phase of the Mela, planning by the PMA in collaboration with the Uttar Pradesh Jal Nigam established a water supply pipeline network of 1,249 km(PIB Release Maha Kumbh, 2025). Water provision during this phase was primarily facilitated through tap connections and a limited number of operational water ATMs. Initially, tap connections and handpump stations were adequately distributed in areas accommodating pilgrims and sadhus. These facilities, along with the limited water ATMs, effectively met the needs of both the floating population and construction workers in the pre-phase of the Kumbh Mela. (Observations and stakeholder discussions).
- **Types and number of water distribution systems (tankers, distribution tanks, etc.):** In the context of Maha Kumbh Mela 2025, tubewell points served as the primary node of water distribution. The tube well points comprised of water pumping components such as, motors, pumps, tube wells, etc. The number of water distribution points is equal to the number of tube wells present on Maha Kumbh Mela site.
- **Types and number of water treatment plants (filtration, sedimentation, disinfection units, etc.):** Water extracted from tubewells and borewells underwent on site (at water extraction units present in Kumbh site) treatment, with chlorination serving as the principal disinfection method.
- **Quality of water services:** No data available in pre-phase as the infrastructural provision were ongoing. However, water quality was not perceived as a concern due to deeply held religious beliefs. Pilgrims commonly hold that the sanctity of the River Ganga is inherently preserved, regardless of effluent discharge, reflecting its revered status in Hinduism. As a local priest stated, "*Ganga Ji ka Jal hamesha pavitra rehta hai.*"

B. Service-Sanitation

- **Types & number of toilets (latrines, urinals):** While installation of toilets facilities was ongoing, the different types of toilets were installed in the pre-phase (Observation, Figure 6.22, Figure 6.23). Further, the type and number of toilets is explained in Table 6.4. The toilet facilities were color-coded to demarcate gender segregation (Observation, Figure 6.24). Based on the floating crowd influx, hotspot areas, and presence of akharas sadhus, other pilot sanitation facilities such as urinals and dustbins



Figure 6.22. Mobile Compartment toilets



Figure 6.23. Open urinals and dustbins are installed at crossroads near PMA office.



Figure 6.24. Gender based colour coded toilets and ongoing septic tank connections



Figure 6.25. Connection to septic tank still to be made in Jhunsi side of the Mela.

- **Types and number of handwashing stations:** The hand pumps, tap connections, and standposts provided in Kumbh Mela served as handwashing stations. Tap connections, hand pumps, and standposts were under construction in pre-phase of the Mela. The

hand pumps and standposts available in the pre-phase of the mela catered to the multipurpose use of water supply, including handwashing.

- **Types and number of wastewater collection units:** This indicator displays the infrastructure (Wastewater Drains) provided to collect wastewater in the sectors of Maha Kumbh Mela 2025. Temporary toilets and soak pits were being laid (Observation, Figure 6.26). No data were available on wastewater drains as laying of main roads and 'gata' roads were ongoing, after which kutcha drains were to be laid. However, for sectors 1, 2, 3, and 4, sewer lines were laid, which were connected to the STP. Additionally, a nature-based solution was also observed to absorb wastewater at the *Mansaita* drain (Observation, Figure 6.27), where a plant-based system was installed to absorb the sewage water from the drain.



Figure 6.26. Temporary toilets and soak pits at inventory site on parade ground ready for installation



Figure 6.27. Plant species installed to absorb sewage water at the Mansaita drain in Jhunsi.

- **Types and number of wastewater transportation units:** This indicator displays the diversity and distribution of vehicles deployed to transport wastewater from the Kumbh catchment to nearby treatment plants**.** No data was recorded during the pre-phase, as wastewater infrastructure provision was still in progress.
- **Types and number of wastewater disposal units:** This indicator describes the wastewater disposal points other than Treatment facilities. One such disposal facility present on site in Maha Kumbh Mela 2025 was the stabilisation ponds. No operational data were available during the pre-phase, as infrastructure development was ongoing. Construction of stabilisation ponds was underway to intercept wastewater from kutcha drains, with subsequent transportation to designated treatment facilities.

- **Treatment Plants:** This indicator discusses infrastructure provision made to treat wastewater generated at Maha Kumbh Mela 2025.The infrastructure provision made for wastewater treatment is discussed in Table 6.2.

Table 6.12 Wastewater infrastructure respective to sector

S.No.	Sectors	Waste water infrastructure (STP and Geo-tubes)
1.	Sector 1,2,3,4	Sewer lines connected to a newly constructed *Salori* STP
2.	Sector 6,7	*Salori* STP
3.	Sector 8,9,10	*Phaphamau* Temporary STP
4.	Sector 5, 18,19, 20, 21, 22	*Jhusi* Adani STP
5.	Sector 11,12,14	Temporary STP (Geotubes)

(Source: Stakeholder discussions)

- **Quality of toilet facilities:** This indicator measures the cleanliness of toilet facilities provided in Maha Kumbh Mela 2025. No operational data were noted during the pre-phase, as the infrastructure provision was still under development.
- **Percentage of hand washing stations with soap and continuous supply of water:** This indicator measures the proportion of hand washing stations within the toilet facility in Maha Kumbh Mela that are equipped with both soap and a continuous, reliable supply of water. No data were available as infrastructure provisioning was still in progress during the pre-phase.
- **Solid waste collection units:** This indicator measures the solid waste collection units deployed at the Kumbh catchment. Based on the influx of population during the pre-phase of Kumbh Mela, dustbins were provided. Color-coded metal segregation bins were placed at the main roads in the pre-phase. While having discussions with pilgrims on the ground, a pilgrim from Haridwar, visiting Prayagraj for the first time to participate in Maha Kumbh, said that people are reluctant to maintain the cleanliness and sanctity of the river Ganga in Prayagraj, even though the administration is adequately providing infrastructure. Based on the survey responses, an overwhelming majority of government authorities (98%) agreed that waste disposal facilities will be adequately placed throughout the Kumbh Mela site to meet the needs of pilgrims, reflecting their confidence that the planned services will sufficiently accommodate the large influx of people.

C. Service-Hygiene

- **Quality of handwashing stations (safely managed/basic/limited/unimproved) % of stations with soap and continuous water.** This indicator evaluates the functionality and hygiene standards of handwashing stations present in the Kumbh Mela. Estimated by quality of water supply points such as standposts and hand pumps, which were found to be satisfactory in terms of functionality and hygienic standards as per on-site observation in pre-phase of Mela.
- **Quality of bathing facilities:** This indicator assesses the adequacy of bathing facilities provided in the Kumbh Mela. The infrastructure provision done under this indicator is changing rooms at the ghats. In the pre-phase of Kumbh Mela, the status of changing rooms was clean with modified design from previous Kumbh Melas. However, there is no data on the number of changing rooms provided.
- **Power and backup systems-** This indicator assesses the availability of inventory and power backup systems that support the functioning of water sanitation and hygiene services. Power backup for bore wells were available on site. A set of toilets and water ATMs were being placed on site as a backup WaSH facility to cater to high influx on peak days. (Stakeholder consultation/Observation)
- **Access roads for waste transport-** This indicator evaluates the availability of access roads used for the transport of solid and liquid waste from collection points to disposal or treatment sites. No dedicated access routes for waste transport were observed. (Stakeholder consultation/Observation)
- **Availability of Signages:** Signage infrastructure in the Kumbh Mela displays the system of visual communication tools—such as signs or boards, used to guide and



Figure 6.28. Waste Segregation Poster



Figure 6.29 Gender Demarcation Signage

inform pilgrims about WASH infrastructure. No data as infrastructure provision was ongoing in the pre-phase. Based on observation, fewer signages were placed. However, changing booths near ghats were in usable conditions with a poster conveying messages on waste segregation (Observation, Figure 6.28, and gender demarcation (Observation, Figure 6.29).

6.4.1.2. State of Equitable Access to WaSH Facilities

A. Service-Water Supply

- **Water Availability in Kumbh Mela: This indicator assesses the availability of water in the** pre-phase of the Kumbh Mela, the surveyed population showed some concerns regarding availability of water based on their experiences from 2019. This may be due to ongoing infrastructure provision (Stakeholder Consultation).
- **Percentage of floating population collecting water from improved sources for drinking purposes:** Respondents consumed water from available improved water access only (Observation, Stakeholder Consultation).
- **Proximity to nearest water access point:** This indicator assesses typical one-way effort required for a respondent or pilgrim to reach the closest potable water source (e.g., free standpost, Water-ATM, tanker-tap) that is safe for drinking. Our field observation indicates that water ATMs and standposts were being installed at major crossroads and junctions within the site. The distribution appeared non-uniform with a greater number of access points near the periphery.
- **Percentage accessing from various water facility types such as water ATMs, standposts and bottled water:** This indicator assesses perceived ease of respondents to locate, reach, and use water points when needed. This could not be determined as the facilities were being installed and as such no data could be collected (ICCW Report).
- **Water facility functionality and non-functionality (percent of people reporting functional water ATMs)**: This could not be determined as the facilities were being installed and as such no data could be collected.
- **Percentage of floating population reported on water sufficiency**: This indicator captures the respondents' judgment that enough water was available when needed (volume/flow, refill frequency, and ability to obtain adequate personal consumption. Based on the visit to a camp accommodation of a *Kalpvasi* (priest) in sector 19 where the accommodation could be arranged for 30 pilgrims/visitors, sanitation facilities include 5 *kanath* toilets. However, there were no taps inside the toilet facility, and the

user followed pour and flush method. However, a tap was present in the precinct, which served as the source of water for day-to-day activities. The pilgrims residing in that facility were satisfied with the WaSH services provided by the government (onsite stakeholder consultation and field observation).

B. Service-Sanitation: Proximity to nearest sanitation facilities i.e. toilets, dustbins, handwashing stations

- **Sanitation facility location (within 100-200 m):** No data as infrastructure provision was ongoing.
- **Sanitation facility location (within 500 m):** No data as infrastructure provision was ongoing.
- **Sanitation facility availability (Easy):** No data as infrastructure provision was ongoing.
- **Sanitation facility (Manageable)**: No data as infrastructure provision was ongoing.: The infrastructure provision of WaSH facilities in Pre-phase was ongoing. However, PMA along with other government implementing bodies provided WaSH facilities in such a manner proximity requirements for WaSH infrastructure could be met. For instance, it was observed that high density areas had toilets at proximal distances with gender-based segregation. However, based on onsite discussions with stakeholders, which highlighted a lack of adherence by various actors, especially local street vendors performing OD/OU in open grounds.
- **Percentage of floating population reported on accessibility of sanitation facilities:** This indicator captures perceived ease of respondents to locate, reach, and use an appropriate and functional toilet when needed. In the pre-Kumbh period, the survey indicated that 46% were able to locate sanitation facility easily, 16% of the survey respondents were able to access very easily while 39% were neutral on accessibility issues. It is important to note that these facilities were being installed during the filed visit. No respondents reported that they had difficulty or some difficulty in accessing sanitation facilities (Figure 6.30). Stakeholder experiences from previous Kumbh Mela, indicated that open defecation can be a problem, especially by women due to lack of adequate restroom facilities. In this phase, there was substantially fewer number of sanitation facilities for women (Field Observation; Stakeholder Consultation).

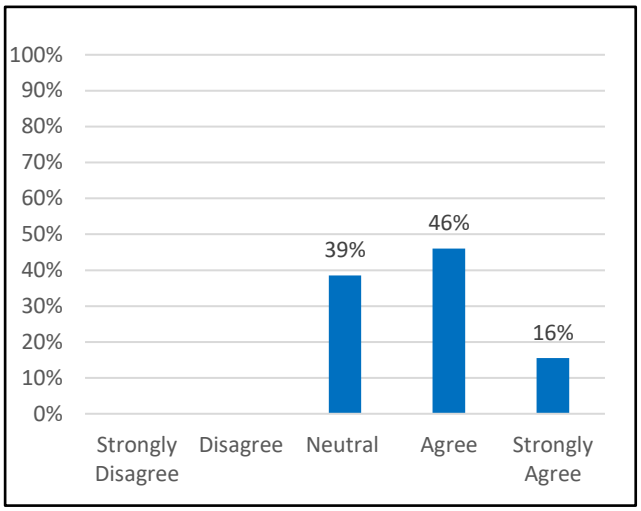


Figure 6. 30. Accessibility of sanitation facilities by floating population

- **Percentage of floating population reported on availability of sanitation facilities**: This could not be determined as the facilities were being installed and as such no data could be collected.
- **Percentage of floating population reported bad odor near sanitation facilities:** No data was captured on this point in the pre-Phase however, our field observations indicated that bad odor regions are usually limited to areas where porta cabins are installed. (Field Observation)

C. Service-Hygiene

- **Availability and proximity to handwashing stations:** Observations indicate that handwashing stations were installed near toilets, but were sparse during the pre-Kumbh phase, including near the ghat, contributing to inappropriate WaSH practices among the floating population (Figure 6.31).

- **Percentage of floating population reported using handwashing stations after communal toilets:** Based on our survey, during the pre-Kumbh Mela period, 25% of the respondents 'Agreed', while 73% respondents 'Strongly Agreed' for using of handwashing practice, with negligible disagreement towards the hygiene practice. (Figure 6.32).



Figure 6.31. Pilgrim had to wash hands over a dustbin at pucca ghat at Sangam.

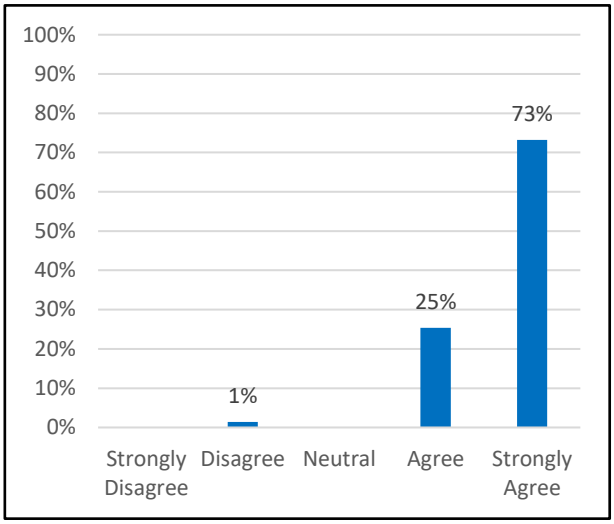


Figure 6.32. Percentage of floating population using handwashing after using toilet

Based on our survey responses, there was near-complete agreement amongst the floating population regarding the availability of handwashing facilities during the pre-phase of the Kumbh Mela, indicating that adequate infrastructure was in place in terms of both quality and quantity. However, field observations revealed that some pilgrims were washing their hands near dustbins, suggesting a limited awareness or understanding of the proper use and location of designated handwashing facilities.

- **Indication [percentage] of population drinking water from surface sources (river water)**: Field observations and stakeholder consultations indicated that no attendees consumed river water, which was generally perceived as unsafe for drinking.
- **Percentage of population showing affinity for Hygiene Practices:** Survey findings from the pre-Kumbh phase (Figure 6.33) indicate that 40% of pilgrims expressed a positive affinity towards hygiene practices (often), while 31% remained neutral (sometimes). Overall, 68% of the floating population reported actively following sanitation measures, reflecting broad awareness and willingness to engage in hygienic behaviour (Often + Every time). The remaining 32% showed moderately positive

attitudes, with no signs of resistance. These trends suggest a conducive behavioural environment that can be further reinforced through targeted awareness and facilitation efforts.

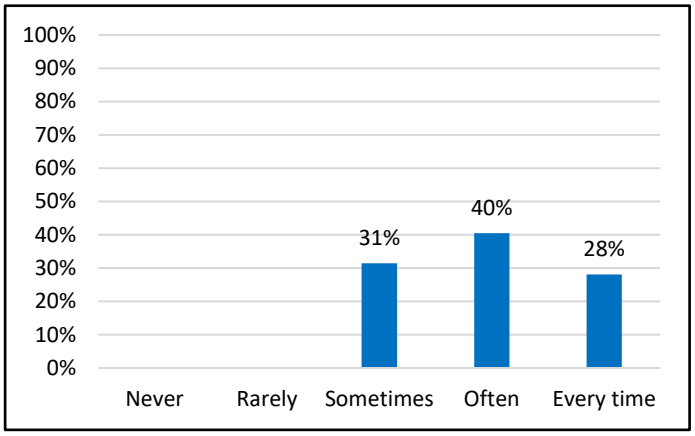


Figure 6.33. Floating population's affinity for hygiene practices

- **Health related concerns**: This indicator assesses the extent to which respondents felt at risk of illness due to WASH conditions (e.g., unsafe water, dirty/toilet surfaces, inadequate hand-washing enablers, crowding near facilities).

  No health concerns were indicated from the field survey at this period however some stakeholders showed concern over probable inadequate menstrual hygiene facilities and forced open defecation. Field observations have shown instances of open urination in this period, sometimes next to toilet facilities compromise dignity and health that can based on their experience from previous. Still there are occurrences of open urination in pre-phases, sometimes next to the toilet facilities. This may be linked to perceptions of toilet cleanliness or temporary maintenance gaps during high-use periods (Observation).

6.4.1.3. State of Operation, Management and Risk Aversion

A. Service: Water Supply

- **Hygiene (safely managed) of water facilities**:
- **Safe operation and management of water infrastructure such as water ATMs, Water tankers and standposts.:** This indicator reflects ensuring uninterrupted and hygienic access to potable water through proactive maintenance, trained operators, coordinated supply logistics, and swift grievance redressal for the pilgrims. Observations on safe management are not available in the pre-phase of the Mela.

- **Satisfaction with planning and mapping for easy access to water services:** This indicator captures how effectively water infrastructure was strategically placed to ensure pilgrims' easy, timely, and crowd-free access to safe drinking water. The sector wise requirements of water distribution are mapped by the Jal Nigam based on the influx of population in the sector prior to the initiation of the Mela. Moreover, the distribution pipelines for water distribution are laid as per CPHEEO guidelines. Repair and re-boring of existing tube-wells were undertaken before the commencement of Mela to increase water availability.
- Based on the survey responses, about 34% of infrastructure and service providers agreed on the timely planning and adequacy of water facilities, while the remaining 66% maintained a neutral or cautiously optimistic view. The absence of negative responses indicates overall confidence in preparedness; however, since these assessments were made during the pre-phase, respondents reasonably anticipated that the true adequacy of facilities would be tested based on how effectively they perform under the actual population load in the during phase.
- **Frequency of regular checks of water quality:** This indicator reflects how consistently and effectively water sources like ATMs, tankers and standposts are tested to ensure safe and contamination-free drinking water for pilgrims. The CPCB was conducting regular checks on water quality along with submitting their detailed reports to the National Green Tribunal prior to the Mela. As per the survey responses, the government stakeholders also showed a 100% agreement and confidence towards continuous monitoring of water quality in the pre-phase.

B. Continuity of WaSH Services:

- **Operational Capacity of Water infrastructure such as water ATMs, Water tankers and standposts:** This indicator captures the capacity of water infrastructure to reliably meet the drinking water needs of the pilgrims. As discussed in Infrastructure and Technology section, water supply facilities were operational in selected areas (Figure 6.34)
- Moreover, the survey data indicates that 68% of the floating population expressed satisfaction with the clean water infrastructure, with no reported disagreement, demonstrating that the management and operational strategies were highly effective in ensuring uninterrupted and reliable access to clean water during a large-scale, high-pressure event like the Kumbh Mela



Figure 6.34. Water ATM placed on site (un-operational) in pre-Kumbh phase near Sangam.

C. Service-Hygiene

- **Maintenance of a hygienic environment:** This indicator reflects keeping WaSH facilities and their surroundings consistently clean and safe through routine cleaning, timely waste management, adequate cleaning staff and supplies, and prompt response to spills or blockages to protect pilgrim's health.The assessment of hygienic environment prior to the Mela may not lead to comprehensive additions to the data due to limited external pressure and a smaller population influx. However, some evidence from field observation, as shown below in Figure 6.35 and Figure 6.36, shows improper waste disposal and floating religious waste due to the external pressure created by the early arriving floating and religious population.



Figure 6.35. Improper waste disposal in sector 3

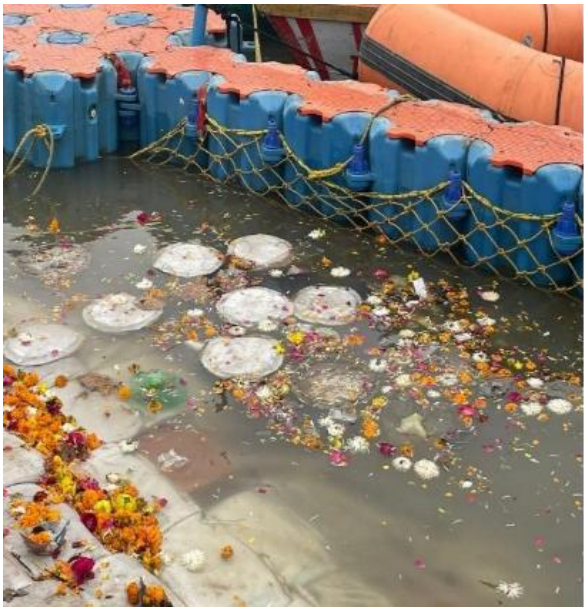


Figure 6.36. Waste Disposal in Sangam

- **Health Risk from River Water-** This indicator refers to the potential exposure of pilgrims to waterborne diseases resulting from activities such as bathing, drinking, or performing rituals in river water that may be contaminated with sewage, waste, or elevated microbial loads. No data was recorded or accessible for this parameter during the study period.

D. Promotion of WaSH Awareness

- **Collaboration & partnership among institutional stakeholders providing WaSH services:** This indicator captures the coordinated action between government bodies, NGOs, service providers, community groups, and private partners to jointly monitor service delivery through promotional campaigns, driving a behavioural shift among pilgrims towards becoming more WaSH sensitive and aware. Training of *"Ganga Sevadoots"* by PMA was conducted in batches (Nov 25–29, 2024) for 1,800 volunteers on cleanliness, sanitation, plastic-free practices, fire safety and inspections conducted specifically to prepare for Maha Kumbh 2025. *'Swachhata Rath Yatra'* awareness drive by Prayagraj Municipal Corporation launched a mobile cleanliness-awareness campaign on Jan 7, 2025 (before the Mela opened), including outreach along city routes. Namami Gange coordinated pre-event behaviour-change communication (street plays, public-address messaging), integrated with the Rath Yatra roll-out (PIB Release, 2025).

E. Service- Sanitation

- **Hygiene (safely managed) of Sanitation Facilities**
  - **Safe operation and management of sanitation services:** This indicator reflects ensuring toilets, urinals, and waste systems remain functional, clean, and accessible through regular maintenance, timely waste disposal, adequate staffing and quick response to breakdowns. Stakeholder consultations suggested that around 45,000 sanitation workers were deployed to ensure cleanliness. For the maintenance and cleaning of toilets, one sweeper was deployed for every 10 toilets, supervised by one supervisor for every 10 sweepers. Each block of 20 urinals was maintained by a designated sweeper under the oversight of a supervisor, ensuring continuous cleaning and monitoring. To uphold service quality and accountability, contracts with toilet vendors incorporated Service Level benchmarks (SLBs), specifying standards for manpower deployment, cesspool management and jet spray cleaning (PIB Release, 2025).
  - **Actionable cleaning protocols to maintain a hygienic and safe environment.:** This indicator examines standardized cleaning protocols for WASH facilities, including defined schedules and oversights. Ahead of Maha Kumbh 2025, authorities implemented robust hygiene infrastructure and operational systems, covering sanitation staffing, digital monitoring and large-scale cleaning logistics (PIB Release, 2025).

6.4.1.4 State of Psychosocial Dimensions of stakeholders:

A. Affinity for Hygiene Practices

- **Overall Respondents' Affinity to Hygiene Practices:** The survey data suggests that the floating population were following hygiene practices in the pre-phase of the Kumbh Mela. The results reflect that approximately 40% of the respondents have reported practicing hygiene "often", followed by another 28% reporting it "every time", with 31% people showing hygiene "sometimes" (Figure 6.37-A). These results show that the respondents were aware of hygienic practices and showed moderate to strong commitment to practicing it, with negligible or none disagreeing on the same, thus indicating a positive affinity of pilgrims towards hygiene practices
- **Affinity for Hygiene Practices based on Age:** When seen with respect to age, the affinity towards hygiene largely remains positive with difference in intensity across age groups. The younger cohort (15-29) reflect higher agreement, with substantial respondents showing a neutral stance, whereas middle aged groups (25-49) display a mixed pattern reflecting growing awareness and commitment towards hygiene

practices. Whereas the older segment (50-69) reflected the strongest commitment towards practicing hygiene in the pre-phase of Kumbh Mela 2025. These diversified views suggest that while consciousness and awareness remain, age specific behavioural nudges must be implemented to ensure a stronger affinity towards hygiene practices by the pilgrims. (Figure 6.37-B)

- **Affinity for Hygiene Practices based on Gender:** In terms of gender, the affinity towards hygiene practices were largely positive in the pre–phase of Kumbh Mela, across genders, with the majority falling into the "agree" and "neutral" categories. Female respondents reflected a slightly higher neutrality, compared to the males who showed higher proportion of strong agreement, but the overall distribution remained very similar. Thus, the findings indicate a uniformly positive perception of hygiene practices across genders (Figure 6.37-C).
- **Affinity for Hygiene Practices based on Socio-Economic Group:** The data reflects distinct socioeconomic differences in the surveyed floating population's affinity towards hygiene practices in the pre-phase of the Kumbh Mela. With such diversity in responses, it can be concluded that the affinity and commitment towards hygiene practices is the strongest in the economic margins, thus necessitating the need for socioeconomic group specific behavioural interventions. (Figure 6.37-D).

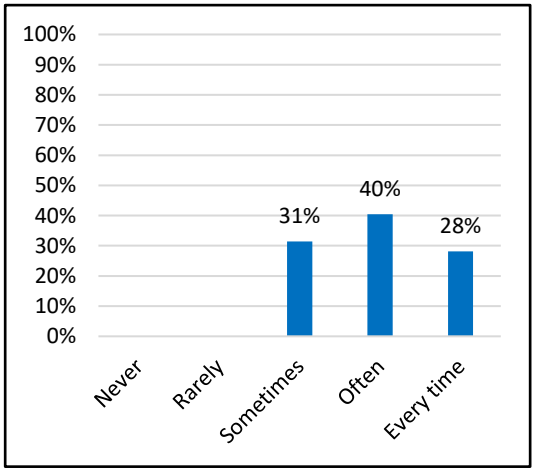


Figure 6.37-A

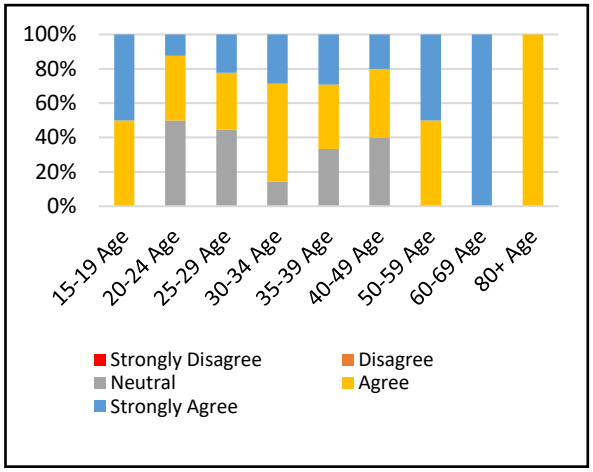


Figure 6.37-B

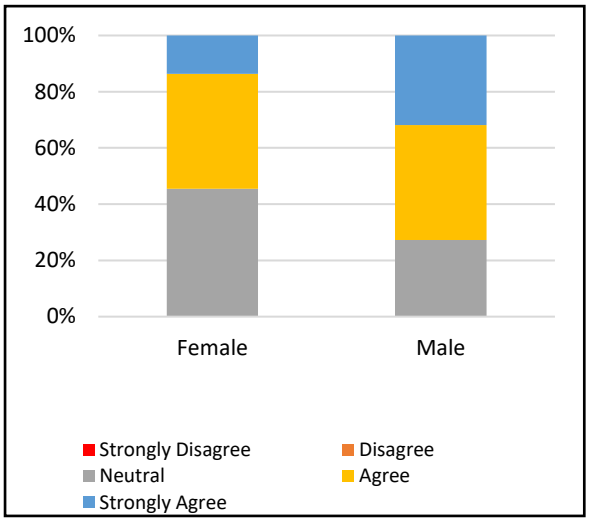


Figure 6.37-C

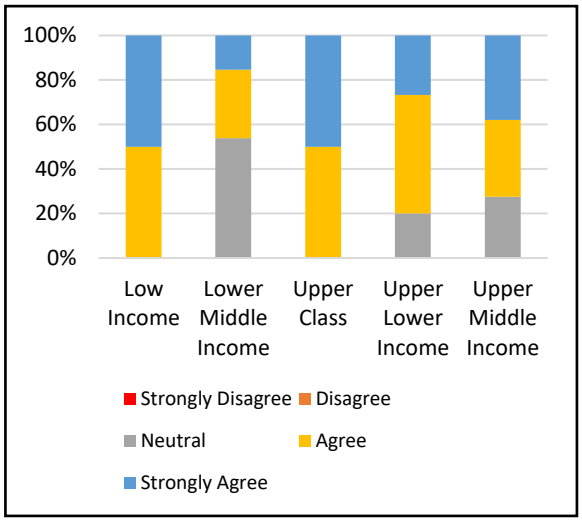


Figure 6.37-D

Figure 6.37. Perception of floating population on affinity to hygiene practices as per Holistic overview (6.37-A), age (6.37-B), gender (6.37-C) and socio-economic groups (6.37-D)

B. Awareness of WaSH Practices

- **Overall respondents' Awareness of WaSH Facilities:** The survey data of self-reported awareness of WaSH practices of the pilgrims indicate that this awareness was nearly universal among the pilgrims, with approximately 95% of the population affirming the knowledge of available services in the pre-phase of the Kumbh Mela, and a negligible percentage of pilgrims having a neutral stance, with no disagreement. This highlighted that both, a well-informed set of attendees and high efficacy of pre-event communications strategies led to a WaSH-friendly event in the pre-phase. (Figure 6.38-A).
- **Awareness of WaSH Facilities based on Age:** A pre-phase analysis of the surveyed population's self-reported awareness of WaSH facilities, segmented by age, reveals a near-universal state of high confidence across all demographics. The total lack of disagreement among every participant suggests a highly effective pre-event outreach approach, according to the data. The data thus reflects that while the surveyed population arrived feeling overwhelmingly informed, this feeling of awareness and knowledge stood differently for different age groups. (Figure 6.38-B)

- **Awareness of WaSH Facilities based on Gender:** When seen in the context of gender, a clear contrast emerges towards awareness of WaSH facilities during the Kumbh Mela pre-phase highlights that, despite near-universal awareness across both groups. With 100% affirming awareness and no neutral or negative responses, female respondents demonstrated total unanimity and a consistently high degree of confidence and certainty (Figure 6.38-C). Male respondents showed a small but significant percentage of neutral responses, suggesting residual uncertainty about their knowledge, even though they also reported relatively high awareness. These results imply that while both genders felt knowledgeable, women were more confident than men.
- **Awareness of WaSH Facilities based on Socio-Economic Group**

  The survey data shows an exceptionally high, near-universal level of awareness towards WaSH facilities across all economic strata in the pre-phase of Kumbh Mela. The most significant finding is a U-shaped confidence pattern, with respondents from both the Low Income and Upper-Class cohorts reporting 100% "Strongly Agree," indicating absolute and maximum preparedness. Thus, while the entire surveyed population felt exceptionally well-informed prior to the Mela, socioeconomic status was a key factor in modulating the uniformity and intensity of this confidence (Figure 6.38-D).

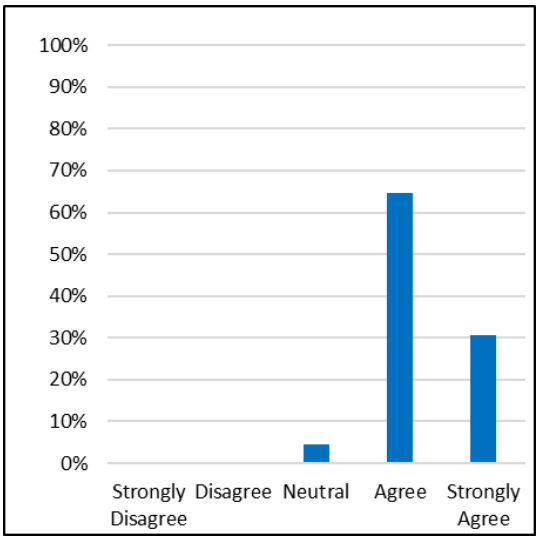


Figure 6.38-A

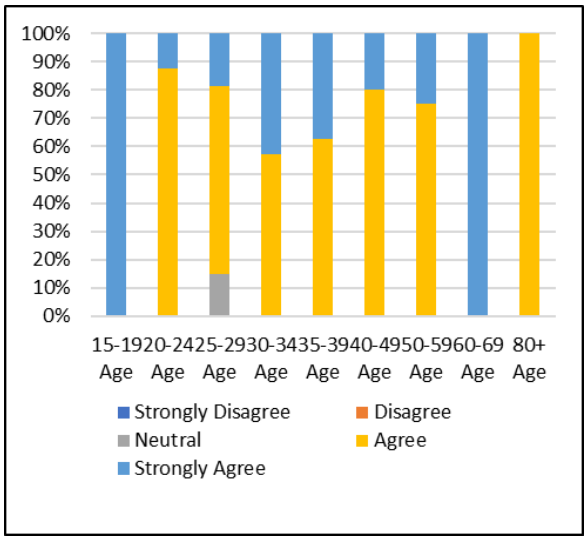


Figure 6.38-B

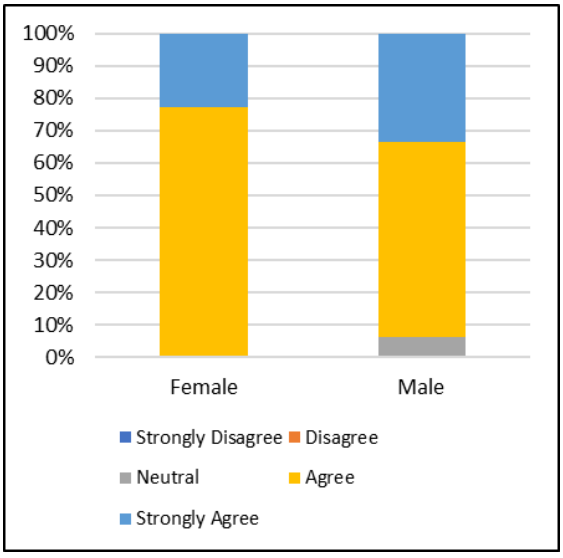


Figure 6.38-C

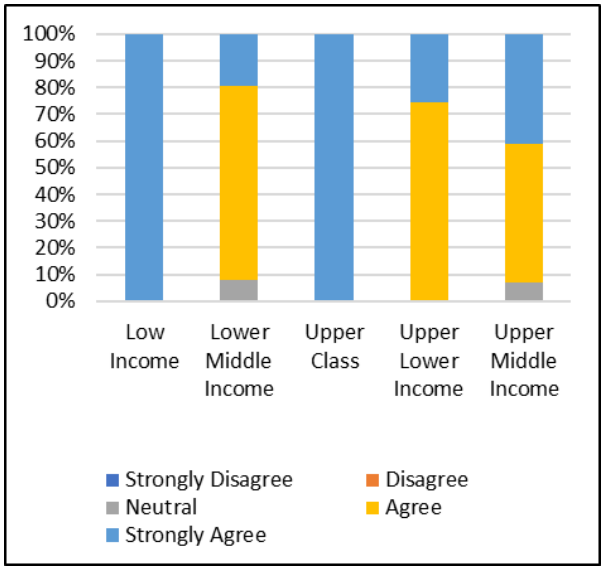


Figure 6.38-D

Figure 6.38 Perception of floating population on affinity to hygiene practices as per Holistic overview (6.37-A), age (6.37-B), gender (6.37-C) and socio-economic groups (6.37-D)

C. Satisfaction on WaSH services at Maha Kumbh Mela 2025

- **Overall Satisfaction Levels towards WaSH services:** The survey data suggests the level of satisfaction of pilgrims with WaSH services in the pre-phase of Kumbh Mela. As the results suggest, most of the respondents were completely satisfied with the services being provided, while some of the respondents held a relatively neutral view on the same. The absence of dissatisfaction suggests that the pre-preparatory efforts of the authorities for the event were largely effective both in terms of the WaSH infrastructure and the knowledge of the respective services in the Mela. (Figure 6.39-A).
- **Satisfaction Levels towards WaSH services based on Age:** The age-wise breakdown reveals a generational gap in awareness regarding WaSH services. The data suggests that the older respondents reflect a strong understanding and preparedness while the younger participants reported slightly lower satisfaction with the arrangements. Considering the preparations during Mahakumbh 2025 were far better and technologically sound than previous Kumbh, those who have a prior Kumbh experience (older generation) had relatively lower expectations, hence the higher satisfaction with the improved resources. (Figure 6.39-B).
- **Satisfaction Levels towards WaSH services based on Gender:** The survey respondents' satisfaction levels with WaSH services are displayed in this graph by

gender. With large percentages falling into the "satisfied" and "highly satisfied" categories, the patterns for male and female respondents are remarkably similar. Dissatisfaction levels are minimal for both groups, and neutral responses are present but comparatively moderate. Accordingly, the gender-wise analysis shows that satisfaction levels are consistent between the genders, indicating the effectiveness of inclusive information-dissemination tactics prior to the Mela. (Fig. 6.39-C).

- **Satisfaction Levels towards WaSH services based on Socio-Economic Group:** The socioeconomic analysis shows that during the Kumbh Mela pre-phase, satisfaction with WaSH facilities is consistently high across all income groups. The high degree of satisfaction shown by both the low-income and lower-middle-income groups indicates that grassroots campaigns and focused outreach initiatives were incredibly successful. Additionally, most people in the upper-middle income group report high levels of satisfaction, suggesting that they are well informed about WaSH services. Responses from the upper-lower-income group showed more variation, which may reflect differences in information access. This might be a reflection of this group's disparate information access. This suggests that pre-phase information distribution prior to the Kumbh Mela was fair and successful (Figure 6.39-D).

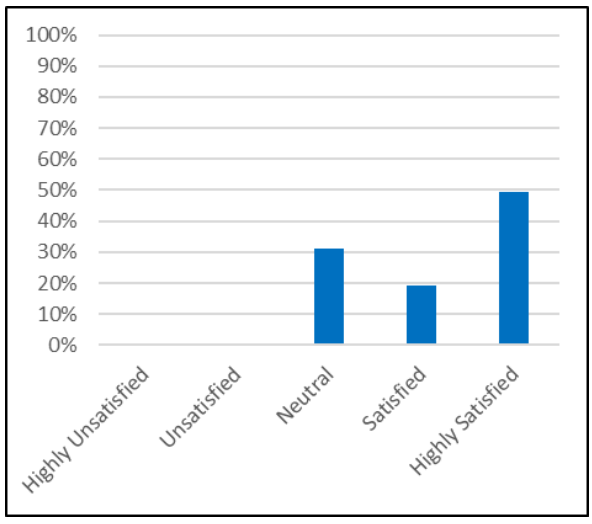


Figure 6.39-A

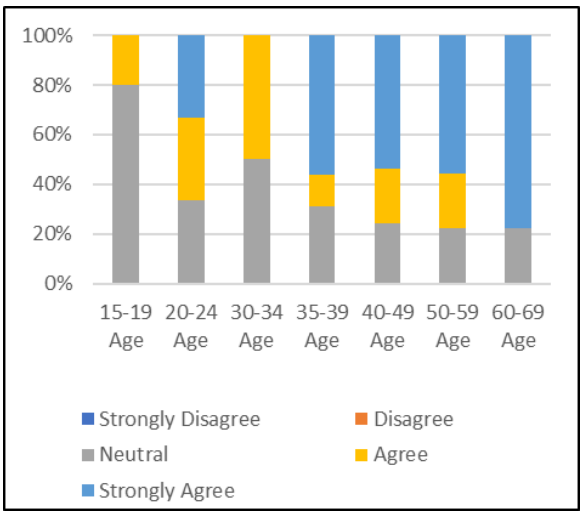


Figure 6.39-B

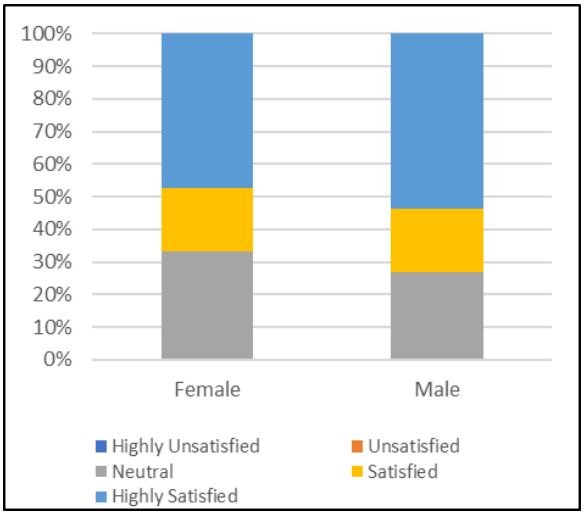


Figure 6.39-C

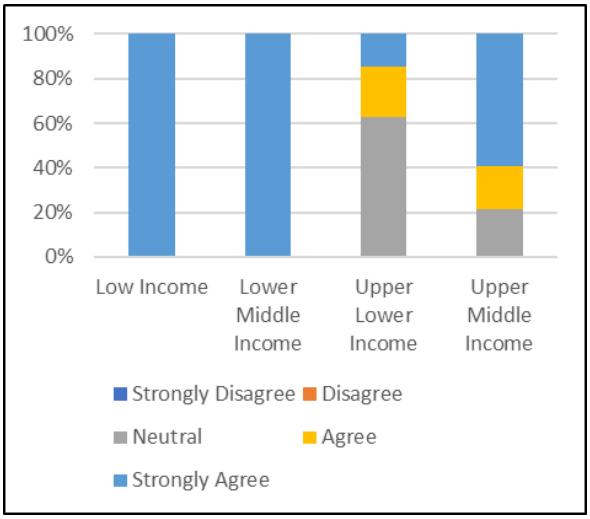


Figure 6.39-D

Figure 6 39. Perception of floating population on Satisfaction on WaSH services in the pre-phase of Kumbh Mela 2025, as per holistic overview (Figure 6.39-A), Age (Figure 6.39-B), Gender (Figure 6.39-C), socio-economic group (Figure 6.39-D)

6.4.2 *During Phase*

6.4.2.1. Improved Infrastructure & Technology

A. Service-Water Supply

- **Water: Types and number of water access points**



Figure 6. 40. A pilgrim taking water from "pi-lo" water ATM at sector 7



Figure 6.41. Water Tanker placed for water supply provision at Bakshi Bandh Road

To meet this demand, the total number of tap connections was increased from 56,000 to 1,12,151, and 233 water ATMs were strategically installed across all sectors of the Mela area (Stakeholder Discussion). Stakeholder consultations confirmed that the implementation of a protected rainwater harvesting system was not feasible due to site-specific constraints and event timelines. To ensure uninterrupted access to safe drinking water for the highly mobile

floating population, drinking water was also supplied through tanker trucks. These were stationed at transition nodes between the Kumbh Mela site and the adjoining city areas, thereby ensuring last-mile delivery and preventing potential water stress (Field observation, Figure 6.41). Apart from water ATMs provided by Prayagraj Mela Authority, other types of water ATMs were present under CSR of various organisations, such as *"Pi-lo"* as shown in Figure 6.40.

- **Types and number of water extraction systems (bore-wells, submersible pumps, etc.):** As discussed in Pre-phase.
- **Delivery of water into water access points- [piped water/tanker-truck/through vendors]:** As discussed in Pre-phase and in A3 indicator of this section.
- **Types and number of water distribution systems (tankers, distribution tanks, etc.):** Discussed in A1 and A3 indicators of this section. However, the number of water access points varied as per the hotspot identified in normal days and *'snan'* days.
- **Types and number of water treatment plants (filtration, sedimentation, disinfection units, etc.)** As discussed in the pre-Kumbh phase. The chlorination was done before the distribution through pipelines at the pumping station. The chlorination levels were also monitored daily at every pumping station and kept below 1.5 ppm. (Primary data; Stakeholder discussion)
- **Quality of water services:**

The quality parameters of water supply points- Tubewells, Standposts and Water ATM are mentioned below (Table 6.3) (Source: ICCW Report).

Table 6.3 Fluctuations in drinking water quality observed over 7-week duration of the mela.

Indices	Drinking water quality levels- Tubewells	Drinking water quality levels- Standposts	Drinking water quality levels- Water ATM
pH	7.52 – 7.72	7.45 – 7.75	7.40 – 7.80
TDS	400 – 627 mg/L (peaked 800 mg/L on Jan 24)	421 – 637 mg/L (peaked 865 mg/L on Feb 14)	390 – 601 mg/L
EC	697 – 959 µS/cm	690 – 976 µS/cm	680 – 950 µS/cm
Turbidity	0.20 – 2.27 NTU	Up to 5.5 NTU (Week 2)	0.15 – 1.2 NTU
FRC	0.09 – 1.24 ppm	0.25 – 1.1 ppm	0.1 – 0.85 ppm

Total Hardness	225 – 295 mg/L	210 – 285 mg/L	220 – 290 mg/L
Total Alkalinity	201 – 309 mg/L	205 – 320 mg/L	210 – 300 mg/L
Chloride	16.4 – 130 mg/L	20 – 140 mg/L	25 – 120 mg/L
Nitrate	≤20 mg/L	≤22 mg/L	≤20 mg/L
Fluoride	0.47 – 2.00 mg/L	Up to 1.8 mg/L (Week 6–7)	0.4 – 2.05 mg/L (Week 4 peak)
Iron	0.42 – 1.0 mg/L (Weeks 2–5)	0.35 – 0.85 mg/L	0.32 – 0.70 mg/L
Ammonia	0.1 – 0.69 mg/L (Weeks 2–7)	0.4 – 0.7 mg/L (Weeks 5–7)	0.3 – 0.6 mg/L

(Source: ICCW Report)

B. Improved Infrastructure & Technology: Sanitation in During phase

- **Types & number of toilets (latrines, urinals):** To address the sanitation needs of the unprecedented influx of pilgrims, a total of 1,50,000 toilets were installed across the Kumbh Mela 2025 site (Stakeholder Consultation; (PIB Release MahaKumbh, 2025). This large-scale deployment represented a critical component of the event's public health and WaSH management strategy, ensuring safe and equitable access to sanitation facilities. The diverse distribution of toilets in Maha Kumbh Mela 2025 is mentioned in Table 6.4. Such an extensive provision reflects proactive planning by the event authorities to maintain hygiene standards, minimize open defecation, and mitigate public health risks in high-density congregation zones.

Table 6.4 Type and number of toilets in Kumbh Mela

S. No.	Type of Toilet	Number
1	VIP toilets	1673
2	*Kanath* toilets	53760
3	FRP with Soak pit	16072
4	FRP with Septic	13212
5	Steel with Septic	11053
6	Steel with Soak pit	22382
7	Urinal with Septic tank	20000
8	Cemented Toilet 6x4	7926
9	Cemented Toilet 8x8	6373
10	Mobile Toilets	2120

(Source: Data shared by partner institution, IIT-BHU; Validated by Stakeholder consultation)

A few types of toilets are depicted in Figure 6.42, Figure 6.43, Figure 6.44, and Figure 6.45



Figure 6.42. Image depicting a typical Steel toilet



Figure 6.43. Image depicting a typical Kanth toilet



Figure 6. 44. Image depicting typical Mobile compartment toilets



Figure 6.45. Image depicting typical FRP toilets

This distribution of toilets is based on the density of population and previous experiences of Mela Authority. Based on the distribution of toilets in Kumbh Mela 2025 gathered from secondary literature, a toilet density map was visualized, as shown in Figure 6.46.

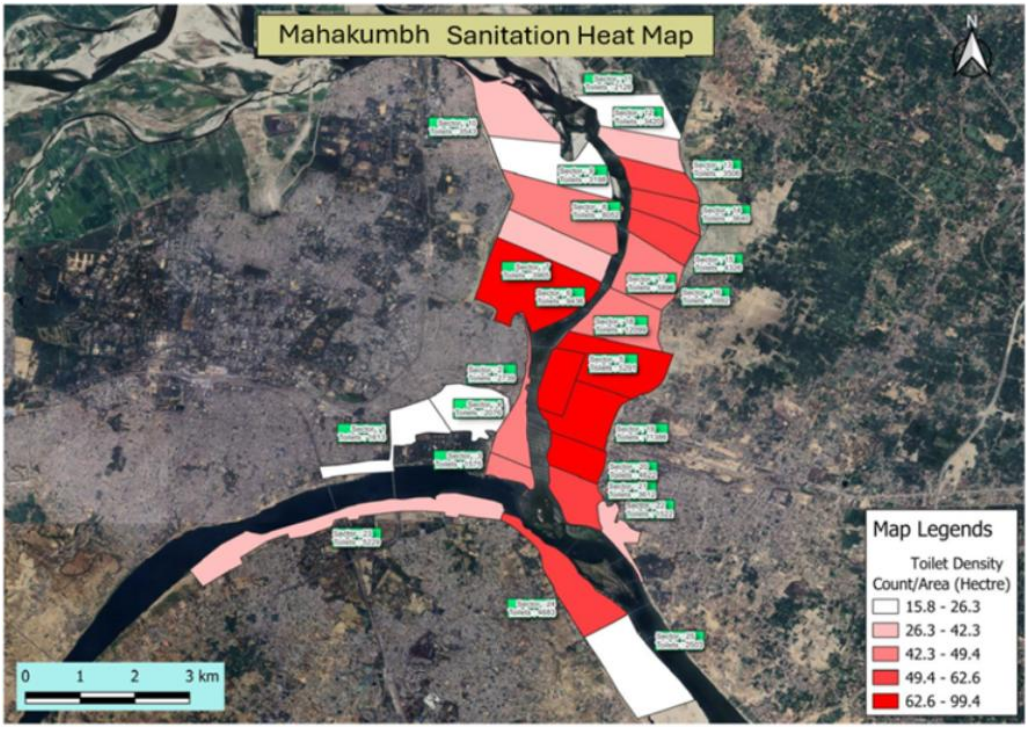


Figure 6.35. Maha Kumbh toilet density Map

- **Types and number of handwashing stations-** 6500 Standposts were under construction catering to the needs of pilgrims in the whole Kumbh catchment. However, the number of standposts varied as per the sectors. Of these, 5,000 were installed through the Dettol Swasth Banega India campaign (PIB Release).
- **Types and number of wastewater collection units:** Infrastructure provision discussed in pre-phase was provided.
- **Types and number of wastewater transportation units -** 300 suction vehicles were deployed. (Stakeholder consultation). A typical suction tanker is depicted in Figure 6.47.



Figure 6.47. Suction pump tankers making trips to clean the toilets



Figure 6.48. Stabilisation Pond in sector 22.

- **Types and number of wastewater disposal units:** 50 stabilisation ponds were constructed where bio-culturing of wastewater was done before transporting it to STPs, as shown in Figure 6.48.
- **Treatment Plants –** As discussed in the Pre-Phase.
- **Quality of toilet facilities:** In the initial phase of the Kumbh Mela 2025, the toilet infrastructure was adequate to meet the sanitation demand. However, as the event progressed and footfall intensified, the experienced strain during peak footfall periods, reflecting the high-frequency usage and the natural limits of maintenance cycles during large congregations. Additionally, establishing predictive maintenance schedules and deploying sensor-based usage tracking could prevent quality lapses and ensure compliance with safely managed sanitation standards.
- **Percentage of handwashing station with soap and continuous supply of water:** For every 10 toilets a dedicated tap water and handwashing soap were placed. There was availability of water near sanitation facilities catering to the needs of floating population in Kumbh Mela 2025 as shown in Figure 6.49 and Figure 6.50.
- **Solid waste collection units:** The following waste collection facilities and vehicles were installed during the Kumbh phase and validated by a consultant working in the sanitation department under the Prayagraj Mela Authority, as shown in Table 6.5. A tipper is depicted in Figure 6.51.



Figure 6.49. Proximity of the urinal and the tap in Sector 18



Figure 6.50. Toilet with screening and handwashing facilities

Table 6.5. Items deployed, and their quantity used for waste management

S. No.	Items deployed for waste management	Quantity
1.	Dustbins	20,000 (at every 50- 100m distance)
2.	Compactors	40 (1-2/ sector)
3.	Tippers	145 (5-6/sector)
4.	Liner Bags	3.7 million liner bags (changed thrice a day)
5.	Suction Machines	90 (Prayagraj Mela Authority owned)



Figure 6.51. Tipper making trips for waste collection

A. Service-Hygiene

- **Quality of handwashing stations (safely managed/basic/limited/unimproved) % of stations with soap and continuous water-** The quality and quantity of **handwashing stations** varied significantly across sectors. These variations can be attributed to the diverse hotspots and the presence of varied socio-economic groups with differing needs

and consumption patterns of WaSH facilities across various sectors of mela. (Observation, Figure 6.52, Figure 6.53)



Figure 6.52. Presence of handwashing taps in toilet facility at sector 19, Kumbh Mela



Figure 6.53. Availability of soaps and water in the toilet by Lallooji and sons in sector 23

- **Quality of bathing facilities:** Bathing stations inside tented accommodation were well maintained (Observation). The quality of the Changing rooms at the ghat deteriorated as the Mela progressed due to their heavy use. Some pilgrims reported misuse of changing rooms, which underscores the need for additional behavioural guidance and monitoring (Stakeholder consultation on site).
- **Power and backup systems-** As discussed in Pre-Phase.
- **Access roads for waste transport-** As discussed in Pre-Phase.
- **Language signage:** Colour coding of Toilets for easy identification based on gender was implemented as shown in Figure 6.54. On-site discussions with pilgrims revealed that the number of signage was insufficient, leading to limited awareness about the availability and location of WaSH facilities. However, signage showcasing gender-based segregation of toilets was present.



Figure 6.54. Signages highlighting female toilets in sector 22

6.4.2.2 State of Equitable Access

A. Service-Water Supply

- **Availability of water in Kumbh Mela** (Source: Stakeholder Consultation and Observation)
  - **Stakeholder Consultation:** Survey findings indicate a high level of public satisfaction with water supply arrangements during Kumbh Mela 2025, despite the unprecedented attendance of nearly 600 million people. Respondents reported high satisfaction with water supply services, appreciating uninterrupted supply, strategically located water ATMs and clear signages. These perceptions reflect effective pre-event planning and infrastructure deployment regarding water supply services, ensuring equitable access to safe water during mass gatherings. *"I've been coming for Kumbh from 2001, so compared to 2001, 2025 is like another world so therefore I would say that the overall efficiency and the effectiveness of especially Water-Sanitation, everything has grown at least 20X times, so I'm personally very delighted"* – Shri Gaurang Das Prabhu ji (A religious and spiritual leader)



Figure 6.55. People drinking water from water ATM at sector 19, Kumbh Mela 2025



Figure 6.56. Water access point with signage at sector 20, Kumbh Mela 2025

- **Percentage of floating population collecting water from improved sources for drinking purposes:** Stakeholder consultations and field observations confirmed universal access (100%) to improved, treated drinking water sources for the floating population during the pre-phase of Kumbh Mela 2025. This reflects the successful implementation of planned water infrastructure and distribution mechanisms, ensuring equitable service delivery to all attendees. Additionally on-site stakeholder consultations underscored perception of the pilgrims regarding surface water as unsuitable for drinking purposes. This perception assisted in higher compliance towards the use of treated water for drinking purposes.

- **Proximity to the nearest water access point**
  - **Distance:** During the Kumbh Mela, 63% of the population reported accessing water within 100-200 m, while 37% within 500 m. However, some of the attendees experienced minor navigation challenges, suggesting that additional signage or orientation aids could further enhance user convenience and navigation aids, leading to extensive walking (ICCW Report 2025).
  - **Accessibility:** During Kumbh Mela, 78.5% of the population reported 'Easy' access and availability of water, while 21.5% found it was 'Manageable.' No surveyed stakeholder reported difficulty in finding improved water sources. **Secondary Literature** (ICCW Report 2025)
- **Percentage of access from various water facility types such as water ATMs, standposts and bottled water:** During the Kumbh Mela, 40% of the population accessed water by standposts, 47.7% accessed using Water ATMs, and 12.3% managed using bottled water. **Secondary Literature (ICCW Report 2025)**

- **Water facility functionality and non-functionality (percentage of people reporting functional water ATMs**): During the Kumbh Mela, 89.2% of the population reported always having access to functional water ATMs, and 10.8% reported access to water ATMs sometimes. **Secondary Literature (ICCW Report 2025)**
- **Percentage of the floating population reported on water sufficiency and waiting time**
  - **Sufficiency:** During the Kumbh Mela, 93.84% of the population reported having always sufficient water during their stay at the Mela Site, and only 6.15% found it was sufficient sometimes. **Secondary Literature** (ICCW Report 2025)
  - **Waiting Time:** At the same time, 75.38% reported no waiting time to access water, while 24.62% reported waiting time under 5 minutes. No person reported waiting time for over 5 minutes. **Secondary Literature** (ICCW Report 2025)

B. Service-Sanitation

- **Percentage of the floating population reported on the accessibility of sanitation facilities**

The findings suggest that while sanitation infrastructure during the Kumbh Mela was largely adequate, with most respondents reporting easy access, gaps persist in user experience. The 27% neutral responses and 10% reporting difficulty indicate that, despite sufficient facilities, a portion of respondents indicated that enhanced visibility, clearer signage and user guidance could further optimize access. Overall, the focus now needs to shift from quantity to improving qualitative aspects of accessibility for more inclusive and efficient service delivery. (Survey, Figure 6.57). Most toilets functioned through shared tap connections serving 10 cubicles, which is a common arrangement for large events and generally met user requirements, though individual taps were not part of the design.

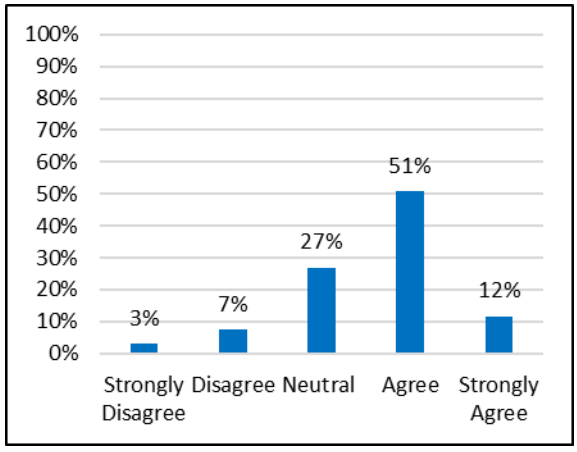


Figure 6.57. Perception of floating population on the accessibility of sanitation facilities

C. Field Observations

- **Percentage of floating population reported on availability of sanitation facilities: Secondary Literature** (ICCW Report 2025): During the Kumbh Mela, 87.7% of the surveyed population expressed they always had access to sanitation facilities, 10.8% said sometimes, and only 1.53% said they rarely had availability of sanitation facilities.

Our observations and data from PMA indicate that the service capacity of sanitation facilities was estimated at at 40 persons per hour per toilet; however, this fluctuated during main snan due to an unprecedented influx of population.

D. Service-Hygiene

- **Availability and proximity to handwashing stations.** Our observations indicate that handwashing stations were available, especially near toilets and urinals. There were at least 2 handwashing stations per 10 toilet facilities.
- **Percentage of floating population reported using handwashing stations after communal toilets:** No empirical data was recorded for this parameter during the study period.
- **The percentage of the floating population reported as disposing of solid waste appropriately.** The survey responses indicated a high level of positive waste disposal behaviour among the floating population in the 'During Phase' of Kumbh Mela, with 86% agreeing on proper solid waste disposal. The small proportion of neutral (12%) and disagreeing (2%) responses indicates opportunities for further strengthening behavioural awareness among certain groups.
- **Percentage of population drinking water from surface sources (river water)**
- Field observation and stakeholder consultation indicated that no pilgrims were drinking water from surface sources, i.e. from the rivers.
- **Percentage of population showing affinity for Hygiene Practices:** No empirical data was recorded for this parameter during the study period.
- **Percentage of population reporting on health-related concerns**
- According to the survey responses, 98.46% of the surveyed population did not report any health issues, and only 1.44% reported minor discomfort due to long walking distances to Kumbh Mela

6.4.2.3 State of Operation, Management and Risk Aversion

A. Service-Water supply

- **Hygiene (safely managed) of water facilities**
- **Safe operation and management of water infrastructure such as water ATMs, Water tankers and standposts.:**

The organisational structure for the operations and maintenance of the water supply system during the Maha Kumbh Mela 2025 is illustrated in Figure 6.58. It delineates a clear hierarchical framework established to ensure effective planning, implementation, and oversight of water supply services throughout the event. The operational hierarchy begins with frontline personnel such as, plant machine operators, technicians, and plumbers, who report directly to the next hierarchical level comprising of Junior Engineer, who further reports to the Assistant Engineer, with the Executive Engineer at the apex of the hierarchy. This tiered organisational structure facilitates efficient communication, accountability, and coordination across all levels, thereby supporting the delivery of reliable and sustainable water services during the large-scale event.

For instance, a machine operator is deployed with every Water ATM to monitor the infrastructure. Moreover, each activation of water ATMs dispensed a fixed quantity of 1L of water to measure equitable distribution and reduce wastage. Along with this, a complaint redressal mechanism regarding water availability was deployed through QR codes attached to every Water ATM. (Source: Secondary Literature)

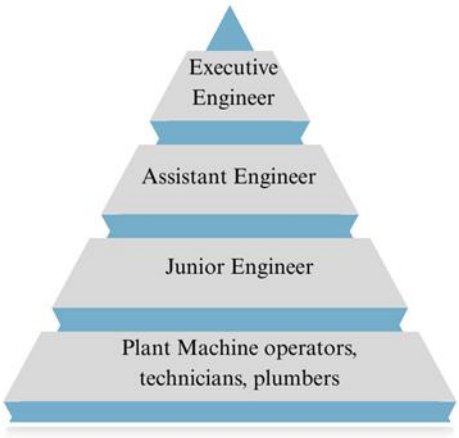


Figure 6.58. Hierarchical Framework for Water Supply Services

- **Satisfaction with planning and mapping for easy access to water services:** Deployment of water tankers at high-demand zones was managed during the Mela. Moreover, on days with increased population influx (Main *Snan* Days), **when** the demand for water increased, backup water sources (such as tubewells and water tankers) were in place to cater to the pilgrims' needs. Furthermore, the surveyed population of infra and service providers was mostly in strong agreement with the adequacy and timely planning of water facilities, in consideration of socio-cultural needs. A total of 90% of the infrastructure and service providers surveyed in the 'During Phase' agreed to the timely planning and adequacy of water facilities, also reflecting that the services were better than their expectations in the Pre-Phase.
- **Frequency of regular checks of water quality:** Water Testing was being conducted by equipping Smart Field-Testing Kits (SFTKs) with digital pH, TDS and chlorine sensors through a third-party organisation to monitor water quality of tap water and water ATMs, and the data gathered is mapped in a web-based application, accessible through the public domain.
- **Continuity of WaSH Services:** Services should be consistent and reliable for water facilities
- **Operational Capacity of Water infrastructure, such as water ATMs, Water tankers and standposts**: Consultations with the stakeholders suggested that ATMs were dispensing **12,000–15,000 litres** of RO water daily, **which was sufficient** to meet the needs of the population. Moreover, on *Snan* days, with an increased population, the additional and backup water sources (Tubewells) were also utilised to cater to the water needs. All Water ATMs were equipped with SIM-based technology, keeping them connected to the administration's central network, thus enabling continuous monitoring of total water consumption, water level management, water quality, and distribution volume, which helped the administration with qualitative and quantitative water needs.
- **Reasons for Non-operational Capacity of Water Sources and Access Points:**

According to the field observation and stakeholder consultations, there were no issues reported with the quantity and quality of water access points in any phase. Moreover, the survey data verified this opinion by demonstrating high confidence and satisfaction among infrastructure and service providers (87%) regarding the reliability and resilience of water services, thus suggesting that preparedness measures such as backup power and rapid repair protocols were effectively planned and implemented, minimising risks of service interruptions.

B. Service: Hygiene

- **Maintenance of a hygienic environment:** The organisational structure gathered from stakeholder consultation for sanitation operations during Maha Kumbh Mela 2025 follows a clearly tiered hierarchy to ensure effective implementation and oversight (See Figure 6.59). At the base are sanitation workers, reporting to 'mates', who are supervised by Ganga sevadoots/supervisors. These, in turn, report to circle in charge, with overall coordination led by sector medical officer. This structured chain of supervision enabled clear accountability, streamlined communication and efficient service delivery throughout the event. A systematic hygiene protocol was followed to maintain hygienic environment as depicted in Figure 6.60 and Figure 6.61.

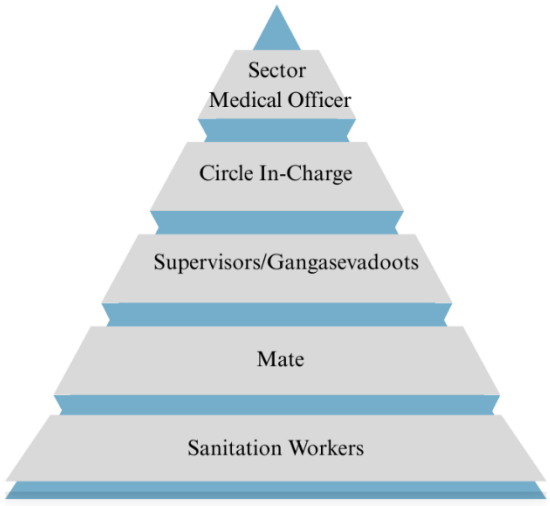


Figure 6.59. Hierarichal Framework for Sanitation Services



Figure 6.60. Sprinkling of malathion and bleaching powder to mitigate bad odour and to minimise further vector disease risks in Sector 19 of Kumbh Mela



Figure 6.36. A sanitation worker cleaning water spillage beneath water ATM.

- **Health Risk from River Water**: Survey responses indicate that a majority (54%) of Local Population perceive the condition of the river Ganges during the Kumbh Mela as significantly impacting public health, particularly through diseases such as cholera, diarrhea, and typhoid. In contrast, 29% disagreed with this view. Overall, the results highlight widespread recognition of the association of health risks with river pollution during the festival, though perceptions are not entirely uniform across respondents. (Figure-6.62).

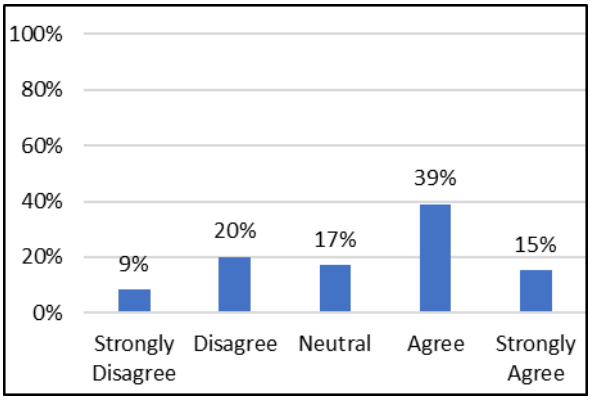


Figure 6.62. Percentage of population perceiving water quality of river impacting public health

However, as per the comprehensive report prepared by CPCB, the median value of pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Faecal Coliform (FC) for

all the monitored locations was found within the respective criteria/permissible limits for Primary Bathing Water Quality Criteria. (twice a week) from 12th January to 20th Feb. Under the NMCG mission, continuous sampling and lab testing of Sangam waters were conducted, with alerts issued on coliform/BOD levels increase. Stakeholders perceived that usable water quality reduced substantially compared to pre-Mela conditions. They also observed a shift in appearance from clear to greenish or darker tones, suggesting possible stress on water quality during peak periods.

- **Promotion of WaSH Awareness**
- **Collaboration and partnership among institutional stakeholders to provide WaSH services:**

"*Dettol Banega Swasth India"* was a Hygiene Promotion Campaign organized during the Kumbh Mela, a collaboration between Reckitt (Dettol), Global Interfaith WaSH Alliance (GIWA) as shown in Figure 6.63, AJ Foundation, Plan India, Jagran Pehel, and support from the UP government. It included distribution of Handwashing Kits, Street Plays and training Sessions, across 25 sectors.



Figure 6.63. Nukkad Natak at sector 5 by GIWA and Dettol to create awareness regarding handwashing.

An NGO Led initiative by *"Mangal Bhumi Foundation"* was led to raise awareness about water conservation and Ganga water purity. "*One Plate, One Bag*" Initiative *Rashtriya Swayamsevak Sangh (RSS)* and supported by vendors, was an initiative to reduce plastic consumption. It included the distribution of over 70,000 cloth bags to pilgrims and food

vendors and the collection and distribution of 2 million steel plates and glasses to replace disposable utensils.

C. Service: Sanitation

- **Hygiene (safely managed) of Sanitation Facilities**
- **Safe operation and management of sanitation services**

Safe operations and maintenance of sanitation services were being managed by authorities such as authorities Sub Divisional Magistrate and the Sector Medical Officer. As suggested by stakeholders, an ICT-based monitoring system was implemented, enabling third-party inspections through digital software to enhance transparency and accountability.

Survey results displayed 68% of respondents viewed sanitation facilities as adequate while 31% were neutral. No negative responses were recorded, indicating broad satisfaction and the presence of safe, functional sanitation infrastructure during the Kumbh Mela.

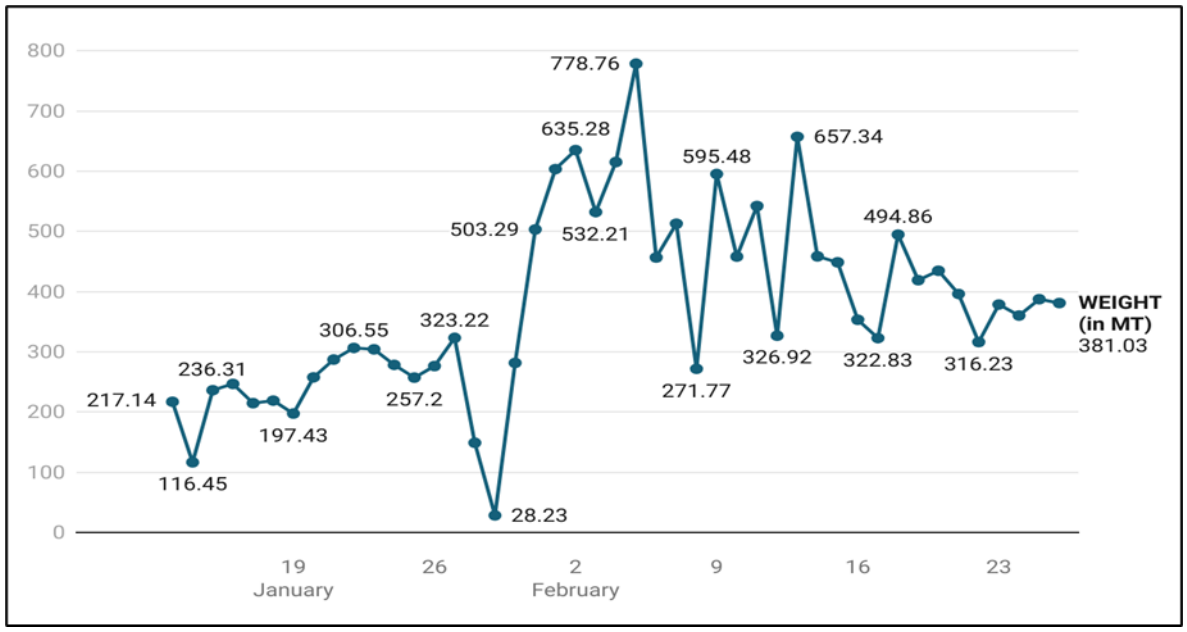


Figure 6.64. Timeline Graph of Daily Waste Collection

Figure 6.64 shows daily waste collection during Maha Kumbh Mela 2025 measured in metric tonnes. January witnessed moderate levels with a dip to 28.23 MT followed by a sharp rise peaking to 778.76 MT in early February, aligning with peak pilgrimage days. February maintained higher volumes, reflecting the waste management system's responsiveness to crowd dynamics.

Frontline workers cleaning toilets, suction tankers, cleaned and maintained toilets/urinals, waste disposal sites as shown in Figure 6.65, Figure 6.66, Figure 6.67 and Figure 6.68.



Figure 6.65. Sanitation workers working to clean Ganga River



Figure 6.66. Cleaning of toilets by frontline workers



Figure 6.67 Satisfaction workers sweeping in sector 15 and sector 16



Figure 6.68. Sanitation workers transporting solid waste to transfer stations through handicrafts

- **Actionable cleaning protocols to maintain a hygienic and safe environment:** The survey findings demonstrate strong confidence of infrastructure and service providers in the hygienic management of drinking water storage, with 78% of respondents agreeing or strongly agreeing that tanks are cleaned daily. A smaller share expressed disagreement (14%) or remained neutral (10%), suggesting limited but present scepticism. (Survey Data, Figure 6.69)

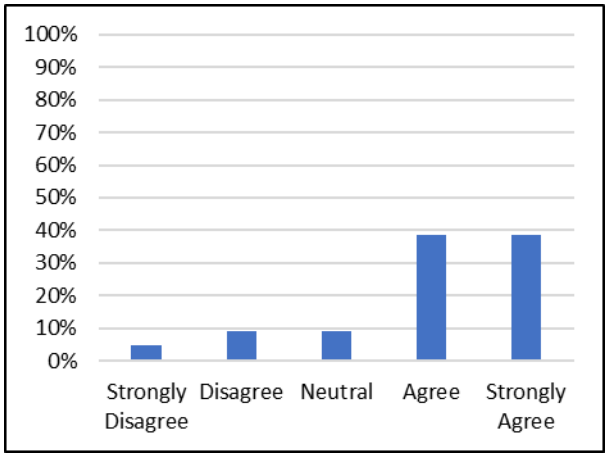


Figure 6.69. Perception of service providers on maintaining protocols during Maha Kumbh Mela 2025

6.4.2.4 Psychosocial

A. Affinity for Hygiene Practices

- **Over all respondents' Affinity to Hygiene Practices:** The survey data shows a largely positive perception of hygiene practices among the floating population in the during phase of the Kumbh Mela. A clear majority, 68%, reported that they "often" engage in hygiene practices, while another 18% indicated they follow such practices "every time." This reflects a strong overall commitment to maintaining cleanliness during the event. Conversely the responses to neglect were negligible, showing minimal disregard for hygiene. Overall, this indicates that most participants are mindful of hygiene, demonstrating the effectiveness of hygiene awareness initiatives and infrastructure provided during the Kumbh Mela. (Figure 6.70-A)

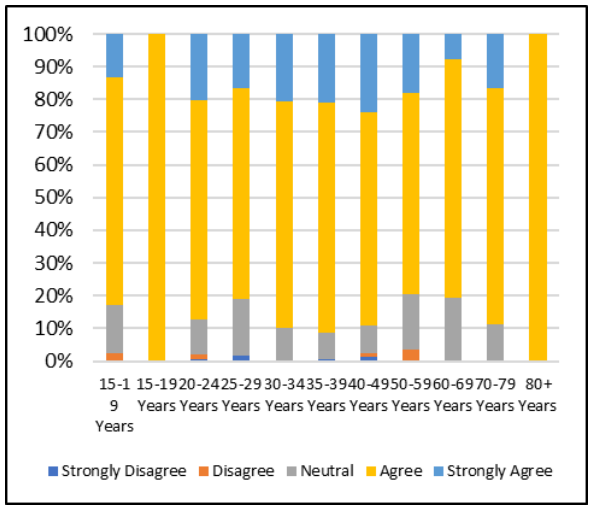


Figure: 6.70-A

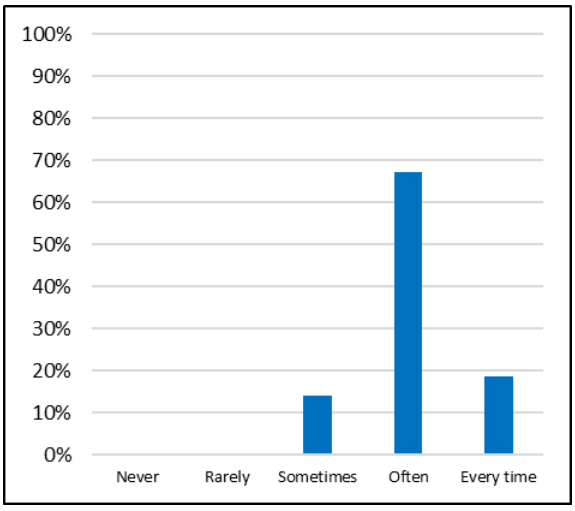


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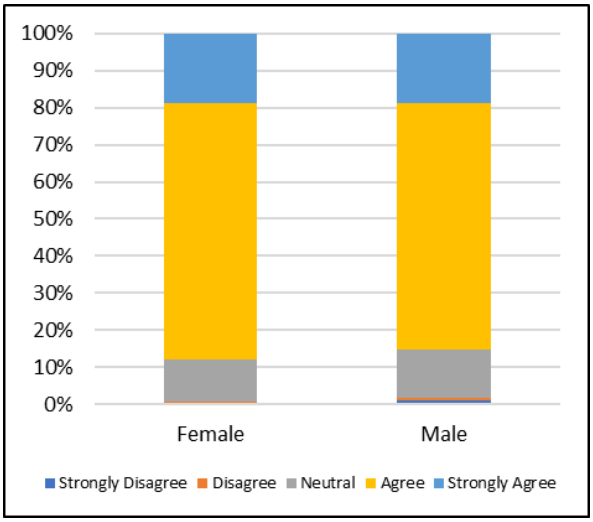


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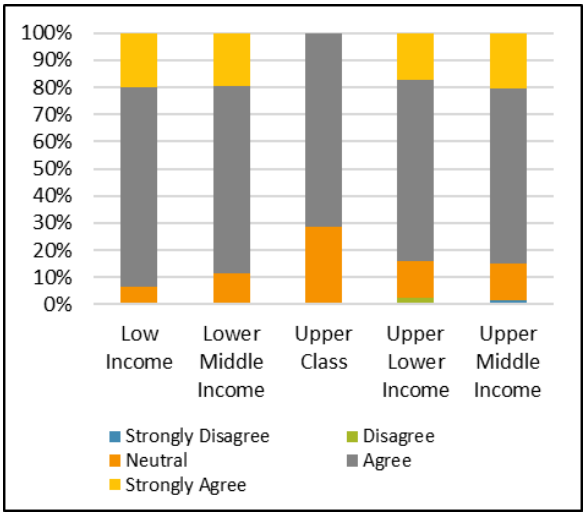


Figure: 6.70-D

Figure 6.70. Perception of floating population on their affinity towards hygiene practices of in the during phase of Kumbh Mela 2025, as per holistic overview (6.70-A), age (6.70-B), gender (6.70-C). Socioeconomic group (6.70-D)

- **Affinity for Hygiene practices based on Age**

The survey data of floating population's perception of hygiene practices during the Kumbh Mela reveals a strong, cross-generational consensus on its importance, however, its intensity and certainty vary with age. Younger attendees, particularly those aged 20-24 and 35-39, exhibit the strongest conviction, with a large proportion selecting "Strongly Agree." On the contrary, the eldest cohort (80+ Years) shows overwhelming agreement but with minimal "Strongly Agree" responses, suggesting a more moderate or traditional affirmation of hygiene (Figure 6.70-B).

- **Affinity for Hygiene practices based on Gender**

Survey data shows a strong, gender-neutral consensus on hygiene practices, with almost 90% of both male and female respondents expressing positive perceptions. Neutral views were minimal, and disagreements were negligible, displaying shared behavioural norms across genders as shown in Figure 6.70-C.

- **Affinity for Hygiene practices based on socio-economic Group**

Survey data shows strong hygiene affinity across all income groups, with ‘agree’ responses prevailing. The upper-class respondents showed the highest agreement, while minor neutrality and negligible disagreement were observed in lower strata, underscoring a broad consensus with slight variation in intensity as illustrated in Figure 6.70-D.

B. Awareness of WaSH Practices

- **Overall respondent's Awareness of WASH practices**

During the Kumbh Mela 2025, 94% of respondents affirmed strong WASH awareness, sustaining pre-phase knowledge with increased conviction. Disagreement was negligible, indicating successful integration of infrastructure with public understanding as shown in Figure 6.71-A.

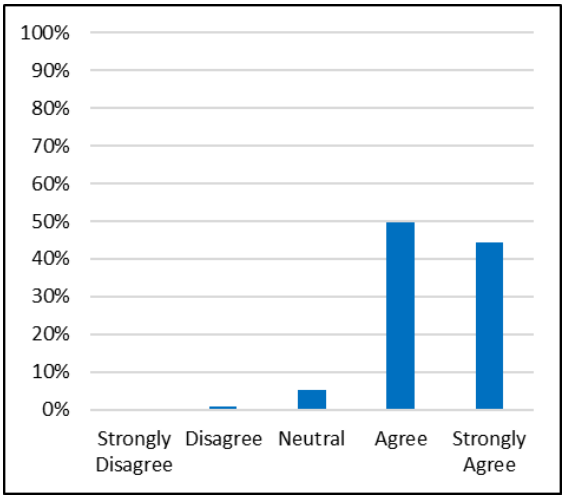


Figure: 6.71-A

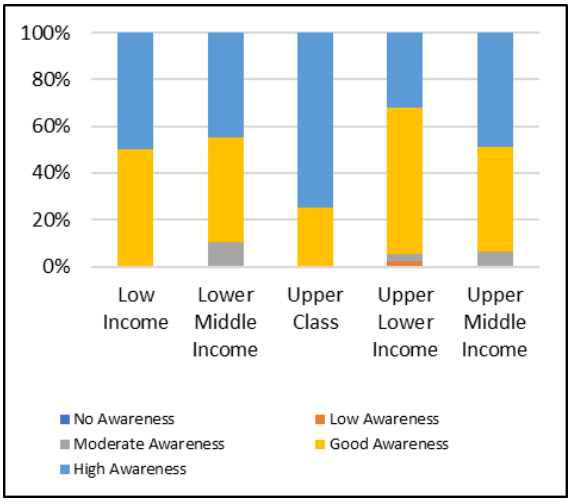


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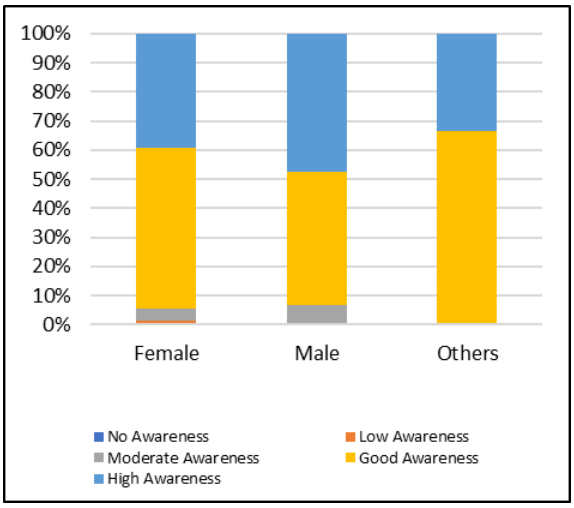


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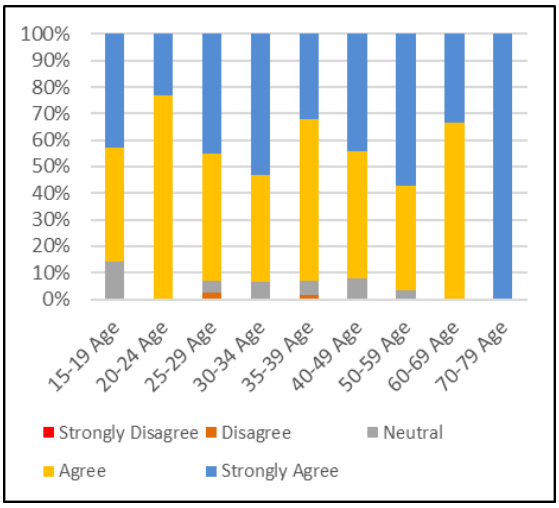


Figure: 6.71-D

Figure 6.71. Perception of floating Population on the Awareness of WaSH practices of floating population in the during phase of Kumbh mela 2025, holistic overview, (Figure: 6.71-A) age (Figure: 6.71-B), gender(Figure 6.71-C), socioeconomic group, (Figure: 6.71-D).

- **Awareness of WASH practices based on Age**

During the Kumbh Mela, self- reported WASH awareness transitioned from pre-phase confidence to practical affirmation with 100% 'High awareness' among seniors (60-79),

validating their expectations. Younger cohorts also showed strong awareness, though slightly tempered by event complexities. Overall, the data confirms the effectiveness of WASH infrastructure across age groups as illustrated in Figure 6.71-B.

- **Awareness of WASH practices based on Gender**

During the Mela, self-reported WASH awareness remained exceptionally high across all gender groups- Female (95%), male (93%) and, others (100%) with only slight moderation from pre-phase confidence as shown in Figure 6.71-C.

- **Awareness of WASH practices based on Socio-Economic Group**

The survey results illustrate the self-reported awareness of WaSH facilities and services among the surveyed population, segmented by socioeconomic categories, in the during phase of the Mela. The data indicates that while overall awareness remained exceptionally high, the practical, on-the-ground experience of the event significantly transformed the patterns of confidence observed in the pre-phase. The distinct U-shaped pattern of confidence seen in the pre-phase has completely dissolved. The lived experience of the Mela has moderated these extremes and introduced a more nuanced distribution of awareness across all socioeconomic strata. The most dramatic shift occurred among the Upper-Class respondents, whose 100% pre-event confidence was significantly moderated, resulting in the largest "Moderate Awareness" segment (approx. 25%) of any group. In contrast, other cohorts like the Low-Income group maintained 100% positive awareness, while Middle-Income groups sustained their already high levels of confidence. The data suggests that the lived experience of the Mela refined initial expectations, while still affirming an exceptionally high level of practical awareness across all socioeconomic strata. This points to a highly effective and accessible WaSH system in operation (Figure 6.71-D).

- **Satisfaction on WaSH services at Maha Kumbh Mela 2025**
  - **Overall Satisfaction Levels towards WaSH services**

An analysis of the surveyed population's overall satisfaction with WaSH services during the Kumbh Mela reveals a predominantly positive response, a notable minority of respondents were left dissatisfied. A large majority, approximately 82%, reported being satisfied with the WaSH services, this points to a high-quality service delivery that met or exceeded the expectations of most of the population. However, a combined 13% of respondents reported being "Unsatisfied" or "Highly Unsatisfied," with another 8% remaining "Neutral. "This suggests that while the WaSH initiative was broadly successful, there were inconsistencies in

the user experience that led to a segment of the population having their needs or expectations unmet (Figure 6.72-A).

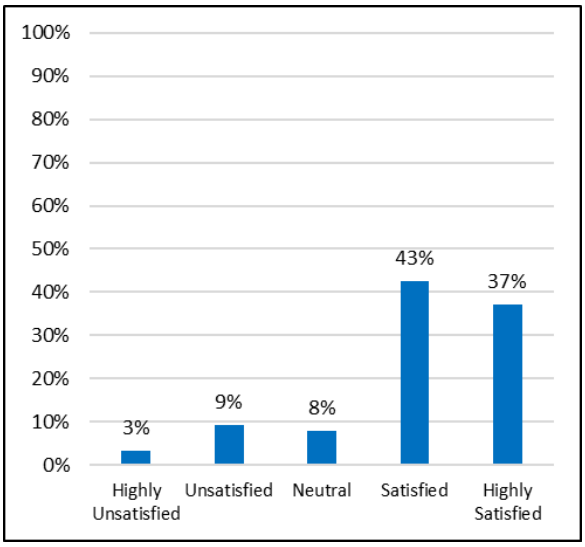


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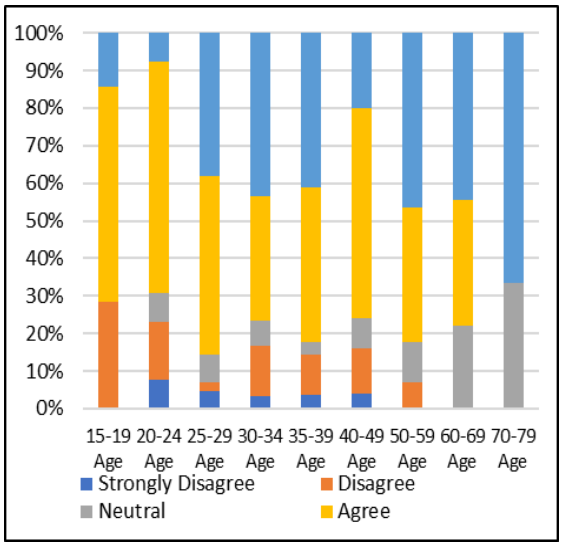


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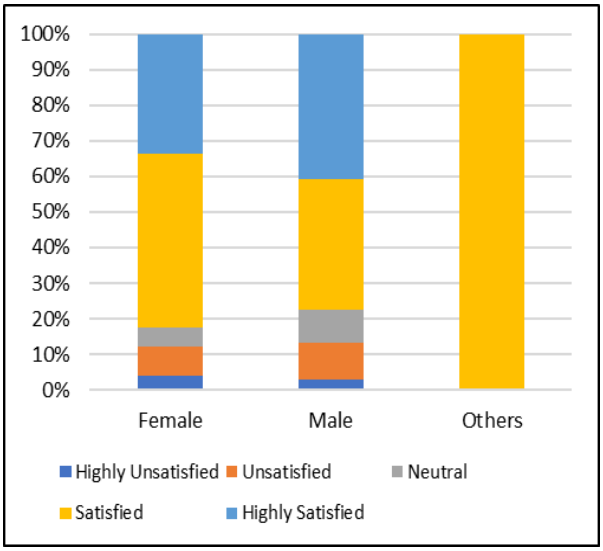


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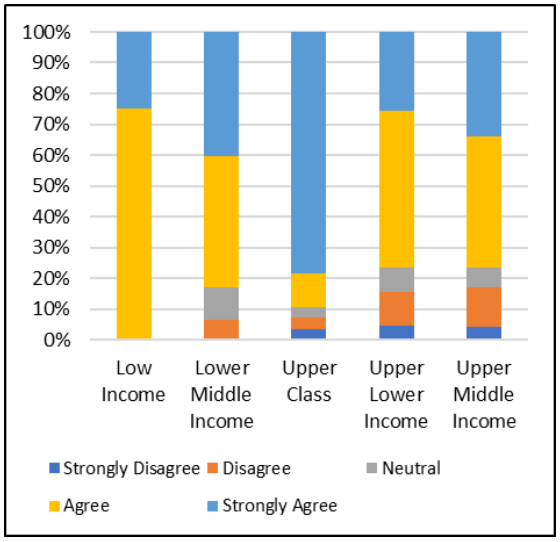


Figure:6.72-D

Figure 6.37. Perception of floating population on Satisfaction on WaSH services in the during phase of Kumbh mela 2025, as per holistic overview (Figure 6.72-A), age (Figure 6.72-B), gender (Figure 6.72-C) and socioeconomic group (Figure 6.72-D)

- **Satisfaction Levels towards WaSH services based on Age**

During the Mela, middle-aged respondents (30-59) reported highest satisfaction, while youth (15-19) showed notable dissatisfaction and seniors (70-79) expressed neutrality. These patterns

suggest services were best aligned with the needs of middle-aged respondents, with gaps in accessibilities and expectations affecting the youngest and the oldest cohorts (Figure 6.72-B).

- **Satisfaction Levels towards WaSH services based on Gender**

Analysis of WASH service satisfaction during the Kumbh Mela shows almost equal responses from male and female cohorts, with almost 88% expressing satisfaction and 12% dissatisfaction. The 'other' gender category reported 100% satisfaction, indicating universally strong and positive perception among gender diverse responses (Figure 6.72-C).

- **Satisfaction Levels towards WaSH services based on Socio-Economic Group**

Analysis of satisfaction of WASH services by socio economic status shows highest satisfaction among low income and upper-class cohorts. Upper Lower and Upper middle-income groups showed the most dissatisfaction, indicating that service effectiveness was perceived most positively at economic extremes while middle income expectations were less fully met (Figure 6.72-D).

6.4.3 Post Phase

6.4.3.1 Infrastructure and Technology

A. **Water: Types and number of water access points-** Field observation suggested that dismantling of temporary facilities was ongoing in the Post phase. However, water access points were retained in the Sangam area and Sectors 3 and 4.

B. **Types and number of water extraction systems (bore-wells, submersible pumps, etc.):** The water extraction units are the only permanent infrastructure that is retained in the floodplain area. The tubewells were sealed and packed, safeguarding them from river water in the monsoon season, as they are located in the floodplain area. These tubewells are used in every mela (Magh Mela, Ardh Kumbh Mela, Kumbh Mela) as required. Additionally, while sealing these tubewells are flagged by raising a vertical iron rod at the top for their location identification (Stakeholder consultation).

C. **Delivery of water into water access points (piped water/tanker-truck/through vendors)-** Dismantling of temporary facilities was ongoing in the Post-Phase (Figure 6.73). However, water access points were retained in operational areas such as the Sangam area and Sectors 3 and 4.



Figure 6.73. Dismantling of pipeline in sector 20 in the post phase

D. **Types and number of water distribution systems:** As discussed in Pre-Phase.
E. **Types and number of water treatment plants -** As discussed in Pre-phase.
F. **Quality of water services:** Chlorination was done in the pumping stations of operational areas only (Observation).

6.4.3.2 Improved Infrastructure & Technology: Sanitation in the Post-Phase

A. **Types & number of toilets (latrines, urinals)-** Dismantling of temporary facilities was ongoing in the post-phase, as shown in Figure 6.74 and Figure 6.75. However, toilet and urinal units were retained in the operational areas in the post-Kumbh phase.



Figure 6.74. Accumulation of shelters of toilets (inventories) of AP Enterprises sector 19, including Kanaat Toilets and steel toilets



Figure 6.75. Dismantling temporary toilets in Sector 23.

A. **Types and number of handwashing stations-** - Standposts were operational in limited areas.

B. **Types and number of wastewater collection units-** Dismantling of temporary facilities not in use was ongoing in Post phase as shown in Figure 6.76 and Figure 6.77.



Figure 6.38. Septic Tanks excavation from beneath the ground in sector 20



Figure 6.77. Manager from Bhutani International is supervising as per guidelines to restore the ecosystem after septic tanks excavation

C. **Types and number of wastewater transportation units-** Dismantling of temporary facilities was ongoing in Post phase and vehicles were operational to clean the floodplains as per directed by Prayagraj Mela Authority (Figure 6.78).



Figure 6.78. Suction vehicles making trips at sector 20 to clean Kumbh Mela area in post phase

D. **Types and number of wastewater disposal units-** Dismantling of temporary facilities was ongoing in Post phase.

E. **Treatment Plants:** As discussed in Pre-phase.

F. **Quality of toilet facilities:** No data for dismantling of temporary facilities was ongoing in Post phase as shown in Figure 6.79.



Figure 6.39. Demolition of temporary toilet facilities is ongoing in (A)

G. **Percentage of handwashing stations with soap and continuous supply of water:** No data as dismantling of temporary facilities was ongoing in Post phase (Observation).

H. **Solid waste collection units:** As dismantling of temporary facilities was ongoing in Post phase, solid waste collection units were gradually consolidated to operational areas as part of the planned dismantling process. Bigger vehicles were deployed to transport the waste (Observation).

I. **Quality of handwashing stations, Percentage of stations with soap and continuous water:** As dismantling of temporary facilities such as standposts was ongoing in Post phase, its number reduced to operational areas only (Observation).

J. **Quality of bathing facilities:** As dismantling of temporary facilities such as changing rooms was ongoing in Post phase, its number was reduced to operational areas only (Observation).

K. Power and backup systems: The power backup system was in demolition state (Observation).

L. **Access roads for waste transport-** As discussed in Pre-phase.

6.3.4.2 State of Equitable Access to WaSH facilities: Water Supply in Post Phase

A. **Availability of water in Kumbh Mela**

B. During the post-phase of Kumbh Mela, water accessibility patterns changed compared to the main event phase, mainly because temporary structures were being systematically dismantled after the event. This is because as the event was over, the temporary structures that were set-up were deconstructed and removed thus reducing accessibility (Source: Stakeholder Consultation and Survey).
C. **Percentage of floating population collecting water from improved sources for drinking purposes:** No data available for post phase as demolition of WaSH facilities is ongoing.
D. **Proximity to nearest water access point** (Source: ICCW report): The facility distribution became less structured as temporary systems were being removed during the post-phase. The Mela was in its concluding phase, and the installed facilities were in the process of removal, indicating randomness in proximity.
E. **Percentage accessing from various water facility types such as water ATMs, standposts and bottled water (ICCW Report):** Not available across all sources.
F. **Water facility functionality and non-functionality (percentage of people reporting functional water ATMs):** Water ATMs were functional in operational areas where pilgrims were present such as sectors 3 and 4 as shown in Figure 6.80.



Figure 6.40. A person taking water from water ATM in sector 3 of Mela

G. **Percentage of floating population reported on water sufficiency (ICCW Report, Stakeholder survey and consultation):** Field Notes and Stakeholder consultations suggest there was adequate sufficiency of water in the post phase.

6.3.4.3 Service- Sanitation

A. **Percentage of floating population reported on accessibility of sanitation facilities:** In the post phase, 49% of the surveyed population indicated ease in accessibility to sanitation facilities. Moreover, 12% reported that the facilities were easily accessible. 21% of the surveyed population indicated accessibility to facilities was neutral. However, there was some difficulty reported by 14% of the population. Similarly, 4% of indicated higher difficulty in accessing facilities during the transition period towards accessibility (Figure 6.81).

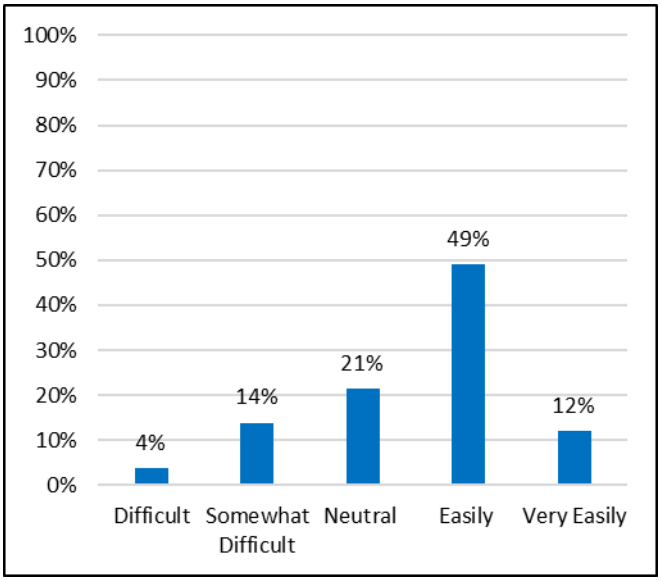


Figure 6.81. Accessibility of sanitation facilities by floating population in Post phase

6.3.4.4 Service- Hygiene

A. **Availability and proximity to handwashing stations:** No data available for post phase as demolition of WaSH facilities is ongoing.

B. **Percentage of floating population reported using handwashing stations after communal toilets:** No data available for post phase as demolition of WaSH facilities is ongoing.

C. Percentage of floating population reported disposing of solid waste appropriately: No data available for post phase as demolition of WaSH facilities is ongoing.

D. Percentage of population drinking water from surface sources (river water): No data available for post phase as demolition of WaSH facilities is ongoing.

E. Percentage of population showing affinity for Hygiene Practices: No data available for post phase as demolition of WaSH facilities is ongoing.

F. **Health related concerns:** No data available for post phase as demolition of WaSH facilities is ongoing.

6.3.4.5 State of Operation, Management and Risk Aversion

A. **Service-Water**

- **Hygiene (safely managed) of water facilities**
  - **Safe operation and management of water infrastructure such as water ATMs, Water tankers and standposts.:**

- Post the Kumbh Mela was over, the task of dismantling existing infrastructure and restoring the city, which included the removal of about 1,306 km of underground drinking water pipelines, 70,000 tap connections, and 85 tubewells. However, for Water ATMs, rather a reuse policy was followed. They were moved to other districts to be reused for the annual Magh Mela next year or distributed to districts that needed them. (Source: Secondary Literature)
- **Satisfaction with planning and mapping for easy access to water services:** This indicator is not applicable at this phase; hence, no data is available.
- **Frequency of regular checks of water quality**

- **Continuity of WaSH Services:**
  - **C2a. Operational Capacity of Water infrastructure such as water ATMs, Water tankers and standposts:** The surveyed infrastructure and service providers view the post-mela water infrastructure as mostly efficient and sufficient (75%). Moreover, the low level of disagreement suggests that operational transition and dismantling did not significantly disrupt accessibility.
  - **C2b. Reasons for Non-operational Capacity of Water Sources and Access Points:** This indicator is not applicable at this phase; hence, no data is available.

6.3.4.6 Service: Hygiene

A. **Maintenance of a hygienic environment**

During the post-phase of the Kumbh Mela, as the dismantling of sanitation and water infrastructure was underway, regular cleaning protocols and maintenance practices were implemented to ensure the continued upkeep of a hygienic environment. (Figure 6.82).



Figure 6.82. Suction cleaning of left out waste of eroded temporary toilets in sector 18

B. **Health Risk from River Water**

Survey responses suggested that most respondents agreed that the condition of the Ganga River during the Kumbh Mela has a negative impact on public health. The data revealed that a

combined 45% of respondents agreed. Conversely, 34% of respondents disagreed with the same, thus the overall sentiment suggests that more people perceive a negative health impact from the river than those who do not. (Figure 6.83)

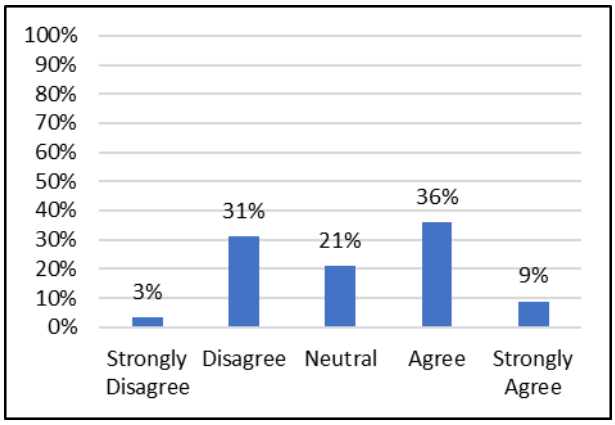


Figure 6.83. Perception of surveyed population on public health risks from river water in post phase of Maha Kumbh 2025

C. **Promotion of WaSH Awareness**

- **Collaboration and partnership among institutional stakeholders to provide WaSH services:** This indicator is not applicable at this phase; hence, no data is available.

D. **Service: Sanitation**

- **Hygiene (safely managed) of Sanitation Facilities**
  - **Safe operation and management of sanitation services:** A comprehensive post-fair sanitation campaign was held in Sangam city, led by the Prayagraj Municipal Corporation to restore the city. It was an intensive 7-day drive which focused on removing plastic waste, discarded clothing, and other non-biodegradable materials. About 8500 sanitation workers, and over 500 machines were deployed to carry out this operation. At the infrastructural front, over 1.5 lakh portable toilets installed for the event were systematically removed, as well as garbage collected from the Kumbh area was transported to the Basware plant in Naini for proper disposal.
  - **Actionable cleaning protocols to maintain a hygienic and safe environment:** Mela Sanitation Measures included the systematic dismantling and removal of all toilets. Hygienic uninstallation was ensured by the sanitation team, using Malathion (5%) and Slaked Lime for effective disinfection and neutralization of waste.

The sanitation campaign held by Prayagraj Municipal Corporation post the end of Kumbh Mela also incorporated targeted mosquito control efforts, with seven vehicle-mounted and 20 cycle-mounted fogging machines deployed for the task.

The surveyed data reflects that a substantial majority of infrastructure and service providers hold the belief that storage tanks for drinking water are cleaned and maintained daily to ensure hygiene. A combined 64% of respondents agreed indicating a high level of public confidence in the daily maintenance of water storage facilities, with a minimal disagreement.

6.3.4.7 State of Psychosocial

- **Affinity for Hygiene Practices**
  - **Overall respondent's Affinity for Hygiene Practices**

The survey data for the post phase of Kumbh Mela indicated sustained hygiene commitment among the floating population, with 85% affirming continued practices and only 2% expressing disagreement. The trend reflects a lasting impact of mela infrastructure and awareness efforts on participant behaviour (Figure 6.84-A).

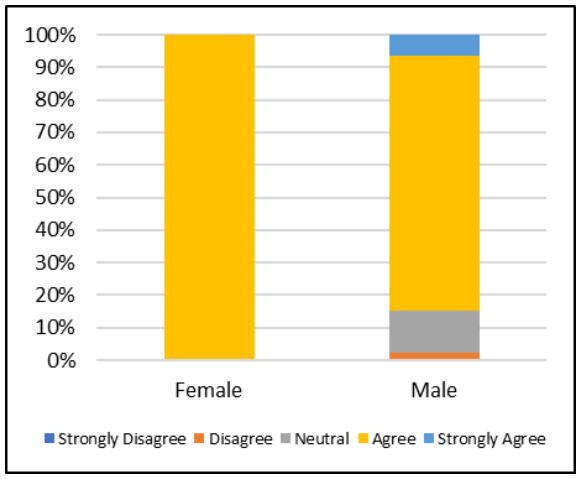


Figure:6.84-A

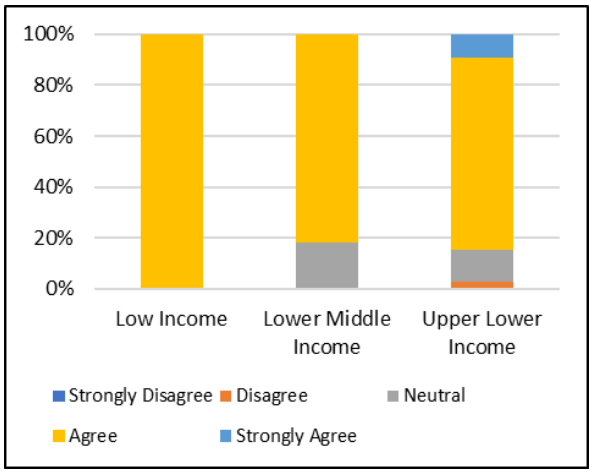


Figure:6.84-B

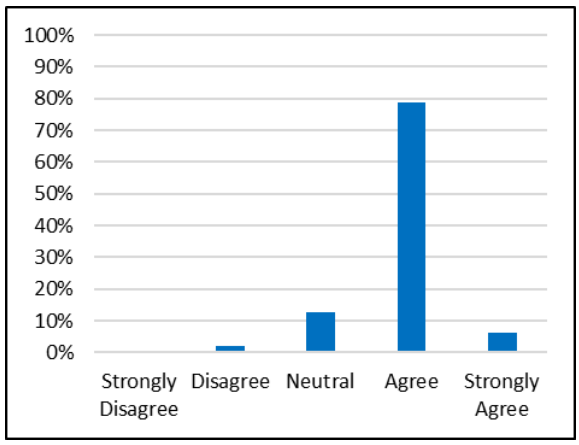


Figure:6.84-C

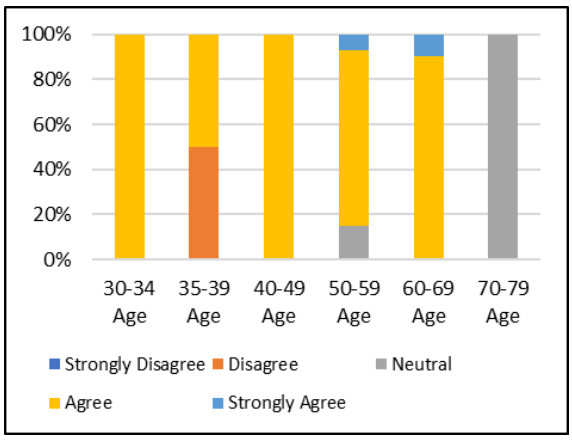


Figure:6.84-D

Figure 6.84. Perception of floating population on their Affinity for Hygiene practices in post phase of Kumbh mela as per holistic overview (Figure 6.84-A), age (Figure 6.84-B), gender (Figure 6.84-C) and socioeconomic group (Figure 6.84-D)

- **Affinity for Hygiene Practices based on Age**

Post phase survey data (Figure 6.84-B) indicates a shift from collective consensus to age wise perceptions of hygiene affinity. The 35-39 cohort showed a notable shift in perceptions, with 50% perceiving poor hygiene while the 70-79 group adopted full neutrality.

- **Affinity for Hygiene Practices based on Gender**

Post phase data (Figure-6.84-C) shows 100% hygiene affinity among female respondents, indicating uniform commitment. Male respondents also reported high agreement with slight variability. Overall, hygiene affinity remained consistently strong across genders.

- **Affinity for Hygiene Practices based on Socio-Economic Group**

Post phase data (Figure 6.84 D) reveals stratified hygiene perception by income. Upper Lower Income respondents showed highest agreement, including the only strongly agree responses. Lower Middle Income displayed peak neutrality and least agreement, while low-income respondents maintained moderate consensus.

- **Awareness of WaSH Practices**

- **Overall respondent's Awareness of WaSH Practices**

Post event data (Figure 6.85-A) shows a shift from high consensus to fragmented WASH awareness, with increased "Moderate" and emergent "Low/No Awareness" segments. This indicates a transient impact of exposure during the Mela.

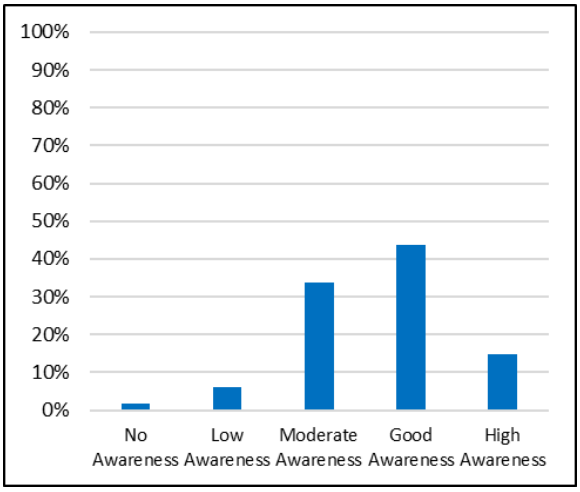


Figure 6.85-A

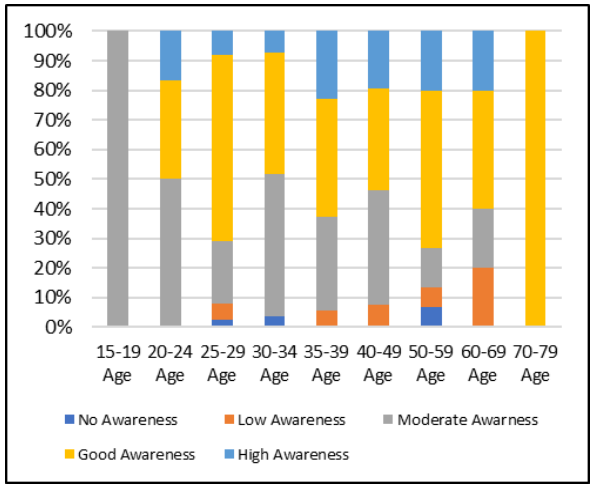


Figure 6.85-B

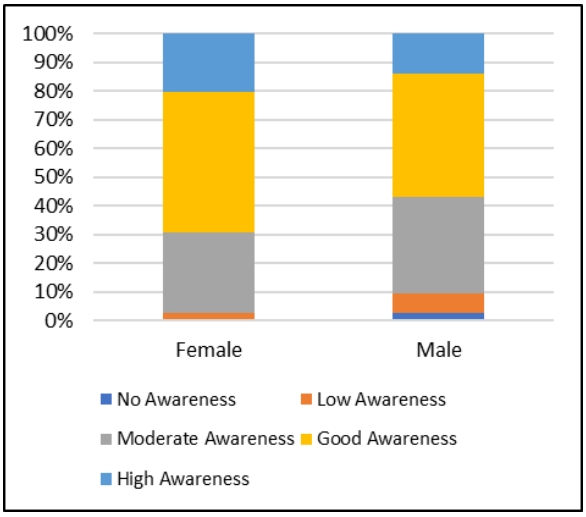


Figure 6.85-C

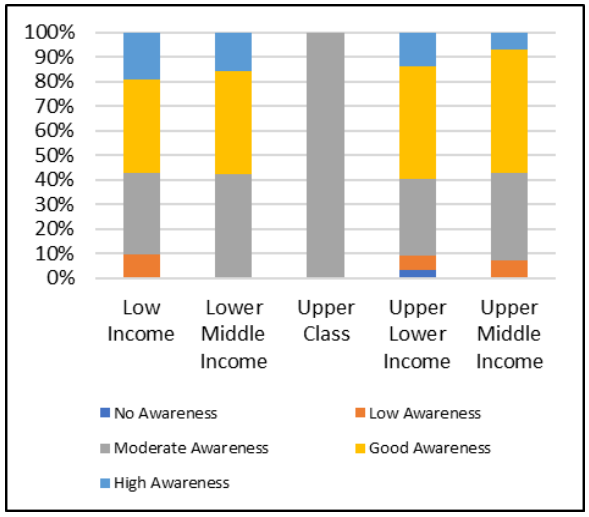


Figure 6.85-D

- **Awareness of WaSH Practices based on Age**

Post phase data (Figure 6.85-B) shows marked decline in WASH awareness across age groups, with sharp drops in the 15-19 age cohort and 60-69 cohorts, and highest "No awareness" in 50-59. The findings highlight the transient nature of event-based awareness and its demographic variability.

- **Awareness of WaSH Practices based on Gender**

Post phase data shows a moderated decline in WASH awareness compared to the unanimous affirmation during the Mela (Figure 6.85-C). While 69% of females and 57% of males maintained high awareness, female respondents exhibited greater consistency, with negligible reports of low awareness. In contrast, male responses were more fragmented, indicating gendered variation in post event knowledge retention.

- **Awareness of WaSH Practices based on Socio-Economic Group**

Post phase data shows a marked decline in WASH awareness across socioeconomic groups, shifting from uniformly high levels during the Mela to fragmented "Moderate", "Low" and "No Awareness" responses (Figure 6.85-D). This indicates transient impact and varied retention of knowledge.

- **Satisfaction on WaSH services at Maha Kumbh Mela 2025**
  - **Overall satisfaction levels towards WaSH services**

Post event data for satisfaction levels shows satisfaction with WASH services declined to almost 65%, with neutrality rising to 20% and dissatisfaction to 16%. Reflections post mela indicate a shift towards more ambivalent and critical evaluations (Figure 6.86-A).

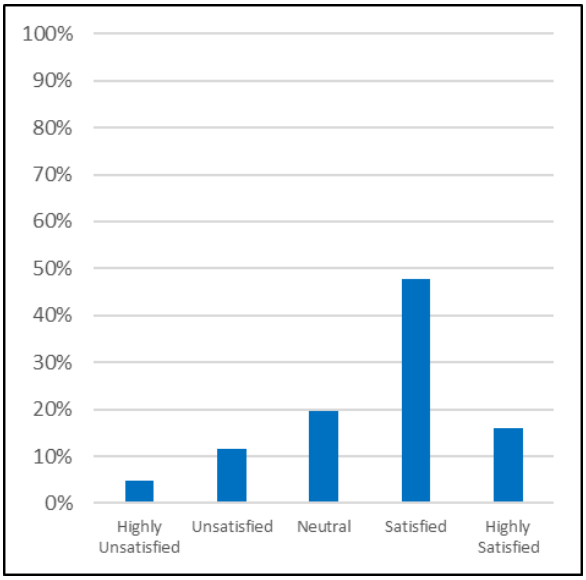


Figure 6.86-A

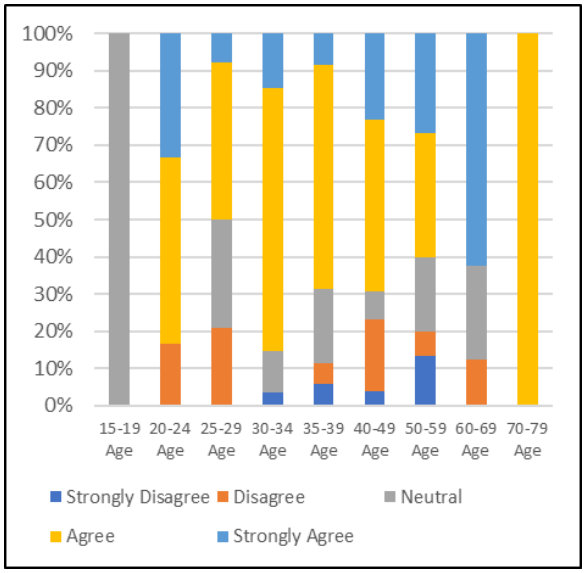


Figure 6.86-B

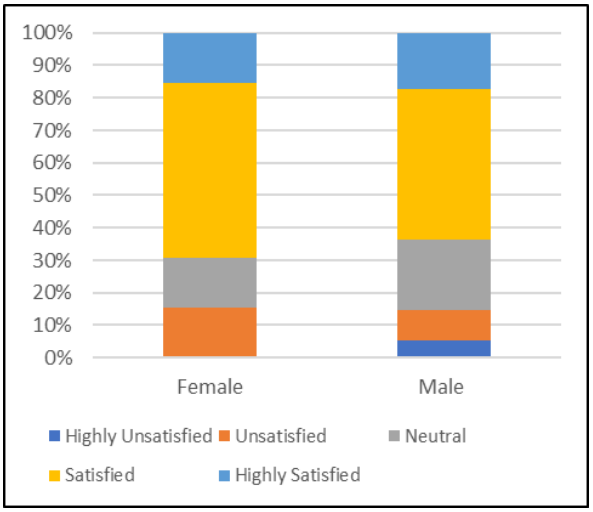


Figure 6.86-C

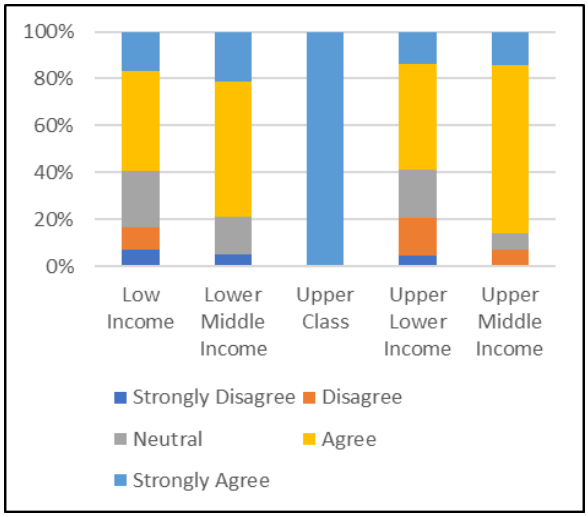


Figure 6.86-D

Figure 6.86. Perception of floating population on Satisfaction on WaSH services in the post phase of Kumbh mela 2025, as per holistic overview (Figure 6.86-A), age (Figure 6.86-B), gender (Figure 6.86-C) and socioeconomic group (Figure 6.86-D)

- **Satisfaction levels towards WaSH services based on Age**

The post Kumbh satisfaction levels analysis shows stark polarization such as 15-19 years cohort shifted to 100% neutrality, 70-79 age group to full satisfaction, while 50-59 reported lower levels of satisfaction. These findings highlight age wise divergence in post Kumbh evaluations (Figure 6.86-B).

- **Satisfaction levels towards WaSH services based on Gender**

The post Kumbh analysis demonstrates a gender gap in WASH satisfaction. For instance, 70% of females versus 80% of males reported satisfaction. Higher neutrality and dissatisfaction among women suggest more critical post event evaluations underscoring gender specific needs (Figure 6.86-C).

- **Satisfaction levels towards WaSH services based on Socio-Economic Group**

Post-Kumbh data reveals sharp socioeconomic polarization in WASH satisfaction. The upper-class cohort reported 100% satisfaction, while low and upper lower income groups showed significant dissatisfaction, indicating unequal service experiences and variation in perception persisted across socioeconomic groups (Figure 6.86-D).

6.4 Impacts on WaSH services due to the Floating Population in Maha Kumbh Mela 2025

The perceived impacts in this section have been inferred from the 'State' of WaSH facilities in Kumbh Mela 2025 (Section 4.2). The Impacts observed and inferred are based on from pilgrims 'behaviour, administrative infrastructure provision, operation, and maintenance, and the psychosocial dynamics of the attendees. Below, we have highlighted the multifaceted impacts on WaSH management at the Maha Kumbh 2025 under the four indicators of Impacts described in Section 2.

6.4.1 Environmental Impact

6.4.1.1 Contamination of water sources and rivers

The installation of Geo tubes, enhancement of sewage treatment plant (STP) capacities as discussed in the 'state' section, has proven effective in reducing the risk of contamination of water sources, thereby generating a positive environmental impact.

6.4.1.2 Chemical Contamination from Bathing Practices

Despite the concerned efforts of sanitation workers and *Ganga Sevadoots* to maintain cleanliness across the Ganga, Yamuna, and Sangam areas, including public education initiatives aimed at promoting responsible behaviour, avoiding certain ritualistic practices by pilgrims such as offering religious substances such as vermilion to river bodies, use of soaps and detergents for washing clothes and utensils, continued to contribute to chemical pollution (Figure 6.87).



Figure 6.87. woman washing dishes at Sangam ghat

6.5.1.3 Overwhelming of local waste management infrastructure

On-site observations showed that while waste collection was efficient as Prayagraj Mela Authority deployed various high-capacity vehicles to transport waste, waste transportation was still challenged by high population influx in hotspot areas, making it difficult for waste transportation across the sectors.

6.5.1.4 Disruption of Local Ecology and Biodiversity

The discussed overall establishment of WaSH infrastructure, with optimum accessibility, efficient operation and maintenance, and risk aversions in the state section, has demonstrated the positive impact. These practices have not only contributed to improved ecological results but have set a case example for the effective implementation of WaSH systems in temporary religious gatherings.

6.5.2 Economic Impacts

6.5.2.1. Extra Financial Expenditure

No emergency related expenditure was reported across all three phases of Kumbh, highlighting effective planning and preventive measures adoption in WASH management.

6.5.2.2. Reputation and future investments

Maha Kumbh 2025 elevated the profile of Prayagraj city through exemplary event management and major WASH upgrades, gaining national and global attention and identifying the city as a hub for future investment and tourism.

6.5.3 Health Impacts from Waterborne & Hygiene-Related Diseases Outbreak

6.5.3.1. Risk of spread of diseases

Despite minor wastewater spillage risks, swift vector control measures adopted in Maha Kumbh 2025 such as, DDT, insecticides, ensured a safe and contamination free environment for pilgrims.

6.5.3.2 Hand hygiene facilities and practices

Targeted sanitation and hand hygiene efforts at Maha Kumbh 2025 significantly in terms of WASH infrastructure placement, service delivery and efforts in making change in pilgrims' behaviour through various awareness initiatives reduced disease risks, highlighting string public health impact.

6.5.3.3. Strain on local health care system

Real time surveillance, vector control and rapid response minimized outbreaks and prevented healthcare strain, ensuring public health resilience during and after Maha Kumbh 2025

6.5.4 Impacts on humans especially affecting vulnerable population and spiritual sanctity of water

6.5.4.1 Impact on Women's Health and Hygiene

As per reported by secondary literature, at Maha Kumbh 2025, free sanitary pads, menstrual hygiene kiosks and awareness campaigns ensured access to menstrual care, promoting dignity and health for women attendees.

6.5.4.2. Conflict and Inequities within the Mela Site

No conflicts and inequities regarding WaSH facilities within mela site reported. Population-based infrastructure provision, equitable access and rigorous operation and maintenance have delivered in a successful manner creating a positive impact.

6.5.4.3 Concerns of sanitation workers:

While increasing the number of sanitation workers could help distribute workload, the existing workforce at Maha Kumbh 2025 was equipped with jet spray machines and other advanced tools, enabling faster and more efficient cleaning of toilets.

6.5.4.4 Perception of impurity from unclean surroundings affecting spiritual experience

The perception of impurity from unclean surroundings can diminish pilgrims' spiritual experiences at Maha Kumbh 2025. Authorities address this through rigorous sanitation, waste

management and plastic free zones, regular cleanliness drives, *Nukkad Nataks* fostering a pure and spiritually uplifting environment.

6.5 Responses to elevate experience and management of K-WaSH services at Kumbh Mela

In this section, we discuss the Driving forces that helped in the successful delivery of the Kumbh Mela WaSH services along with the Pressures observed in the Kumbh Mela Site (Section 3). Based on the understanding of the Drivers and Pressures, we have developed a set of Recommendations (Responses) to elevate the experience and management of K-WaSH services at Kumbh Mela.

6.5.1 Drivers influencing the successful delivery of WaSH services in Maha Kumbh Mela 2025

This study conceptualises "Drivers" as human factors and activities that directly shape WaSH service delivery at the Kumbh Mela (Section 2). From an empirical vantage point, it is imperative to note that even though all three categorical factors play a vital role in shaping human actions, however, from our on-ground survey results, field observations, and stakeholder consultations, all suggest a unique emphasis on the Psychosocial drivers in the case of Kumbh Mela. We have inferred that Psychosocial drivers assessing the beliefs, perceptions, knowledge, and awareness of the vested stakeholders are the most important drivers. Institutional and Governance drivers and Infrastructure and Technology drivers are essential factors, but they are not as inherently woven into the human factors and behaviours as Psychosocial drivers that showcase their intrinsic and extrinsic knowledge, their socio-economic profiling, and their cultural and religious beliefs.

The influence of these drivers on human factors and activities has been assessed using data from various sources.

a. Psychosocial drivers have been assessed using data from our conducted survey, and since the aim of this study is to assess the impact of the floating population, the data picked for this analysis primarily relates to the responses recorded from the floating population from an on-field survey that was conducted.

b. For the assessment of Institutional and Governance drivers, and Infrastructure and Technology drivers, primarily secondary literature, field observations, and stakeholder consultations have been used.

Subsequently we analyse these drivers individually, along with their results, to provide a vivid understanding of how these drivers impact the delivery of WaSH services at the Kumbh Mela.

6.5.2 Psychosocial Drivers: Assessment of Knowledge, Perception and Awareness factors and Correlation with Demographics in the Floating Population

The Psychosocial driver captures how stakeholder knowledge and awareness shape WaSH behaviours and service use. It consists of:

- The floating population's perceptions, awareness, and knowledge (both intrinsic and extrinsic) of WaSH practices and facilities; and
- Qualitative data and stakeholder consultations were evaluated to assess the limited, targeted information on accessible facilities.
- Influence of Cultural and religious norms was evaluated separately through the same survey data, illustrating their pronounced significance in this religious gathering.

Taken together, these analyses contribute to a structured empirical evidence base for the importance of psychosocial drivers.

6.5.2.1 Knowledge and Awareness of stakeholders:

A. **Intrinsic knowledge of the floating population on usage of WaSH facilities and practice**: Findings from the Pre-phase show a significant knowledge gap, the respondents strongly disagreeing amount to 46.59 to having intrinsic knowledge about usage and practices related to WaSH facilities and 51.14% remain neutral about their knowledge (mostly knowledgeable on toilet usage but not on other practices or facilities), with negligible agreement suggesting limited baseline understanding. During the Mela, responses to questions related to intrinsic knowledge appear to solidify as 59.9% agree to having knowledge and 20.22% strongly agree, while neutrality falls to 14.14% and disagreement to 5.74%. This abrupt change suggests that knowledge gaps are gradually filled with informed knowledge through in-situ exposure, such as wayfinding, demonstrations, volunteer instructions, peer norms, and visible facility performance. In order to maintain improvements, replicate these cues at entry points and high-flow routes, update high-salience signage, and keep volunteer touchpoints open during peak hours. The data highlights the importance of intensive ground-level communication and just-in-time education.

- **Correlation Analysis:** In Pre-phase, age showed no association with responses to questions assessing intrinsic knowledge (Spearman $\rho = -0.131$, $p = 0.224$; $n = 88$), while

during the event a statistically detectable but small negative slope appeared (ρ = -0.0605, p = 0.036; n = 1,202), suggesting older respondents were only marginally less intrinsically knowledgeable. Gender differences were evident only in the Pre-phase, males were significantly less knowledgeable than females (Mann–Whitney U = 974, p = 0.0064; rank-biserial r = −0.342). Socio-economic class was not associated with responses in either phase (PRE: ρ = -0.173, p = 0.105; n = 89; DURING: ρ = -0.025, p = 0.379; n = 1,202).

- **Inference:** The surveyed population in the Pre-phase had minimal intrinsic knowledge about usage of WaSH facilities and its related practices suggesting low self-efficacy and reliance on external knowledge to understand best behaviour. Activities focusing on providing behavioural nudges before the initiation of the Mela could be pivotal in such a context. As our results suggest responses to questions related to intrinsic knowledge in the during phase received a much larger positive response as on-site cues and demonstrations created familiarity and gradual informed understanding leading to the population gaining basic knowledge and understanding on usage of WaSH facilities. Intrinsic knowledge of the floating population on usage of WaSH services and practices appear broadly uniform across age and Socio-economic classes across phases, with a transient pre-event gender gap on intrinsic knowledge wherein males were less inherently knowledgeable. During the mela, the intrinsic knowledge on WaSH facilities usage was marginally less in the older population groups, indicating that they captured the extrinsic knowledge being provided in the Mela but were unable to fully understand the captured information to be intrinsically aware moving forward.

B. **Extrinsic Knowledge captured by the floating population**: The floating population showed strong extrinsic knowledge being provided towards WaSH facilities and practices across phases at Kumbh Mela 2025. Pre-event, two-thirds, i.e. 68% expressed positive extrinsic knowledge being provided with no disagreement, indicating a solid baseline. During Kumbh, positivity peaks with 86% of the respondents in Agree/Strongly Agree bracket, neutrals shrink to merely 12%, and disagreement stays <2%, suggesting on-site cues, peer norms, and messaging provided knowledge, turning it into intent. Post-event, positivity remains high at 81% but disagreement rises modestly to 6% of the population showcasing disagreement, likely reflecting fatigue or gaps between expectations and service quality after the peak. Overall, extrinsic knowledge being provided at the mela is strong and is most effectively activated during

the event, and declines only slightly afterward, underscoring the need for sustained reinforcement (reminders, nudges, visible facilities) in the post phase

- **Correlation Analysis:** Across phases, age shows no consistent relationship with extrinsic knowledge being provided towards WaSH facilities and practices, and gender differences are also similarly negligible. For gender, Pre-phase shows a borderline but non-significant tendency for males to respond slightly more positively towards extrinsic knowledge being provided (Mann–Whitney U = 540.0, p = 0.0566; rank-biserial r = −0.256; n_F = 22, n_M = 66), while DURING indicates no meaningful difference. POST phase gender comparisons are also negligible.
- **Inference:** In conclusion, majority of the respondents agree to extrinsic knowledge being provided at the Mela, showcasing that there were appropriate efforts made to inform the floating population regarding WaSH facility usage. Hence, it would be fair to argue that providing extrinsic knowledge does act as a driver. Moreover, the agreement was uniform across social subgroups suggesting minimal variance dependent on age and gender.

6.5.2.2 Provision of information about Kumbh Mela Management

The government and the Prayagraj Mela Authority made extensive efforts to educate pilgrims about various aspects of event management, particularly sanitation and WaSH (Water, Sanitation, and Hygiene) practices given the population influx at mass gatherings. Even though some stakeholders perceived gaps in information on mela management, our field observations and consultations indicate that substantial efforts were made to disseminate information, particularly on sanitation and WaSH. Kumbh Mela Widespread signage about sanitary facilities was placed strategically throughout the mela zone, and numerous pre-campaign drives were conducted to increase awareness of the value of hygiene. This commitment to maintaining a hygienic environment is further demonstrated by the deployment of a sizable and highly skilled sanitation workforce, including thousands of sanitation workers and 'Ganga Sevadoots', who had received extensive training in sanitation procedures, disaster mitigation, and rapid response.

Mela management officials used a variety of platforms, including digital platforms and sign boards, to efficiently communicate sanitation and WaSH facility usage protocols. Closer examination reveals that while macro-level management and wider communication were strong, some opportunities remain at the micro level to further strengthen the delivery of more targeted and nuanced information.For example, there is scope to further enhance wayfinding,

for example by adding clearer directions or maps showing the locations of sanitary facilities and preferred routes, particularly at entry points. Even though the number of signs has been improved, more could be added and placed in strategic locations at busy intersections and important junctions.

Furthermore, some specialized information needs such as clearer communication on menstrual hygiene facilities could be further strengthened in future editions. Special provisions for the elderly, such as clear markings for accessible toilets or additional assistance, were also areas that could benefit from enhanced information drives. Behavioural nudges and WaSH-related protocols were more visible during peak periods; future editions could consider more proactive, advance dissemination to maximize their impact. International and domestic studies on mass gatherings stress the value of targeted behavioural interventions and anticipatory guidance for improving compliance and user experience.

6.5.2.3 Cultural and Religious Norms of floating population affecting delivery of WaSH services

The floating population's responses to our survey questions targeting religion and spirituality as drivers show a clear, phase-wise consolidation of the view that cultural and religious norms directly impact WaSH facility use and service delivery. In the pre-phase, about 70% (130/187) of the respondents agreed to the fact that cultural and religious norms impact delivery of WaSH services within Kumbh Mela, with 27% of surveyed population being uncertain/neutral. During the event, once participants engaged in *snan, aarti,* ablutions, and purity practices, agreement rose to 84% (1,098/1,313) and uncertainty halved to 15%. In the post phase, agreement remained high at 87% (41/47), with minimal disagreement at any stage.

Inference: This pattern indicates that religious and cultural norms govern when, where, and how water points, toilets, and hygiene services are demanded and maintained especially in the context of religious mass gatherings such the Kumbh Mela.

Age-wise perceptions illustrate this shift most starkly. In Pre-phase, there was very high recognition among 15–34 years nearly 86–100% of the respondents were in the Agree/Strongly Agree bracket. In contrast, there was ambivalence among 40–59 years with only 50% of the respondents agreeing, which further fell in the 60–69 years category (27% agreement). During the event, consensus emerges across ages, with endorsement typically 80–88%, and even 70–79 and 80+ reporting full agreement. Post-phase, recognition remains high across reporting age groups (≥82%).

Inference: Largely all age groups across phases show agreement towards cultural and religious impacting WaSH service delivery.

Gendered patterns do show an intricate difference in perception across genders. Women report stronger effects of religious and cultural norms on WaSH: 71% vs 68% pre-phase and 88% vs 82% during the event. In the post phase there was no such varied perception across genders.

Inference: The difference in perception across genders aligns with the fact that females need more privacy and safety, have menstrual-hygiene needs, and often look after children or elders. Toilets and queues don't always account for this, so crowded days make it tougher for women to use facilities comfortably and correctly. After the event, when crowds thin and pressure drops, the difference between men and women mostly disappears.

Socio-economic patterns show heterogeneity before and convergence during the event. In the Pre-phase, agreement ranges from 57% in Upper-Middle to 93% in Lower-Middle and 85% in Upper-Lower, with very small bases at the extremes (Low and Upper Class). During the event, recognition converges to 79–86% across all classes (Low, Lower-Middle, Upper-Lower, Upper-Middle, Upper), and post-phase remains high across reported groups.

Inference: Respondents across income strata perceive cultural and religious norms driving WaSH service delivery dynamics, suggesting that cultural and religious norms supersede class-based differences in expectations or prior knowledge.

Taken together, the floating population's testimony implies that ritual norms and cultural protocols are fundamental drivers of WaSH services demand and operations, not just peripheral factors.

A. Institutional and Governance Drivers:

- **Best Practices Protocols:**
  - **Water facilities:** Phased demand estimation, safe source identification, and CPHEEO-compliant distribution, alongside 24×7 Water ATMs with sensitized oversight, improved access and continuity of Water related services (MoHUA, 2019; Government of Uttar Pradesh, 2025).
  - **Sanitation:** Conducted a two-month training programme of all local sanitation volunteers before the Mela as per Swachh Bharat Mission training module to ensure capacity building and proper guidance for smooth operation and monitoring of sanitation facilities.

- **Hygiene:** Round-the-clock AYUSH OPDs and on-site holistic services strengthened first-line care and triage capacity; continuous river sampling was mandated throughout the event to issue alerts on coliform/BOD levels increase (Ministry of AYUSH, 2025; National Green Tribunal [NGT], 2025; Central Pollution Control Board [CPCB], 2025).

Inference: Best practices protocols deployed at Maha Kumbh 2025 did influence delivery of WaSH services within the mela setup. With these protocols in place, the pilgrim population was more convinced and assured of proper WaSH facilities being available at Maha Kumbh 2025. However,

- **Integration of National Strategies:** Maha Kumbh 2025 was mapped closely to SBM-Urban 2.0 and Swachh Survekshan for ODF+/ODF++/Water+, third-party checks, and QR-based citizen feedback, FSSM Policy (2017) was aligned for septage and used-water management, Jal Jeevan Mission field protocols were used for assessing water quality. (MoHUA, 2017, 2021, 2024; Ministry of Jal Shakti, 2020; CPCB, 2019; Ministry of Environment, Forest and Climate Change [MoEFCC], 2016, 2022). These alignments provided structure, key performance indicators, and resources even where local enforcement was variable (MoHUA, 2021; CPCB, 2025).

Inference: Focus on WaSH services during Maha Kumbh 2025 was a priority and because of this integration with National Strategies, Maha Kumbh 2025 successfully delivered better outcomes with regards to WaSH services and facilities as compared to its previous editions.

- **Accountability:** According to primary data from field observations and stakeholder consultations, senior officials demonstrated strong accountability by participating in constant preparation for the upcoming event and being open to suggestions. To increase preparedness and service results, the Prayagraj Mela Authority's sanitation and water service units started early coordination and infrastructure improvements (primary data). Additionally, institutionalized accountability and time-bound response were demonstrated by sector-wise sweeping teams with assigned supervisors, QR-enabled grievance redressal, and operation routing through the Integrated Command & Control Center (MoHUA, 2021, 2024; Government of Uttar Pradesh, 2025). Additionally, Jal Nigam engineers provided technical oversight of water-supply facilities, strengthening agency-to-agency accountability (Government of Uttar Pradesh, 2025).

Inference: Pronounced accountability among senior officials and nodal officers translated into clear lines of authority, timely decisions, and sustained oversight of WaSH operations. With responsible officers for sanitation and water facilities, planning became continuous across pre-, during-, and post-event phases, enabling early risk mapping and targeted deployment of crews and supplies. This reduced coordination failures during peak loads and improved facility uptime. In effect, accountability functioned as an enabling condition that converted plans into consistent on-ground WaSH service delivery.

- **Networks and Coalitions:** Throughout the Maha Kumbh 2025, hygiene information, education, and communication (IEC) was delivered through a multi-actor coalition led by government agencies and supported by NGOs and CSR platforms for example, GIWA/Parmarth outreach and Banega Swasth India partnerships thereby broadening reach and reducing message fatigue (MoHUA, 2021; Government of Uttar Pradesh, 2025). In parallel, PET-reduction coalitions such as the Jal Kalash initiative and the HCL Foundation achieved visible recovery of plastic waste. However, on peak days, plastic usage still tends to increase, suggesting the value of further strengthening upstream measures such as more robust extended producer responsibility so that less waste reaches the site in the first place (MoEFCC, 2016, 2022).

Inference: In Maha Kumbh 2025, these networks and coalitions played a crucial role in providing better delivery of WaSH services by promoting hygiene practices and logistical support on ground. Moreover, these collaborations and networks also acted as a source of knowledge sharing toward the pilgrims by promoting a strong nudge towards usage of WaSH facilities and practices.

- **Monitoring Framework:** Mobile and QR code–based audits for cleaning, third-party checks of sanitation assets, and routine sampling of STPs and ponds were implemented, with directions to disclose results online (MoHUA, 2021; CPCB, 2025; NGT, 2025). Water ATMs were equipped with sensors and supported by on-site operators to maintain service continuity (Government of Uttar Pradesh, 2025). However, an independent study on Kumbh 2025 operations flagged a subset of Water ATMs showing TDS above CPHEEO-referenced ranges, indicating the need for tighter last-mile Quality monitoring and rapid rectification loops (IFC, 2025).

Inference: There were standardised monitoring mechanisms in place for both sanitation and water facilities suggesting quality assurance and rapid rectification. However, continuity in monitoring and reporting of water and sanitation quality was a point of contention as instances occurred wherein the instruments were in place, but quality remained questionable. Monitoring frameworks do influence delivery of WaSH services and facilities, and hence without continuity these monitoring frameworks may negatively influence pilgrim behaviour towards WaSH facilities in the context of upcoming Kumbh gatherings.

B. Infrastructure & Technology Drivers:

Infra & Tech Innovation: During Maha Kumbh 2025 varied kinds of infrastructure and digital systems were deployed that tightened WaSH delivery at scale. A network of 233 sensor-enabled Water ATMs dispensed RO water round-the-clock, while an app-based Water Monitoring Management System tracked consumption, storage levels, quality, and distribution in near-real time. On the wastewater side, authorities added drain-end treatment using geosynthetic dewatering tubes (Geo tubes) to intercept and filter flows before discharge, with reporting to regulators. Selected sites paired this with ozonisation as a disinfection alternative to chlorination. Solid-waste operations piloted AI-powered detection vans that flagged garbage piles and auto-routed crews to hotspots, aiming to reduce overflow and cut response times (Times of India, 2024; Invest UP, 2024; IJRTI, 2025). However, despite these advances, stakeholder consultations indicated that simply adding more tech or AI tools would have diminishing returns because many pilgrims lack the intrinsic knowledge and familiarity to use or respond to them effectively, consistent with our findings on intrinsic knowledge among the floating population on usage of WaSH facilities.

6.5.3 Pressure

The provision of WaSH facilities at the Kumbh was subjected to a series of pressures, many of which stem from a confluence of institutional gaps and context-specific limitations, socio-cultural predispositions, and behavioural tendencies. In this section we infer the Pressures that emerged due to the Drivers discussed in Section 5.1 and comparing them with State of WaSH services (Section 4.2) for triangulation.

6.6.3.1 Operational and Management pressures

These pressures primarily emerge from the immediate stress posed by Institutional and Governance drivers, namely, gaps in systematic protocols (SOPs), complex accountability structures, evolving monitoring frameworks, and constrained contingency planning. Based on

our analysis of drivers in the previous section, the following were the most prominent O&M pressures generated by the negative influence of specific categorical drivers. Their causal linkage is discussed below:

A. **Limited backup facilities or buffer infrastructure**: This pressure arose from limited formalisation of best-practice protocols (Institutional and Governance driver) for backup infrastructure during the Kumbh Mela. Buffer assets (e.g., additional toilets, spare pumps/generators, extra desludging capacity, Water ATMs, and critical spares) were not consistently pre-positioned with clear activation triggers for peak-influx days. Stakeholder consultations also indicated hesitation to maintain buffers due to storage and operational constraints and concerns about limited intrinsic knowledge among pilgrims, including risks of misuse or damage of spare parts. The net effect was slower fault recovery, longer queues, occasional overflows, and periodic challenges in WaSH service delivery.
B. **Pressure on sanitation workers:** This pressure reflected combined stress from Institutional and Governance and Psychosocial drivers. Although the workforce was numerically large, constraints related to living conditions, rest areas, supervisory ratios, and shift design may have affected worker comfort and motivation. Concurrently, varying levels of familiarity among the floating population about appropriate WaSH use increased cleaning loads, forcing overtime and compressed cleaning cycles. This compounded fatigue, raised error rates, and strained coverage in other zones.
C. **Service gaps in WaSH delivery:** When planned supply did not correspond with temporal and spatial demand, service gaps were noted as a result of institutional and governance factors. Tanker routing was disrupted, desludging was delayed, and there were sporadic toilet outages in high-traffic areas due to traffic diversions, security-related movements, and variable contractor performance. Short but significant service interruptions resulted from pumping, chlorination, and coordination being occasionally affected by power and network outages.
D. **Limited real-time monitoring of waste hotspots:** Owing to evolving monitoring frameworks and limited pre-planning protocols (Institutional and Governance driver), dynamic detection and prioritisation of waste hotspots were delayed. On peak days, this translated into visible hygiene deterioration and delays in waste collection, increasing downstream operational pressure on sanitation teams and supervisors.

6.6.3.2 Pressures linked to Behavioural and Cultural norms

These pressures mainly relate to the stress caused by Psychosocial drivers, consisting of lack of intrinsic and extrinsic knowledge on WaSH facilities among pilgrims, their cultural and religious beliefs, and behavioural patterns based on age, gender, or socio-economic class. Pressures under this bracket reflect the absence of certain key behavioural and choice patterns among pilgrims that would otherwise support better delivery of WaSH services. Our analysis of psychosocial drivers revealed the presence of these pressures explicitly and in some cases implicitly. Their causal linkages are illustrated below:

A. **Lack of knowledge and awareness by the floating population**: This is a significant pressure emerging from the stress posed by Psychosocial drivers on WaSH services. Limited intrinsic knowledge among pilgrims places considerable stress on WaSH facility usage and delivery and has compounding effects such as poor hygiene practices (e.g., inadequate handwashing, incorrect toilet use, unsafe water handling, improper waste segregation). Moreover, the lack of awareness about how individual practices affect system performance further exacerbates the situation, leading to misuse, fasterwear-and-tear, higher cleaning frequency, and slowdowns during peak hours.
B. **Lack of access to menstrual hygiene support:** This pressure stems from the combined drivers of limited information on Mela management (Psychosocial) and gaps in infrastructure availability (Infrastructure & Technology). Micro-level analysis of mela information showed limited messaging and dissemination regarding access points for menstrual hygiene support (e.g., locations of products, disposal units, private washing areas, or trained female staff). Field observations indicated insufficient scale of dedicated infrastructure. The presence of this pressure contributed to lower female participation, heightened infection risk, and overall deterioration in hygiene where safedisposal options were absent.
C. **Resistance to latrine use due to ritual impurity beliefs:** This pressure can be attributed to strong religious and cultural beliefs among the pilgrim population. Our analysis of the cultural and religious norms driver indicated a clear link between spirituality and WaSH service uptake. In mass gatherings, many pilgrims consider latrine use “impure” before performing rituals, which leads to resistance in using WaSH facilities or to postponement until after rituals. This behaviour concentrates demand into shorter windows, creates localized surges, and increases the likelihood of overflow, queuing, and environmental contamination.

6.6.3.3 Financial and Economic pressures

Even though our analysis revealed limited direct evidence due to data gaps, financial and economic pressures play a pivotal role in determining the "State" and the resources available to keep WaSH facilities at the Mela up to the mark.

A. **High initial costs for infrastructure setup:** Though implicitly indicated in our Drivers section, infrastructure setup costs were reported to be high, as also corroborated in stakeholder consultations. This likely created stress on (i) capital budgets that forced trade-offs between buffer toilets, spare pumps, extra desludging capacity, and quality upgrades; (ii) operating expenditure because of upfront payments and higher than anticipated expenditures cutting into the day-to-day budget, leaving less money for staff, safety gear, fuel, cleaning chemicals (including chlorine), and quick emergency fixes. Because much of the infrastructure is temporary, costs can only partially be amortized over long periods, raising the per-day cost of delivery service.

6.6.3.4 Infrastructure and Service Gaps

Based on the findings of our analysis in the previous section, pressures under this bracket corroborate stress placed by all three drivers. Infra and Tech drivers create stress on availability in context; Institutional and Governance drivers indicate stress related to monitoring and delivery of infrastructural and service set-ups; and Psychosocial drivers implicate stress related to usage of the infrastructure. These pressures focus on availability, usage, and accessibility of WaSH infrastructure. Their causal linkages are highlighted below:

A. **Lack of proper signage:** Based on our analysis of drivers, this pressure emerged primarily from the underlying driver of service convenience (Infra and Tech Driver) and lack of information about Kumbh Mela management (Psychosocial Driver). In several locations, signage could be improved in terms of readability and clarity, multilingual content, and design for people with disabilities (e.g., high-contrast, tactile/Braille cues). Placement was not always strategic at decision points (intersections, ghat entries, major turns), and lighting and visibility varied. Despite increases in signboards, these quality and placement gaps may have contributed to crowding, misrouting, longer search times, and uneven loads on specific facilities.
B. **Limited access for elderly and disabled pilgrims:** Accessibility gaps such as insufficient ramps and handrails, absence of wheelchair-friendly cubicles, few resting

points or priority queues, and uneven surfaces created barriers to fully safe and dignified use of WaSH facilities for the elderly and disabled pilgrims. The underlying driver here is lack of information about Mela management (Psychosocial driver) as pre-event and on-site communication about the location and availability of accessible toilets, water points, bathing areas, and escort services was inconsistent. As a result, many elderly and disabled pilgrims could not easily locate suitable facilities, leading to longer wait times, and greater dependence on informal assistance. These delays elevated safety risks (e.g., slips, fatigue) and increased dwell times, which in turn slowed overall service throughout and contributed to localized crowding.

C. **Overcrowding at sanitation facilities during peak days:** Peak-day surges often **approached or exceeded** local design and operational capacity, particularly when additional deployment could not be scaled up as rapidly as real-time demand. Uneven gender-segregated capacity and delayed re-routing resulted in long queues. The outcome was extended waiting, overflow, reduced handwashing compliance, and localized hygiene deterioration.

6.7 Recommendations to elevate experience and management of WaSH services for future Kumbh Mela

This section presents a structured set of recommendations aimed at enhancing the delivery and psychosocial impact of Water, Sanitation, and Hygiene (WaSH) services at future iterations of the Kumbh Mela. These recommendations have been systematically derived from an in-depth analysis of the State of WaSH services observed during Maha Kumbh Mela 2025, the Drivers that influenced their performance, and the Impacts and Pressures. These recommendations are informed by field-level observations, stakeholder interviews, and expert validation.

6.7.1 Deriving Responses (Recommendations) using the K-WaSH Framework

To ensure the recommendations are both evidence-based and contextually grounded, the following methodology was adopted:

A literature review was conducted encompassing both academic and grey literature to identify potential solutions that address the observed pressures and elevate the state of WaSH services. This review informed us of the development of preliminary recommendations aligned with the findings presented in Sections 4 and 5.

6.7.1.2 These preliminary recommendations were then validated through stakeholder engagement

A. First, consultations were held with n=16 domain experts specializing in water supply, solid waste management, wastewater treatment, public health, and WaSH systems.
B. Second, field-level stakeholder interviews were conducted with individuals directly involved in the planning, installation, and operational management of WaSH infrastructure and services during the Kumbh Mela.

Our expert and stakeholder consultations with agencies directly in the planning and execution of WaSH services at the Maha Kumbh Mela 2025 indicated that they undertook a wide range of measures to ensure the successful delivery of WaSH services. These measures and efforts that have been developed over the years reflect a significant evolution in WaSH service delivery at the Kumbh Mela such as design of distributions and operational readiness. For example, distribution and supply of safe drinking water, which is a critical indicator under the State of Equitable Access to WaSH services in our K-WaSH framework, was successfully addressed by the authorities by deploying Water ATMs. These gave free access to water to all pilgrims in Kumbh Mela and ensured equitable access to water. Despite these excellent measures taken by the authorities, our analysis and consultations indicate that there remains scope for refinement at a granular level to further enhance efficiency and resilience, especially to address impacts and pressures identified by this study.

We have categorized the recommendations so the users can identify the points of intervention in the delivery of WaSH services. Based on our experience from this study; we observed that the WaSH service delivery is dynamic across the 3 phases of the Kumbh Mela, beginning with planning and designing in the pre-Kumbh phase to deinstallation in the post-Kumbh phase. Secondly, we have categorized it based on the types of Drivers (Institutional and Governance, psychosocial, and infrastructural and technological) that these recommendations can influence. The K-WaSH framework is based on DPSIR framework which highlights that Responses, the recommendations in our case, can become Drivers that leads to change in the State of the WaSH services, if implemented. And finally, we categorized the recommendations in way that they can facilitate the implementation and planning by decision-makers based on their feasibility and time horizon. They have been categorized as:

- *"In Near Future"* includes interventions that are actionable within the next Kumbh cycle.

- *"In Mid to Long Term"* includes systemic and structural reforms that require sustained planning, investment, and institutional coordination.

This categorization is intended to support decision-makers in prioritizing interventions based on resource availability and institutional readiness, while ensuring that both *service improvements in the next edition of Kumbh Mela* and *long-term development planning* are addressed.

6.8 Recommendations for future Kumbh Melas

6.8.1 Service: Water

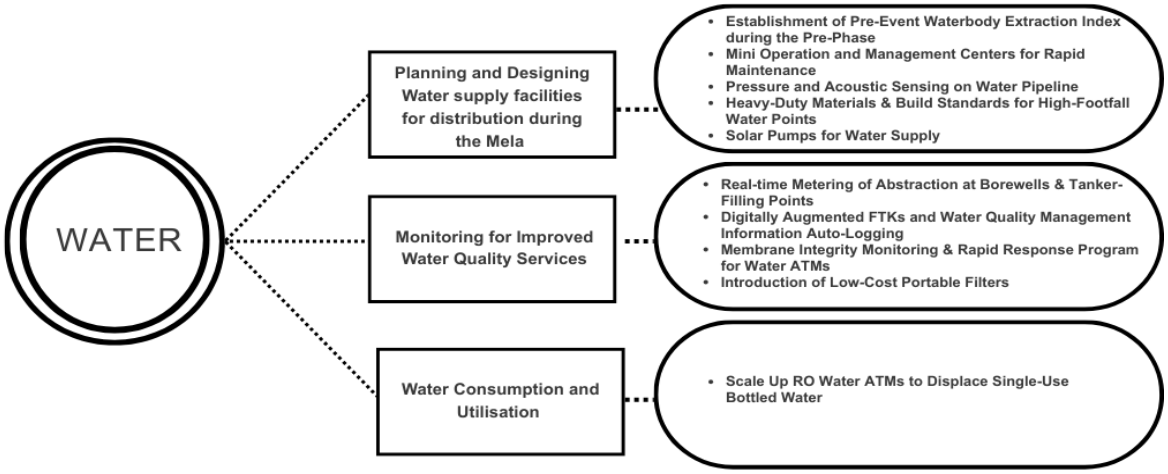


Figure 6.88 Flowchart of recommendations for Water as a service at Kumbh 2025

6.8.1.1. Point of Intervention

Planning and Designing Water supply facilities for distribution during the Mela

A. In Near Future:

a. **Establishment of Pre-Event Waterbody Extraction Index during the Pre-Phase *(Drivers: Institutional and Governance)*:** Establish a pre-event "Waterbody Extraction Index" (WEI) to automatically and accurately delineate surface water features from multispectral satellite imagery, principally Landsat-8 OLI, so that source selection, treatment sizing, and establishment of water points (e.g., Water ATMs, standposts, tanker fill-sites) are grounded in timely hydro-spatial evidence (Yan et al., 2023). This approach provides a standardized WEI that is repeatable and recognises vector hydro lines that materially reduce planning uncertainty and improve equity of access (significant for WaSH use case).

b. **Mini Operation and Management Centers for Rapid Maintenance *(Drivers: Institutional and Governance)*:** At the Maha Kumbh Mela service delivery disruptions

were generally small in scale but occurred at multiple times and locations. Authorities can establish mini-operation centres (MOCs) within the Mela site at specific intervals to maintain and deliver services. This can help in having a response time under 30 minutes. This recommendation is based on stakeholder consultation which indicated that in some of the sectors- such as sector 6,7, 18,19, 20 and 21 service delivery sometimes took more than 4-5 hours. This was mainly attributed due to high influx of population which created logistical challenges for the operations and management team. By decentralizing operational control and embedding response capacity closer to service zones, MOCs can:

- Reduce downtime and service gaps.
- Enhance psychosocial comfort by minimizing wait times and uncertainty.

c. **Heavy-Duty Materials & Build Standards for High-Footfall Water Points *(Drivers: Institutional and Governance; Technology and Infrastructure):*** To ensure uninterrupted access to safe drinking water during peak crowd conditions, authorities can prioritize the installation of high-durability, abuse-resistant materials and assemblies across all public water infrastructure such as Water ATMs, standposts, tanker manifolds, and wash points. Field observations during Maha Kumbh Mela 2025 revealed frequent damage to water infrastructure due to repetitive use, crowd pressure, and occasional misuse or overloading of assets and exposure to harsh weather conditions. These incidents added to service delivery but also increased the burden on emergency response teams and led to avoidable downtime. By adopting heavy-duty pipes, reinforced valves, tamper-proof enclosures, and corrosion-resistant fittings, the infrastructure can better withstand operational stress and environmental wear. This approach offers several key benefits:

- Reduced frequency of burst or leak incidents, especially during peak footfall.
- Minimized service interruptions, ensuring consistent potable water availability.
- Lower operational costs over time, as higher upfront specifications reduce the need for emergency repairs, tanker substitutions, and reactive maintenance.
- Improved water quality assurance, as robust infrastructure helps maintain hygienic conditions and prevents contamination.

6.8.1.2. Point of Intervention: Monitoring for Improved Water Quality Services

A. In Near Future:

d. **Real-time Metering of Abstraction at Borewells & Tanker-Filling Points:** Install tamper-proof digital and smart flow meters with telemetry on all public borewells and

tanker-filling points to measure volumes abstracted in real time for compliance, safeguarding aquifers, and optimizing WaSH service continuity during Kumbh (Mudumbe & Abu-Mahfouz, 2015). This installation will help by providing continuous metering focusing on auditable evidence, enabling rapid switchovers, and reducing "unaccounted" abstraction which is core to safe and reliable WaSH service delivery. Moreover, it aligns with India's CGWA (Central Ground Water Authority) mandate for tamper-proof digital meters with telemetry on abstraction structures.

e. **Digitally Augmented FTK's and Water Quality Management Information Auto-Logging *(Drivers: Technology and Infrastructure)*:** Upgrade the existing water-quality management mechanism by equipping Field Testing Kits (FTKs) with a flow-through sensor module (digital pH, TDS, free chlorine) and a LITE version smartphone app that auto-records, time-stamps, geo-tags, and syncs results to the Jal Jeevan Mission Water-Quality Management Information System (WQMIS) for near real-time surveillance at strategic Kumbh locations (e.g., Water ATMs, standposts, and tanker positions)('From Innovation to Social Impact', 2018). This framework explicitly anticipates IoT and digital data acquisition for faster alerts and system-level decisions. Amalgamating digital FTKs to the WQMIS closes the loop from detection to action, reduces transcription errors, and shortens time-to-remedy during peak footfall.

f. **Membrane Integrity Monitoring & Rapid Response Program for Water ATMs *(Drivers: Drivers: Institutional and Governance; Technology and Infrastructure)*:** Enable Water ATMs with programs for early detection of membrane degradation early; and execute corrective actions (cleaning or part replacement) by a dedicated service team based on detection at Water ATMs so that water safety and uptime are maintained under peak population loads. This would help in reducing calls to helpline numbers during peak days.

g. **Introduction of Low-Cost Portable Filters *(Drivers: Institutional and Governance; Technology and Infrastructure)***: Authorities such as the PMA, NMCG and Ministry of Jal Shakti can establish a public-private-partnership program through which they can promote and sell low-cost, non-electric, price-transparent portable water filters (e.g., gravity-based, ceramic, or equivalent) at the Kumbh Mela grounds so that floating populations can reliably access point-of-use safe drinking water throughout the event ('From Innovation to Social Impact', 2018). Making such units available at the point of need with clear use instructions extends water-safety protection beyond fixed Water ATMs and standposts, and during transit back to camps or lodgings.

6.8.1.3 Point of Intervention: Water Consumption and Utilisation

A. In Near Future:

h. **Scale Up RO Water ATMs to Displace Single-Use Bottled Water:** Our observation from the filed showed high usage of single-use PET-bottles leading to high plastic waste. Authorities may consider rapidly expanding RO-treated Water ATMs across high-footfall corridors and camps to make safe refills the default choice and disincentivize single-use PET bottles (Elasaad et al., 2015). This scaling up would significantly support efforts to minimize plastic use within Mela grounds which will indirectly reduce the burden of plastic disposal. This duality will not only increase the number of drinking water facilities but will also reduce the probability of further environmental degradation.

6.8.2 Service: Sanitation

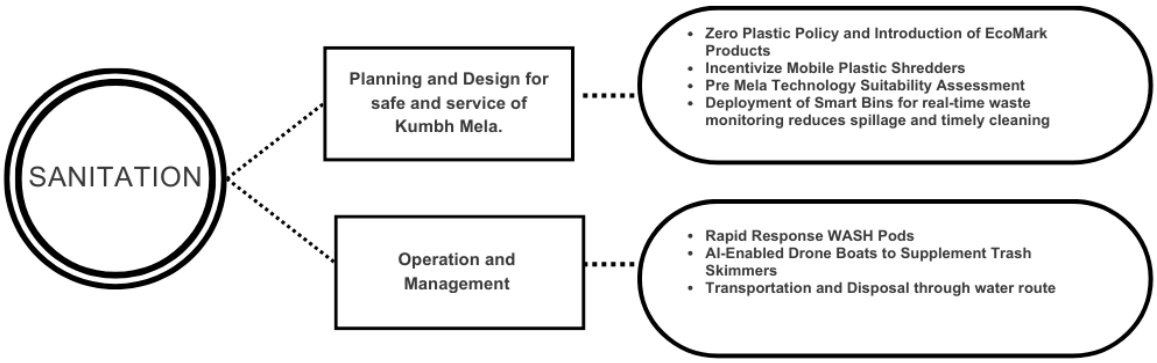


Figure 6.89. Flowchart of recommendations for sanitation as a service at Kumbh 2025

6.8.2.1. Point of Intervention Planning and Design for safety and service of Kumbh Mela

A. In Near Future:

a. **Zero Plastic Policy and Introduction of EcoMark Products *(Driver: Institutional and Governance; Impact: Reducing Environmental impacts*):** The Mela Authority may consider introducing and progressively enforcing a Kumbh-wide restriction on single-use plastics (PET bottles, disposable cups/plates/cutlery, multilayer sachets, plastic flags/garlands, thin carry-bags) across all the designated pilgrimage zones and with on-site deposit-return systems. They can introduce required approved alternatives such as the use of EcoMark-certified products and compostables conforming to IS/ISO 17088 (where categories exist) to cut environmental impact at source, covering packaging/food ware, soaps & detergents, paper, textiles, batteries/electricals, and plastics as a requirement for vendors and service contractors (CPCB, 2017). Mela Authority could explore a permit system that prioritizes EcoMark of products while tendering, stall installations and supply

contracts. A pre-event vendor awareness drives and signage ("Look for the EcoMark") can be conducted to foster voluntary compliance.

B. Mid to Long Term:

b. **Pre Mela Technology Suitability Assessment *(Driver: Infrastructure and Technology)*:** To provide the best services, the procuring committee may consider running a structured technology suitability assessment to test applicability, scalability, and contextual relevance of WaSH tech intervention before procurement or deployment. We recommend the use of Technology Applicability Framework (TAF) to score sustainability of WaSH services across technical, economic, environmental, institutional/legal, skills, and social dimensions (WaSHTech/IRC, 2013). Alternatively, CSTEP's India-specific TAF 2.0, can be followed that adds regulatory compliance, institutional readiness, resource availability, and regional adaptability for Indian conditions (CSTEP, 2023).

c. **Deployment of Smart Bins for real-time waste monitoring reduces spillage and timely cleaning *(Driver: Infrastructure and Technology)*:** Mela Authorities could explore installing IoT-enabled smart bins (e.g., AirBin from an IIT-Madras–incubated startup) in every sector to track fill level and push real-time alerts to the ICCC. This would help in optimizing collection routes. Smart bins prevent overflows, cut fuel-intensive "fixed rounds," and raise segregation quality by directly supporting cleaner ghats and camps during peak footfall (Antariksh Waste Ventures, 2020; MoEFCC, 2016).

6.8.2.2. Point of Intervention: Operation and Management

A. Medium to Long Term:

- **AI-Enabled Drone Boats to Supplement Trash Skimmers:** Complement existing mechanized trash skimmers with AI-enabled, fully electric drone boats (e.g., Clearbot) to patrol bathing stretches and upstream feeders for floating waste, with geofenced routes, remote supervision, and live telemetry to the ICCC. This builds on India's river-surface cleaning practice under Namami Gange and recent AI-boat deployments in Meghalaya's *Umiam* Lake (NDTV, 2023; IndiaAI, 2023), where units have demonstrated high payload/collection capacity (Clearbot, 2024).

a. To assess the feasibility of transportation and disposal through water route: This recommendation was considered not feasible at the time of our consultation due operational constraints, However, as per Mela authority there is feasibility if studied for future purposes and explored further to create a new route for waste disposal that is isolated and does not disrupt in mela crowd movement. For future, a research or

consulting agency can run a network feasibility assessment to move selected waste streams by river routes during Kumbh, mapping each sector to the landfill and nearby navigable waterways. Use proximity network analysis to shortlist docking points, route length, travel time and safety buffers, then define an operations concept with enclosed, double-contained bins/skips on compliant vessels and strict zero-discharge SOPs.

6.8.3 Service: Hygiene

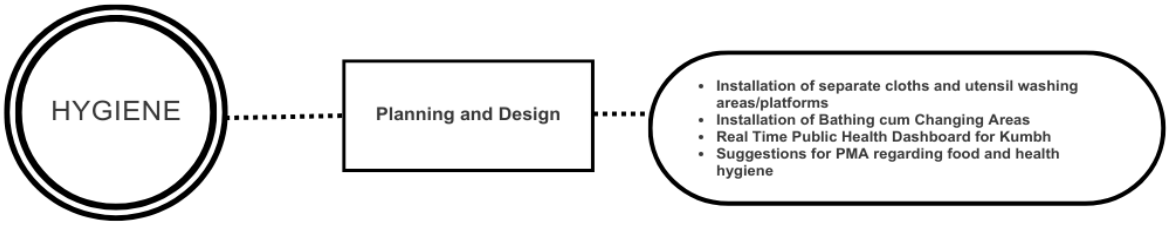


Figure 6.41. Flowchart of recommendations for Hygiene as a service at Kumbh 2025

6.8.3.1 Point of intervention: Planning and Design

a. **Installation of separate cloths and utensil washing areas/platforms:** Our interactions with institutional stakeholders and on field observations have indicated that there is a lack of designated space for washing clothes and utensils for pilgrims observing Kalpavas. We observed pilgrims washing clothes on the banks of the rivers and underwater standposts. This can contribute to contamination risks for both river water and drinking water. As pilgrims wash clothes at standpoints, pools of water develop around it leading to multiple challenges such as reduced accessibility to the point for drinking and potential mosquito breeding in stagnant pools. Thus a few stakeholders promoted the idea of installing separate clothes and utensils washing aeras or platforms.

b. **Real Time Public Health Dashboard for Kumbh:** Develop a real-time public health dashboard for Kumbh Mela by establishing a multi-layered health surveillance model by integrating infection heatmaps, predictive analytics, and geotagged health data. Refer to Saudi Arabia's Hajj health system which offers a useful model with electronic surveillance, vaccination tracking, and heat illness monitoring (World Health Organization Eastern Mediterranean Regional Office, 2018; Alromaihi et al., 2021).

6.8.4 Over all recommendations for WaSH Services at Kumbh Mela

6.8.4.1 Research and Development cell for WaSH (Drivers: Institutional and Governance)

Establish a dedicated R&D cell with Kumbh Fellows to monitor and fine-tune the delivery of WaSH Services. This cell can work along multiple-stakeholders to monitor and develop SOPs for efficient and improved delivery of WaSH services in each Kumbh Mela.

6.8.4.2 Optimisation of Signage

Based on the comments from the floating population we have drawn on that authorities could strengthen signage by installing multilingual and pictorial signages near RO Water ATMs and standposts for high visibility. The facilities should be installed at entry gates, ghats, sanitation clusters, and food zones and other important hot spots areas with micro-nudge prompts such as "Use with care," "Refill, don't waste," and "Clean hands, clean soul" (Houts et al., 2006).

6.8.5 Special recommendations for influencing behaviour of floating population through hygiene knowledge and awareness initiatives

Based on our studies we have concluded that to ensure sustained hygiene and sanitation practices among the millions of pilgrims attending the Kumbh Mela, government and private parties including NGOs need a structured behavioural nudging framework that is actionable from pre-Kumbh phase.

6.8.5.1 Nudging recommendations for Pilgrims

Trained hygiene volunteers *(Swachhagrahis)* can engage pilgrims using culturally resonant messaging, drawing from local idioms, religious metaphors, and visual storytelling (India Water Portal, 2021). These nudges can be delivered through brief, respectful interactions at key congregation points such as ghats, langars, and sanitation facilities.

6.8.5.2 Partnership with religious and spiritual leaders to drive WaSH practices

Faith leaders are uniquely positioned to influence pilgrim behaviour at the Kumbh Mela through trusted, value-based communication that aligns spiritual beliefs with public health goals. Hygiene practices such as handwashing, toilet use, and safe water consumption can be framed as acts of devotion and spiritual purity, using religious discourses, rituals, and symbolic cues to reinforce these behaviours (Kruk & Aboul-Enein, 2024). To support this, faith leaders should be equipped with culturally resonant visual aids and scripts that integrate spiritual values with hygiene messaging. These messages must be consistently delivered across platforms *pravachans,* ghat announcements, and temple rituals to ensure widespread reach and retention. A network of trained volunteers can monitor message dissemination and behavioural uptake,

creating feedback loops that sustain and adapt the intervention over time. To institutionalize this approach, the Mela Authority may consider formally collaborating with religious and faith leaders as partners in WaSH awareness efforts. Strategic partnerships with Akharas and faith institutions can help deliver concise, high-reach messages that align spiritual teachings on water stewardship and environmental responsibility with WaSH goal on water stewardship and environmental responsibility. These messages should be integrated with the use of water infrastructure such as RO Water ATMs, standposts, and ghats through ritual-adjacent announcements and symbolic acts (e.g., offering water responsibly). Furthermore, existing community networks like Ganga Praharis and IEC efforts under the Namami Gange programme can be leveraged to amplify outreach and ensure alignment with broader water and sanitation goals. This faith-led behavioural strategy embeds hygiene and environmental stewardship within the spiritual experience of the Mela, fostering long-term behavioural change on a scale.

6.8.3.3 Commitment drives and social proofing:

Mechanisms such as the *Swachhata Pledge* and visible *Cleanliness Badges* can be scaled up to foster public commitment. Pilgrims who take the pledge can receive symbolic tokens (e.g., wristbands or stickers) reinforcing their role as cleanliness ambassadors. Drawing from *Swachh Survekshan* practices, cleanliness scores for each sector or zone can be displayed on digital boards and mobile apps. These scores, updated in real-time using ICCC dashboards, will create a sense of collective accountability and healthy competition among zones.

6.9 Discussion and Conclusion:

Through this study we explored the Status and Impacts of WaSH services (Water, Sanitation and Hygiene) at Mahah Kumbh Mela 2025 from the floating population. We analysed and recorded several parameters against which we developed reporting and evaluation framework, K-WASH to present the Status and the Impacts. The framework has been developed to analyse multi-dimensional Driving factors such as how the cultural practices of floating population affect the consumption and management of WaSH services.

From our study, using the K-WASH framework for evaluating the Maha Kumbh Mela 2025, we found that the influx population demography was dynamic. Our study indicated that the population shifted from high income group, middle aged, educated and professionally engaged individuals in the pre- Mela phase to a more diverse and broader participation in terms of income, education and occupation during the Mela, and finally to economically vulnerable,

less educated groups in the post-Mela phase. We also observed a surge in younger population with high gender imbalance in during phase, with more male pilgrims over females. Although observational insights indicated a substantial presence of women from rural backgrounds during Kumbh Mela, their representation within the survey sample remained limited, due to their reluctance to answer the survey. The influx showed diversity in during phase, representing national level participation, while in pre and post phase maximum pilgrims were from Uttar Pradesh and nearby states showcasing regional pilgrimage aspects of Kumbh. Highly localized population in pre-phase indicating towards strategic decisions of local pilgrims to avoid congestion in the during phase.

Overall, people were satisfied by the WaSH services provided during the Mela. Some limitations were also noted by pilgrims given the sheer size and magnitude of the floating population. During our consultation with the institutional stakeholders, we found that environmental uncertainties exist that direct Mela related human activities cannot influence better planning of WaSH services. For instance, the entire deployment and installation of WaSH infrastructure is highly dependent on the length of monsoon and water levels at Prayagraj. Since the Mela takes place on the banks Ganga and Yamuna rivers, the riverine flow impacts the execution process of installing and deploying WaSH services. This year's Maha Kumbh Mela was also affected by this scenario which affected the execution of infrastructure provision and service delivery.

During the Mela, we observed that there was pressure on WaSH facilities which led to the state of burdened sanitation workers as they continuously worked hard to provide clean WaSH facilities, highlighting the need for improvements in public behaviour. This problem was more prominent during major *Snan* days. The operation and maintenance of WaSH facilities were managed with efficient governance mechanisms, such as, by privatizing sanitation services in public areas, adopting three types of surveillance system of WaSH services, etc. This showcased the evolution of governance mechanisms incorporating tech-based innovations in the Kumbh Mela settings. However, certain intractable constraints still existed, hampering service delivery in the purview of WaSH services. For example, signage deployment at the Mela could be further strengthened to cater to public needs with a shortage of multi-languages including pictorial directions for the pilgrims. This may have affected perceived accessibility of WaSH facilities as they had to walk long distances.

In the post-phase, WaSH service facilities were dismantled as per the guidelines of PMA, which used disinfection and proper waste disposal to mitigate spread of infection from the Mela site that has been contaminated over the period of 45 days. Activities like cleanliness drives initiated by eminent organizations, such as NMCG, ensured the post recovery of Ganga Yamuna floodplains.

While real time monitoring of WaSH services was primarily confined to surveillance activities, there remains significant scope for its integration across other critical stages of service delivery, which includes planning, resource distribution and operational management. Embedding real time monitoring mechanisms within these domains would enable more responsive and sustainable approaches, such as accurately estimating the carrying capacity of water supply systems and improving predictive forecasting to meet dynamic demand also keeping the health of floodplains in consideration, during mass gatherings, as discussed in various sections of recommendations.

Our overall observation indicates that for a successful WaSH service, beyond the deployment of infrastructure, the floating population visiting the site needs to be imbued with WaSH practices and knowledge. This can be effectively undertaken in the pre-phase of the Mela, across the country as it attracts population from all places of India, where we induce certain WaSH practices and knowledge through social media and campaigns. This would help in reducing pressure both on the facilities and cleaning staff during the Mela. Secondly, both observations and stakeholder consultation in our study suggest that religious and spiritual leaders can play a crucial role in changing the behaviour of the floating populations especially through their sermons. Finally, we think that there is a scope of further developing private partnerships to share the burden of service delivery in the purview of WaSH services. Our consultation with PMA officials shows that are open to the idea and if possible, they might try in the next edition of Kumbh Mela at Prayagraj.

Based on our K-WASH framework which used DPSIR conceptually to understand the state, impacts, drivers and pressures, we found that the overall WaSH services delivery at the Maha Kumbh Mela was satisfactory and well planned given that it was the biggest congregation of humans ever in the world. Given the situation, our framework was valuable in structuring, and logically analysing the WaSH services, however there were a few limitations of both the study and the methodology.

Since the framework was developed parallelly to the Maha Kumbh Mela, this posed both pros and cons for us. As pros, we were able to minutely capture and modify the framework as per the needs and requirements which the research team learnt from the field, however, the cons were in uniformly capturing data across the three phases. As DPSIR based frameworks and models are heavily dependent on the availability of reliable and disaggregated data for each component, in mass gatherings, population estimates, and facility usage data are often uncertain, leading to potential biases in assessing state and impacts, especially when focusing on indicators.

The development of K-WASH framework using DPSIR has huge potential to be developed as a data integrated monitoring and reporting framework. Being the first framework ever developed for monitoring and reporting on WaSH services in religious mega gatherings, it requires further revaluation in next edition of Kumbh Mela held in different cities in India to enhance its output. The framework can be further enhanced to collect and self-report status with AI integration providing continuous and real-time input on the state, impacts and pressures while identifying the drivers. This would help PMA and other associated stakeholders to take instantaneous actions for better WaSH service delivery continuously during Kumbh Melas. This project also develops a dashboard, Kumbh-Manthan, to display the complete inventory of pre-, during-, and post-Kumbh activities related to the IPSA-Kumbh project (see Annexure I). Future research can be undertaken to enhance these features and develop an app or dashboard for the framework.

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ANNEXURES

Annexure A: Sampling Site Images



SP1 – Steel Bridge, River Ganga



SP4 - Salori



SP7 – Ganga, u/s to Sangam



SP8 – Prayagraj Fort



SP9 – Sangam

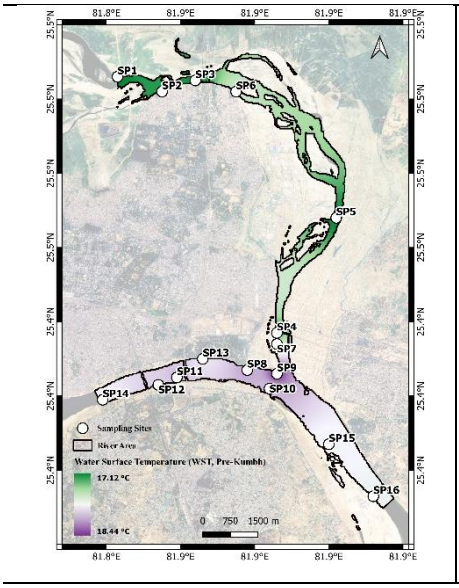
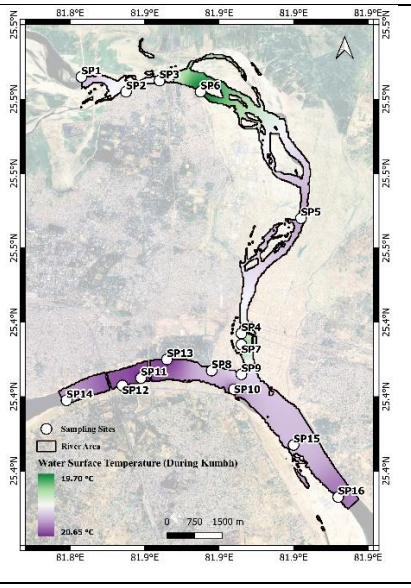
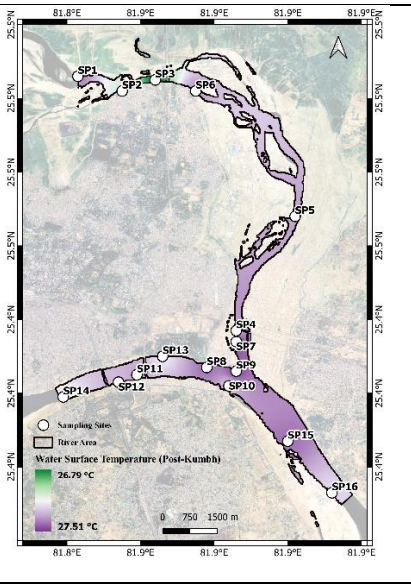
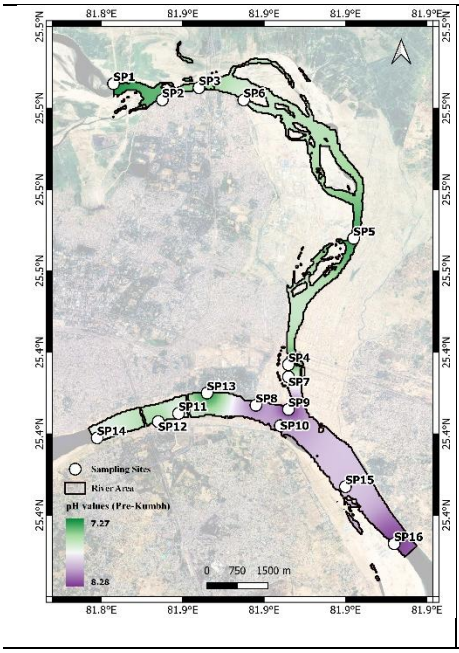
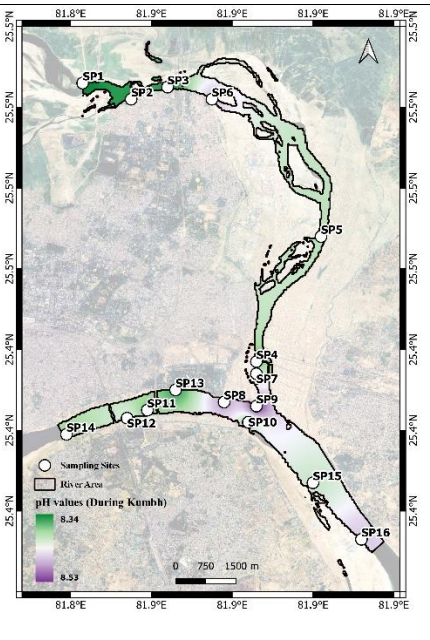
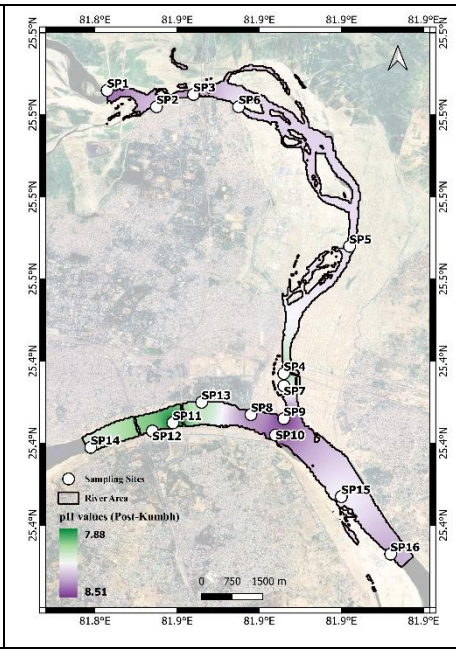


SP13 – Saraswati Ghat

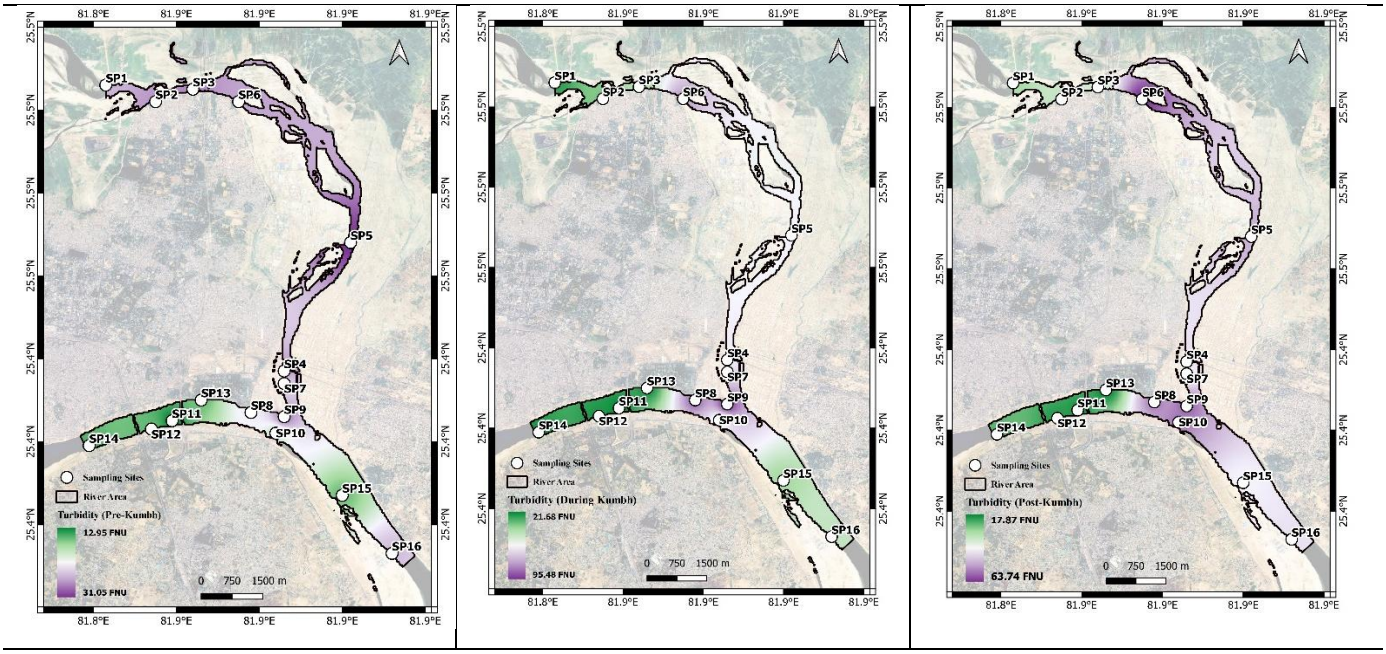
Annexure B: Sampling and Main-Snan dates

	Sampling Dates	Main-Snan
Pre-Kumbh	16-12-2024	
	26-12-2024	
	07-01-2025	
	08-01-2025	
During Kumbh	12-01-2025	
	13-01-2025	Paush Purnima
	14-01-2025	Makar Sankranti
	15-01-2025	
	17-01-2025	
	22-01-2025	
	28-01-2025	
	29-01-2025	Mauni Amavasya
	30-01-2025	
	02-02-2025	
	03-02-2025	Basant Panchami
	04-02-2025	
	06-02-2025	
	11-02-2025	
	12-02-2025	Maagh Purnima
	13-02-2025	
	16-02-2025	
	21-02-2025	
	25-02-2025	
	26-02-2025	Maha Shivratri
	27-02-2025	
Post Kumbh	03-03-2025	
	08-03-2025	
	12-03-2025	
	24-03-2025	

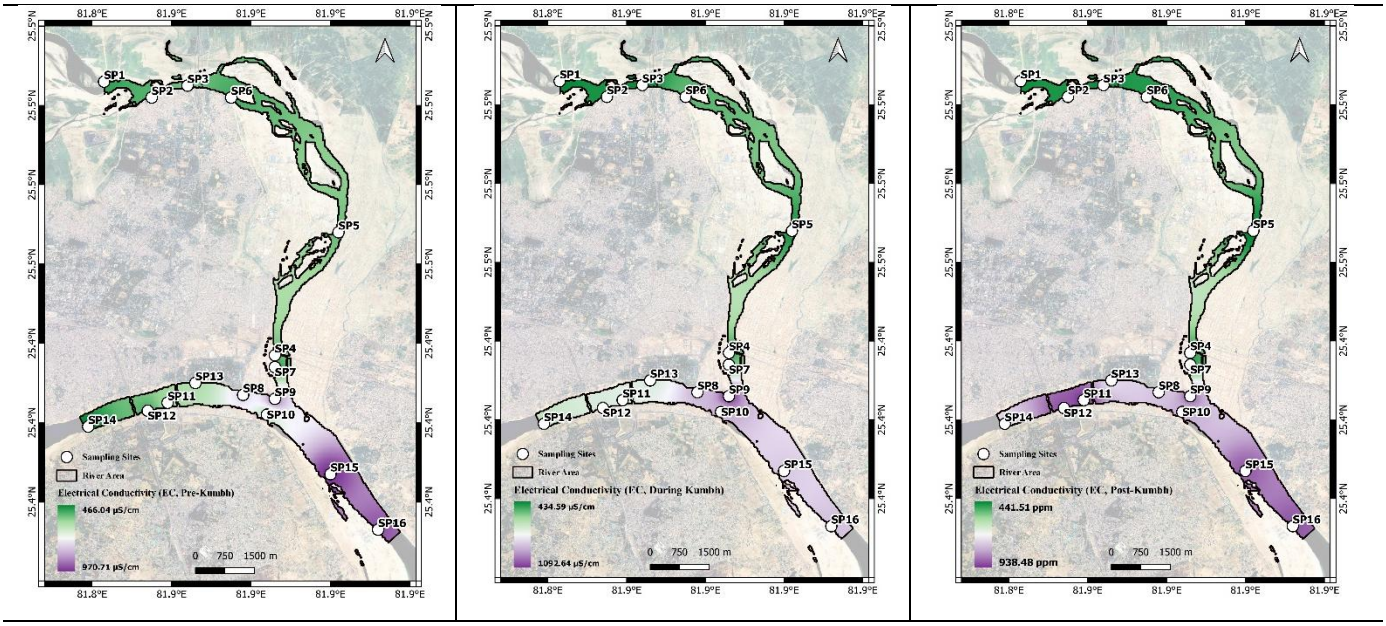
Annexure C: Spatial variation of water quality parameters

PRE-KUMBH (16/12/2024 to 08/01/2025)	DURING KUMBH (12/01/2025 to 27/02/2025)	POST-KUMBH (03/03/2025 to 24/03/2025)
1. Water Surface Temperature (WST, °C)		
		
2. pH Values		
		

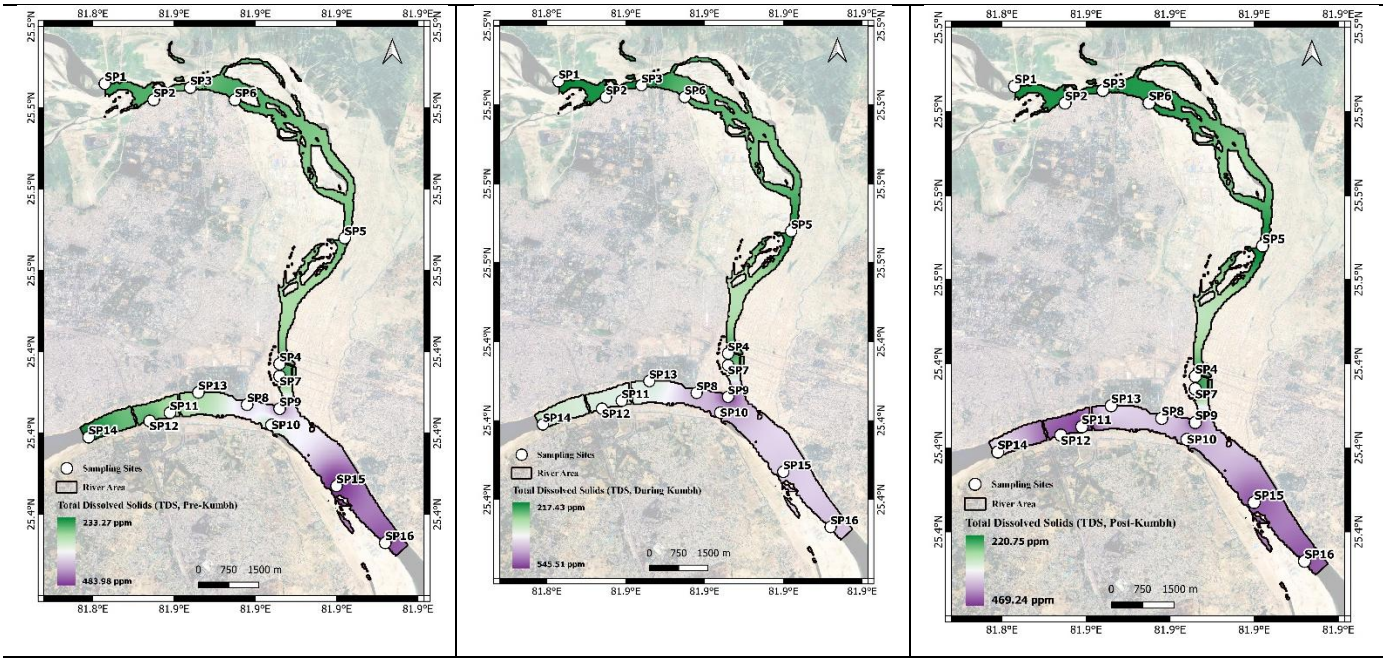
3. Turbidity (FNU)



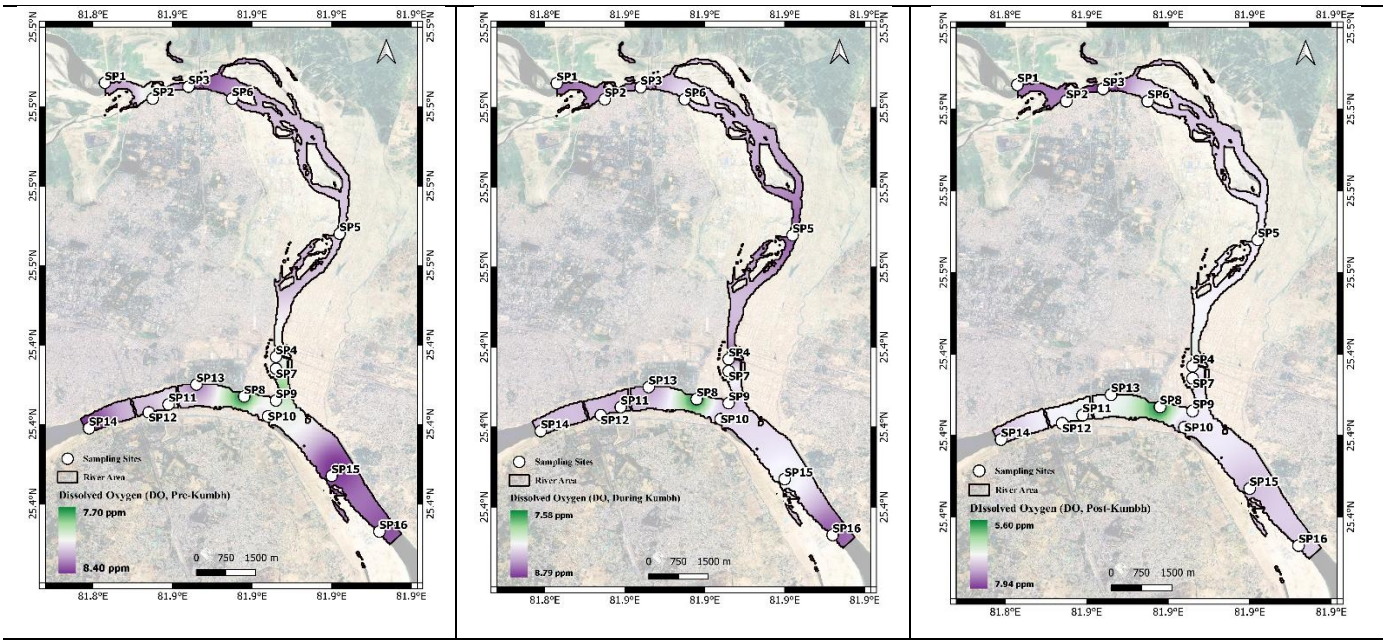
4. Electrical Conductivity (EC, µS/cm)



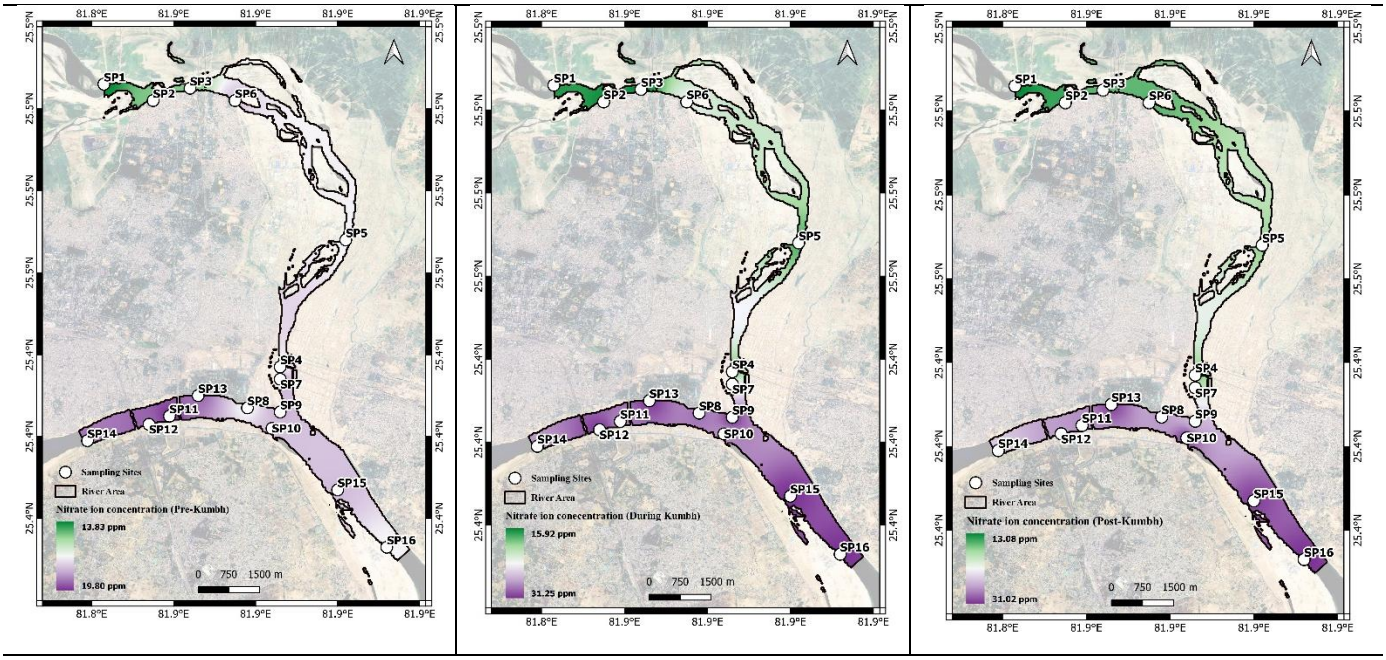
5. Total Dissolved Solids (TDS, ppm)



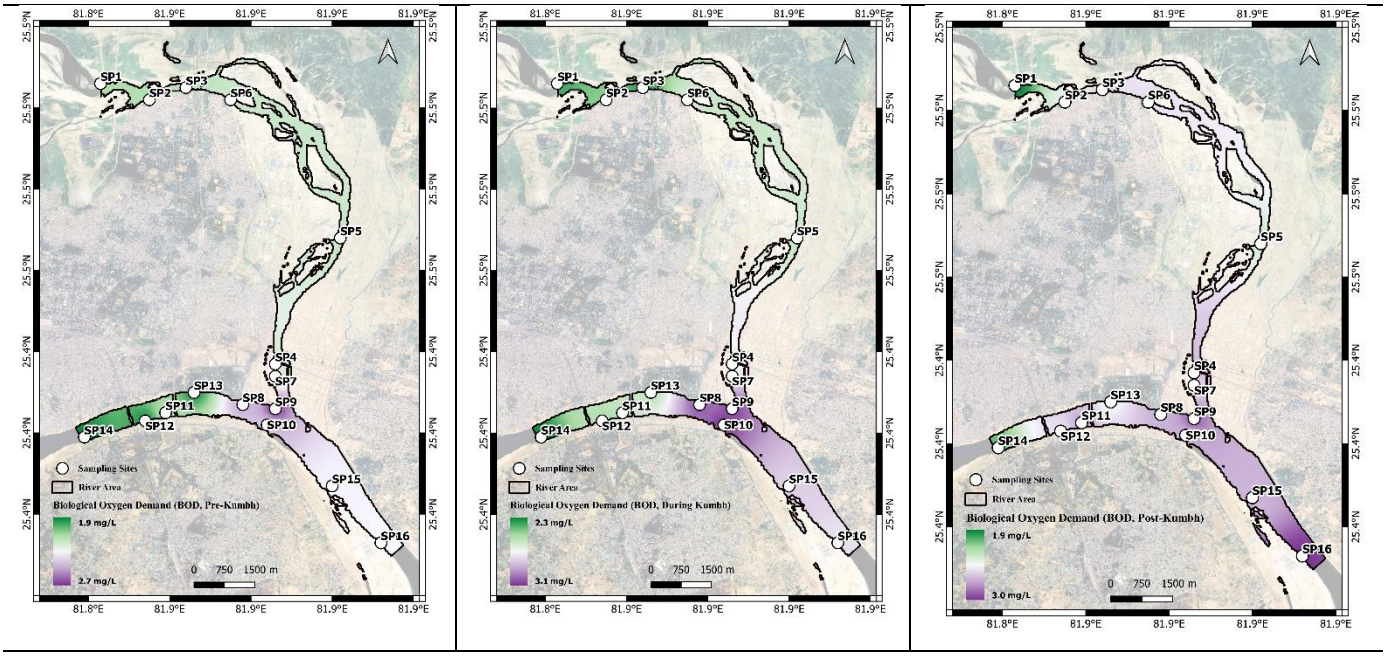
6. Dissolved Oxygen (DO, ppm)



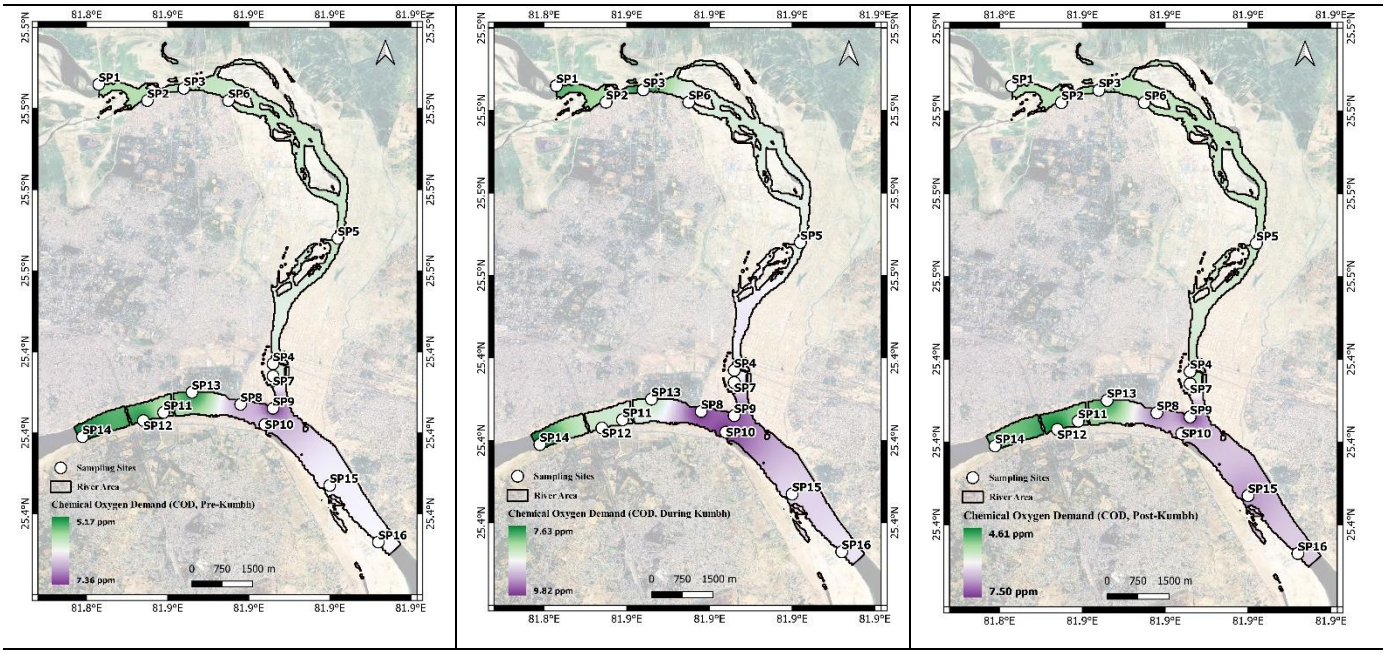
7. Nitrate concentration (ppm)



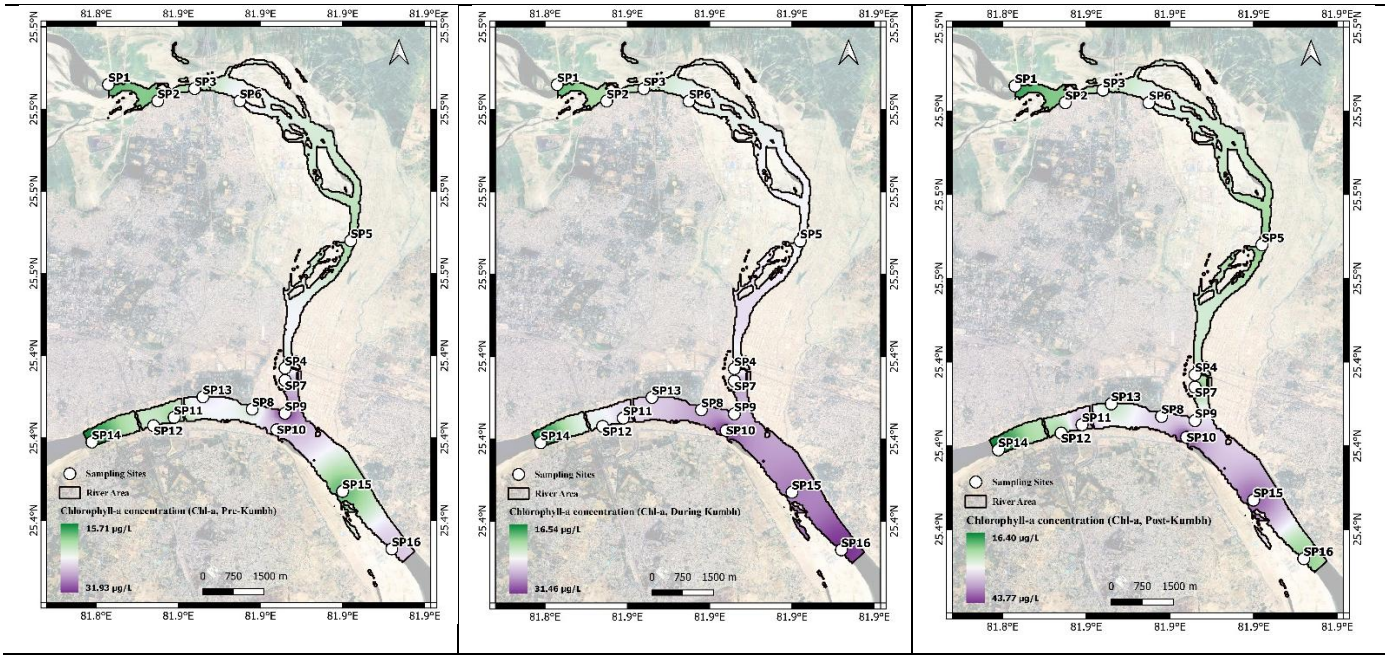
8. Biochemical Oxygen Demand (BOD, mg/L)



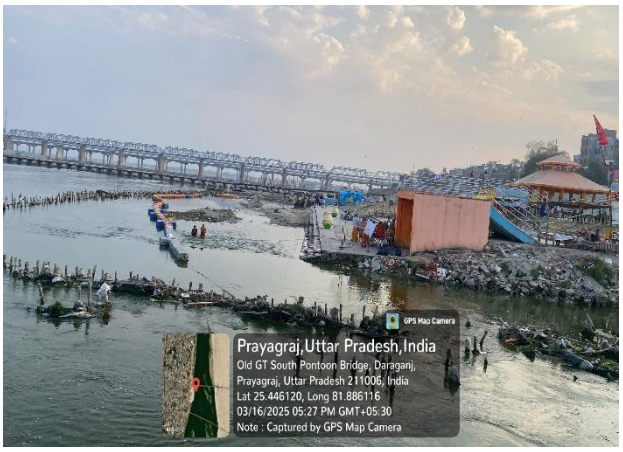
9. Chemical Oxygen Demand (COD, ppm)



10. Chlorophyll-a concentration (Chl-a, µg/L)



Annexure D: Maha-Kumbh 2025: A walk along



In this image, the water level in the channel is observed to be low, likely due to controlled flow regulation. During this period, government authorities carried out cleaning and maintenance activities in the Ghat area. Additionally, repair and restoration work is visible along the banks and adjacent structures, indicating ongoing efforts to upgrade infrastructure and maintain sanitation standards for the public.



This image depicts volunteers actively cleaning the riverbank, collecting plastic waste, ritual materials, lamps, and other discarded items in a black plastic bag to ensure a cleaner and healthier environment

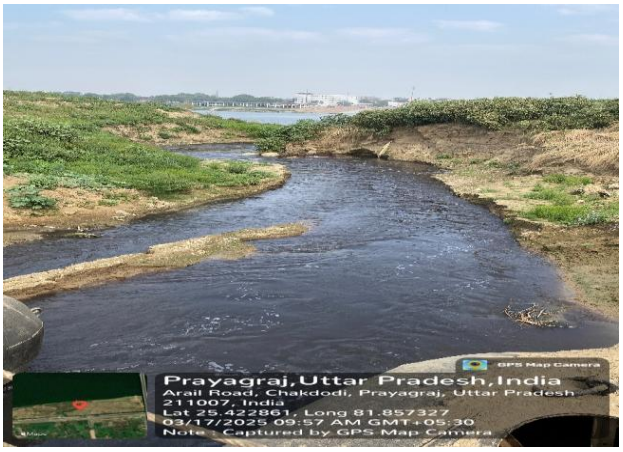


Administrative authority is actively working to prevent people from polluting the river by instructing people not to dispose of waste, throw offerings, or use soap in the water.

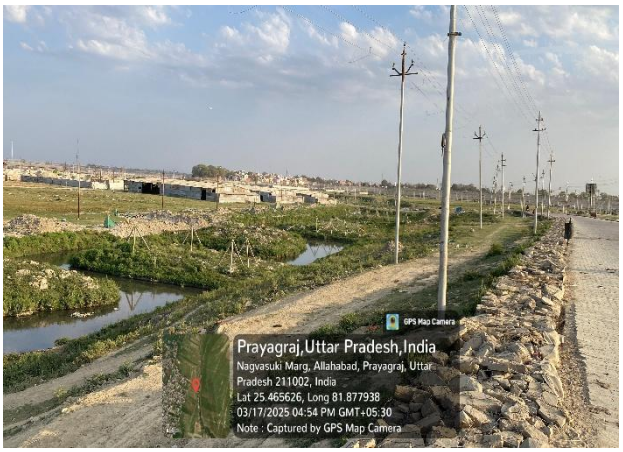
Pollution levels remain minimal in areas where law enforcement and administrative authorities are actively fulfilling their duties



In the Kumbh area, temporary toilet facilities were established with septic tanks designed for sludge storage. As per the NGT guidelines, the Mela authorities ensured that open discharge was strictly avoided, thereby preventing any flow into drains or direct entry into the river system



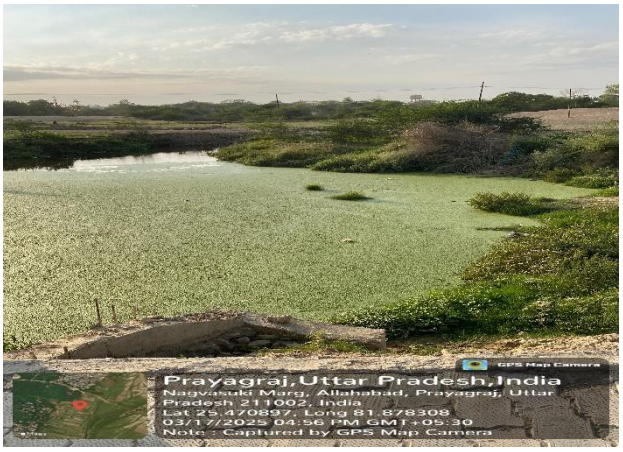
The discharge from the Naini-I 80 MLD STP eventually merges with the Yamuna River, posing a serious threat to water quality. The water may contain a high concentration of phosphates and other organic contaminants, which can significantly degrade the river's ecological health.



A parallel channel runs alongside the mainstream of the River Ganga, serving as a conduit for multiple sources of discharge. This channel receives treated water from the Sewage Treatment Plant (STP), as well as untreated or partially treated city wastewater. Additionally, a Z-shaped flow path is depicted in the figure, which is engineered to regulate flow velocity and enhance aeration. This design helps increase the dissolved oxygen (DO) levels in the water.



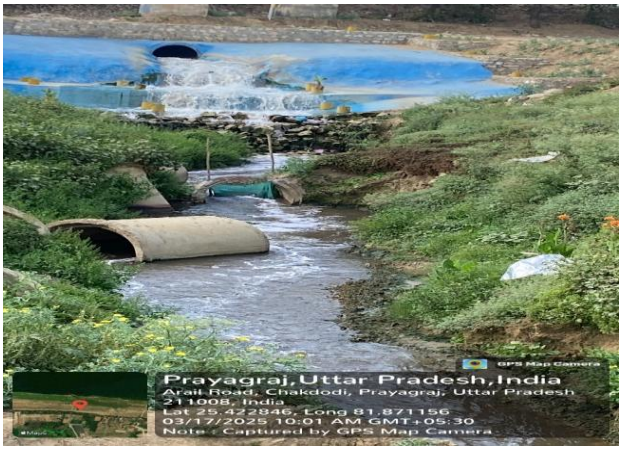
The presence of excessive foam suggests high levels of phosphorus and nitrogen may indicate inefficient wastewater treatment or untreated effluent discharge. The pink color may sign of chemical pollutants, industrial dyes, or microbial activity (such as pigmented bacteria).



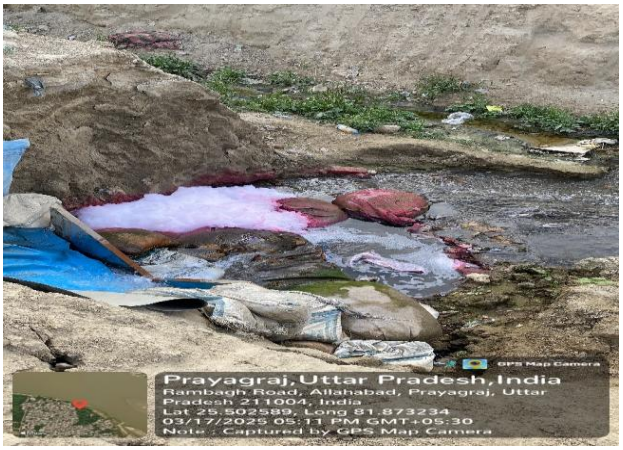
This image shows a water body covered with a dense layer of green aquatic vegetation, most likely algal bloom, indicating eutrophication. The presence of excessive nutrients, likely from wastewater discharge, has led to rapid algal and plant growth, depleting dissolved oxygen.



The presence of foam and black-colored water in the STP outlet indicates that the water might contain high levels of organic matter, detergents, and possibly industrial waste. The black color could indicate high levels of dissolved organic carbon (DOC), sulfides, or untreated sewage, while foam formation can be linked to surfactants, detergents, or excessive microbial activity.



The presence of foam, color, or foul odor in the discharged water could indicate partial treatment. This water may contain phosphate and organic matter levels (often visible as foaming), suggesting potential contamination from detergents, industrial effluents, or biological waste.



This image depicts an STP outlet carrying partially treated wastewater with visible signs of chemical contamination, including white foam and pink-colored effluent. The white foam indicates high concentrations of phosphates and organic pollutants, which can severely degrade water quality. The pink color in the effluent suggests possible contamination from textile dyes, synthetic chemicals, or industrial wastewater.



The image depicts a functional Sewage Treatment Plant (STP) located within the Kumbh city area. The treated effluent discharged from the STP is observed to contain a significant amount of white foam, which is a strong indicator of high phosphate concentrations in the water. This foaming phenomenon suggests incomplete removal of phosphates during the treatment process.



In this image, volunteers are seen collecting flowers, clothes, and other ritual offerings in black/blue color bags, ensuring that these materials are safely removed from the ghat area. This thoughtful practice helps prevent the pollution of the River Ganga by stopping non-biodegradable and organic waste from entering the water.



This image illustrates a large pit excavated during the Mahakumbh, originally intended for storing wastewater generated by the temporary tent settlements along the riverbank. However, the wastewater is directly flowing into the main channel of the River Yamuna. Such unregulated discharge can significantly deteriorate water quality by increasing nutrient loads, promoting microbial contamination, and reducing dissolved oxygen levels.

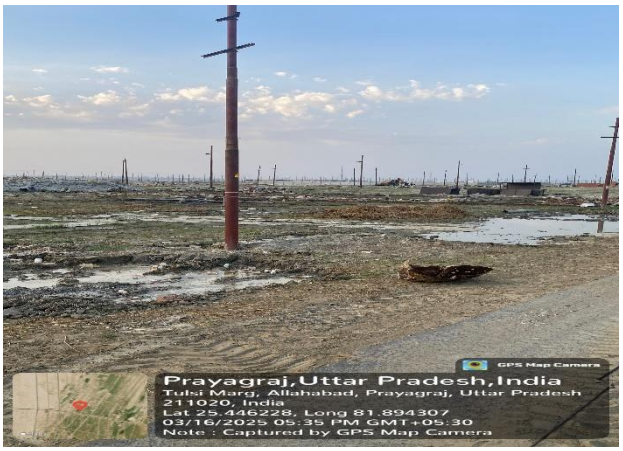


In this image, blue, pink, and yellow-colored cabins can be identified. These cabins were temporary toilet units installed during the Kumbh Mela to provide essential sanitation facilities for pilgrims and visitors. Now that the Kumbh Mela has concluded, these temporary toilets have been dismantled and relocated to a designated area for collection and loading onto trucks. This process ensures that the event site is

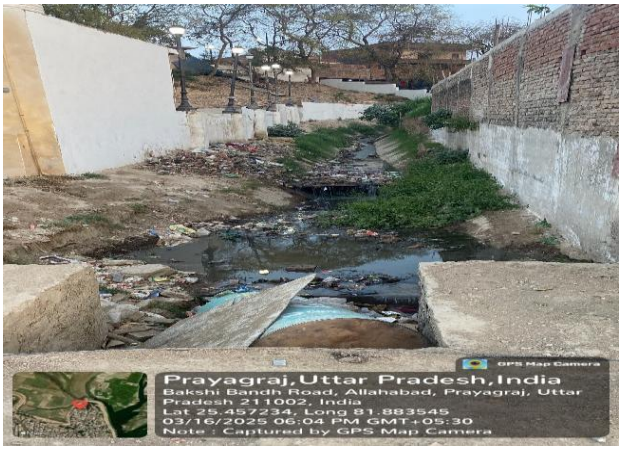
cleared and restored after the large-scale gathering.



The image depicts a city drainage channel carrying household wastewater. The water in the drain contains floating debris, such as plastics and other solid waste, indicating inadequate solid waste management. Additionally, vegetation can be seen along the sides of the drain, which may be a result of nutrient enrichment from the domestic wastewater.



This image depicts the condition of the post-Kumbh area. During the Kumbh Mela, several drains were excavated for temporary wastewater management; however, the wastewater remained stagnant in these drains even after the event.



The image depicts a city drainage channel carrying household wastewater. The water in the drain contains floating debris, such as plastics and other solid waste, indicating inadequate solid waste management. Additionally, vegetation can be seen along the sides of the drain, which may be a result of nutrient enrichment from the domestic wastewater.

Annexure E: River discharge details

Date	Discharge (m^3/s)	Date	Discharge (m^3/s)	Date	Discharge (m^3/s)
31/12/24	227.74	20/1/25	262.04	9/2/25	291.86
1/1/25	265.72	21/1/25	263.17	10/2/25	286.74
2/1/25	303.64	22/1/25	260.65	11/2/25	290.56
3/1/25	297.81	23/1/25	260.09	12/2/25	283.48
4/1/25	303.64	24/1/25	259.80	13/2/25	281.38
5/1/25	303.64	25/1/25	257.51	14/2/25	319.10
6/1/25	303.64	26/1/25	272.63	15/2/25	350.09
7/1/25	303.64	27/1/25	265.61	16/2/25	346.18
8/1/25	291.97	28/1/25	271.39	17/2/25	342.33
9/1/25	291.97	29/1/25	274.44	18/2/25	355.21
10/1/25	274.44	30/1/25	277.53	19/2/25	369.83
11/1/25	256.94	31/1/25	277.53	20/2/25	355.13
12/1/25	256.94	1/2/25	276.91	21/2/25	321.09
13/1/25	233.58	2/2/25	276.60	22/2/25	324.74
14/1/25	239.24	3/2/25	276.60	23/2/25	328.08
15/1/25	258.95	4/2/25	275.97	24/2/25	344.05
16/1/25	258.08	5/2/25	287.73	25/2/25	344.22
17/1/25	258.08	6/2/25	286.14	26/2/25	359.57
18/1/25	258.08	7/2/25	284.55	27/2/25	257.51
19/1/25	259.80	8/2/25	284.13		

Annexure F: Data Collection Instruments and Stakeholder Inputs

S. No.	Annexure Item	Description
1	Pre-Phase Questionnaires	Structured surveys administered to assess baseline perceptions of water quality, sanitation readiness, and infrastructure expectations. Stakeholders covered: 1. Environmental & Social Organisations. 2. Floating population. 3. Govt. officials & Authorities 4. Infrastructure and service providers. 5.Local Residents. 6. Religious & Spiritual leaders 7. Researchers & Academicians
2	During Phase I Questionnaires	Tools used to capture real-time user feedback and monitor early-stage service delivery performance. Stakeholders covered: 1. Environmental & Social Organisations. 2. Floating population. 3. Govt. officials & Authorities 4. Infrastructure and service providers. 5.Local Residents. 6. Religious & Spiritual leaders 7. Researchers & Academicians
3	During Phase II Questionnaires	Extended survey instruments for NGOs, environmental organizations, and sector representatives to evaluate WaSH management under peak population pressure. Stakeholders covered: 1. Environmental & Social Organisations. 2. Floating population. 3. Govt. officials & Authorities 4. Infrastructure and service providers. 5.Local Residents. 6. Religious & Spiritual leaders

		7. Researchers & Academicians
4	Post-Phase Questionnaires	Surveys document retrospective perceptions of service adequacy, health risks, and user satisfaction levels. Stakeholders covered: 1. Environmental & Social Organisations. 2. Floating population. 3. Govt. officials & Authorities 4. Infrastructure and service providers. 5.Local Residents. 6. Religious & Spiritual leaders 7. Researchers & Academicians
5	Stakeholder & Expert Consultations	Key informant interviews and focused group discussions with PMA officials, UP Jal Nigam engineers, local residents, NGOs and public health experts to validate findings and co-create recommendations. Stakeholders covered: 1. Environmental & Social Organisations. 2. Floating population. 3. Govt. officials & Authorities 4. Infrastructure and service providers. 5.Local Residents. 6. Religious & Spiritual leaders 7. Researchers & Academicians

Annexure G: Survey Questions

G1: Common Demographic Questions

The survey was undertaken to evaluate the demographic composition of floating population, across stakeholders mentioned above for three phases of the Maha Kumbh Mela.

a. **Do you agree to take part in this survey, understand how your data will be used?** Yes/No

b. **Place of general residence:** State of Respondent

c. **Age of the Respondent**

5-9 Age	15-19 Age	25-29 Age	35-39 Age	50-59 Age	70-79 Age
10- 14 Age	20-24 Age	30-34 Age	40-49 Age	60-69 Age	80+ Age

d. **Gender of Respondent:** Female/Male/Others

e. **Qualification:**

Illiterate	Primary school	Middle school	High school
Intermediate/Diploma	Graduate	Professional	

f. **What is your occupation?**

Unemployed / Saint	Elementary occupation	Plant and machine operators and assemblers	Craft and related trade workers
Skilled agricultural and fishery workers	Skilled worker, shop and market sales workers	Clerk	Technicians/associate professionals
Professional	Legislators, senior officials, managers		

g. **What is your monthly income?**

≤₹6767	₹6768-₹20273	₹20274-₹33792	₹33793-₹50559
₹50560-₹67586	₹67587-₹135168	≥₹135169	

h. **Do you attend Prayagraj Kumbh Mela?**

No, I do not attend	This is my first time	At least 2 times	3-4 Times
5 Times	More than 5 times		

i. **Do you stay (intend to stay) at the Mela camps (Sevir) during the Kumbh Mela:** No/Maybe/Yes

j. **How many days do you plan to stay at the Kumbh Mela camps?**

<5 days	5-10 days	11-20 days	21-40 days	41-60 days
>60 days / 60	Local Residents			

k. What type of accommodation facility are you availing for the Maha Kumbh Mela

Ashram Tent	Government Tent	Individual Tents	Private Promoters (tents)	NGOs (tents)	Ashram (permanent)	Private Promoters (permanent)

l. How long have you been participating in the Kumbh Mela rituals?

First Time	Less than 6 years	6 to 12 years	12 to 24 years	More than 24 years

G2: Stakeholder Definite Survey of Pre and During-I Phase

For this part of the survey, we have used Likert Scale with the following notations:

Strongly Disagree (1)	*Disagree (2)*	*Neutral (3)*	*Agree (4)*	*Strongly Agree (5)*

Stakeholder: GOVERNMENT AGENCIES AND AUTHORITIES

a. Do you believe that the government will ensure an adequate and consistent supply of clean drinking water for pilgrims during the Kumbh Mela?

b. Do you think sufficient infrastructure will be in place to meet the water needs of pilgrims and participants during the Kumbh Mela?

c. Do you expect that water quality will be continuously monitored during the Kumbh Mela to ensure safety for all pilgrims and attendees?

d. Do you think the authorities will effectively manage water for ritual purposes without compromising public health and safety during the Kumbh Mela?

e. Do you believe that there will be sufficient measures in place to prevent the contamination of water sources at the Kumbh Mela?

f. Do you think waste disposal facilities will be adequately placed throughout the Kumbh Mela site to meet the needs of pilgrims?

g. Do you believe that the sanitation infrastructure, including toilets and washrooms, will meet the needs of the large number of pilgrims and participants at the Kumbh Mela?

h. Do you think the government will successfully implement waste segregation practices at the Kumbh Mela?

i. Do you believe the authorities will take adequate measures to ensure that waste does not accumulate in or near water sources during the Kumbh Mela?

j. Do you think there will be sufficient public awareness and education regarding waste disposal and sanitation at the Kumbh Mela?

k. Do you believe the government will implement measures to minimize pollution at the Kumbh Mela, especially in water bodies?

l. Do you think environmental impacts like water contamination and air pollution will be actively monitored during the Kumbh Mela?

m. Do you think the Prayagraj Mela Authority will coordinate with environmental agencies for sustainable practices during the Kumbh Mela?

n. Do you believe the authorities will take steps to reduce the environmental footprint of the Kumbh Mela, including waste reduction and recycling?

o. Do you think public education on sustainability, water conservation, and waste disposal will be integrated into the event's planning for the Kumbh Mela?

p. Do you believe the government will establish a clear emergency response plan to address waterborne diseases or sanitation-related outbreaks during the Kumbh Mela

q. Do you think there will be effective coordination between government agencies (e.g., health, sanitation, environmental, police) to manage water, waste, and sanitation issues during the Kumbh Mela?

r. Do you think sanitation and waste management will be prioritized during emergency planning, especially in cases of overcrowding or health risks at the Kumbh Mela?

s. Do you think the Prayagraj Mela Authority (PMA) will ensure that waste management and water distribution are adequately funded and supported by resources?

t. Do you believe the authorities will have contingency plans in place to address water shortages or sanitation challenges that might arise due to the scale of the Kumbh Mela?

u. Do you think the authorities will take steps to reduce the environmental footprint of the Kumbh Mela, including waste reduction and recycling?

OPEN ENDED QUESTIONS

v. What specific steps will the Prayagraj Mela Authority (PMA) be taking to ensure that water quality during Kumbh Mela 2025 meets the required standards for drinking and other uses

w. Can you describe the measures in place for waste management at Kumbh Mela 2025, especially regarding segregation, recycling, and disposal in high-traffic areas?

x. How will the authorities ensure that sanitation facilities, including toilets and handwashing stations, are adequate and accessible to all attendees throughout the event, especially in remote or crowded areas?

y. What contingency plans are in place to address potential water shortages or sanitation-related health risks during Kumbh Mela 2025, and how will these be managed in case of overcrowding or emergencies?

z. How will the government ensure the participation of local communities in the planning, implementation, and monitoring of water, sanitation, and waste management systems during Kumbh Mela 2025?

Stakeholder: ENVIRONMENTAL AND SOCIAL ORGANISATIONS (NGOs)

a. Do you expect the water available for bathing and drinking at Kumbh Mela to be clean and safe for consumption?

b. Do you believe that the water facilities provided at Kumbh Mela will be well-maintained and sufficient for the number of pilgrims attending?

c. Do you think there will be a sufficient number of waste disposal bins available at Kumbh Mela for all attendees?

d. Do you anticipate seeing people throwing waste on the ground or in the river during the Kumbh Mela?

e. Are you aware of the environmental impact of littering, especially plastic waste, at Kumbh Mela?

f. Do you think waste management and cleanliness efforts should be given more attention during Kumbh Mela?

g. Do you expect to see efforts by the event organizers to reduce plastic waste and promote recycling at Kumbh Mela?

h. Do you expect to have access to clean and functional toilets during Kumbh Mela?

i. Do you think that the sanitation facilities at Kumbh Mela will be adequate for the number of people attending?

j. Do you think that sanitation facilities at Kumbh Mela will be regularly cleaned and maintained?

k. Are you aware of the health risks associated with improper sanitation during large gatherings like Kumbh Mela (e.g., waterborne diseases)?

l. Do you plan to practice proper hygiene (e.g., handwashing) after using public toilets during Kumbh Mela?

m. Do you expect to observe pilgrims engaging in open defecation or improper waste disposal around the Kumbh Mela area?

n. Are you aware of the importance of using water conservatively during the Kumbh Mela?

o. Do you plan to make efforts to conserve water during your time at Kumbh Mela (e.g., taking short showers, turning off taps)?

p. Are you familiar with the concept of waste segregation (e.g., separating recyclables, compostables, etc.) during Kumbh Mela?

q. Do you think that public awareness campaigns, both before and during the Kumbh Mela, can help reduce waste and improve sanitation practices?

r. Do you believe that pollution in the Ganges River or other water bodies around Kumbh Mela is a significant environmental concern?

s. Do you plan to regularly dispose of your waste in designated bins during the Kumbh Mela?

t. Do you believe that better sanitation facilities would improve the overall experience at Kumbh Mela?

OPEN ENDED QUESTIONS

u. What will be the biggest water management challenges during the Kumbh Mela?

v. How can waste disposal be improved at the Kumbh Mela?

w. What steps can be taken to raise awareness about sanitation among pilgrims?

x. How will cultural practices influence waste and water usage at the Kumbh Mela?

y. What changes would you suggest for better sanitation infrastructure at the event?

Stakeholder: INFRASTRUCTURE AND SERVICE PROVIDERS

a. The current water supply infrastructure will be adequate to meet the needs of visitors during Kumbh Mela 2025

b. There will be sufficient sanitation facilities for both the local population and the large influx of visitors expected at Kumbh Mela 2025

c. The design of the water and sanitation facilities will take into account the socio- cultural and religious needs of the Kumbh Mela attendees

d. Effective collaboration between government bodies and NGOs will be critical in ensuring proper waste management and sanitation at Kumbh Mela 2025

e. The current infrastructure planning for Kumbh Mela 2025 is expected to be sufficient to handle the large-scale event, especially concerning waste and sanitation systems

f. The infrastructure and engineering solutions being planned will consider the socio-cultural dynamics and rituals of Kumbh Mela, such as bathing, rituals, and large gatherings

g. The timelines for constructing and installing water and sanitation infrastructure for Kumbh Mela 2025 are realistic and achievable

h. The power supply infrastructure for Kumbh Mela 2025 will be robust enough to ensure the uninterrupted operation of water and sanitation systems

i. The water supply system for Kumbh Mela 2025 will be sustainable and will meet the demands without overexploiting local water resources

j. Backup power systems will be in place to prevent service interruptions, especially for water pumps and sanitation systems during Kumbh Mela 2025

k. Effective coordination between power, water, and sanitation service providers will be essential for the success of Kumbh Mela 2025

l. Effective collaboration between government bodies and NGOs will be critical in ensuring proper waste management and sanitation at Kumbh Mela 2025

m. The engineering solutions for waste collection, segregation, and disposal at the Mela site are expected to be adequate for both short-term and long-term use

n. Backup power systems will be necessary to prevent interruptions to water and sanitation services during Kumbh Mela 2025

o. There should be effective coordination between power, water, and sanitation service providers to ensure smooth operations during Kumbh Mela 2025

OPEN ENDED QUESTIONS

a. How can water and sanitation infrastructure at Kumbh Mela better take into account the cultural rituals and practices of pilgrims?

b. What cultural barriers do you think need to be addressed when implementing water, waste, and sanitation systems during the Kumbh Mela?

c. What are the most effective ways to engage local communities and pilgrims in sustainable water and sanitation practices during the event?

Stakeholder: LOCAL RESIDENTS

a. How concerned are you about the availability of sufficient clean water for you and your household during the Kumbh Mela?

b. How worried are you about the potential spread of waterborne diseases during the Kumbh Mela?

c. How concerned are you about the crowding in the city due to the Kumbh Mela?

d. How disturbed are you by the possible spread of diseases due to filth and garbage generated by the Kumbh Mela?

e. Do you face challenges due to a lack of water in your daily life?

f. How irritated do you feel due to the lack of sufficient water to meet your daily needs?

g. How overwhelmed do you feel by the challenges that arise due to water shortages during the Kumbh Mela?

h. Do you feel that hand washing stations with soap and water will be adequately available at Kumbh Mela sites?

i. Do you believe that women in your household will have access to safe and clean facilities for menstrual hygiene management during the Kumbh Mela?

j. Do you think that pilgrims will be aware of waste segregation and recycling practices during the Kumbh Mela?

k. How confident are you that the local community understands the importance of maintaining hygiene and sanitation during the Kumbh Mela?

l. Do you think that the influx of pilgrims during the Kumbh Mela will strain local water, waste, and sanitation infrastructure?

m. Do you believe the waste management infrastructure during Kumbh Mela will be sufficient to meet the demands of both pilgrims and locals?

n. Do you think water pollution in the Ganges will increase due to improper disposal of waste during the Kumbh Mela?

o. Do you feel that waste generated at the event will be adequately collected and disposed of by authorities?

p. How confident are you that the sanitation infrastructure will improve due to preparations

for the Kumbh Mela?

q. Are you aware of the water safety measures (e.g., tanker supply, chlorination) being undertaken during the Kumbh Mela?

r. Do you think local authorities have communicated disaster risk reduction (DRR) plans for water, sanitation, and hygiene during the Kumbh Mela?

s. Do you know where to report any waste or sanitation issues during the Kumbh Mela?

t. Are you aware of how your household waste will be managed during the Kumbh Mela?

u. Do you wash your hands after visiting the Mela site using soap and water?

v. Have you made any preparations to ensure your household has a backup water supply during the Kumbh Mela?

w. Do you believe that cultural and spiritual practices during the Kumbh Mela align with sustainable practices such as water conservation and waste reduction?

x. Do you think stronger regulations are needed to ensure proper sanitation and hygiene during the Kumbh Mela?

y. Do you believe that traditional values promote cleanliness and sustainability during the Kumbh Mela?

OPEN ENDED QUESTIONS

z. How can sanitation facilities be improved for both locals and visitors during Kumbh Mela?

aa. What challenges have you faced in accessing safe drinking water during the event?

bb. How can waste segregation and recycling practices be improved during Kumbh Mela?

cc. What suggestions do you have for better collaboration between local authorities and communities for sanitation management?

Stakeholder: LOCAL RESIDENTS

a. How often do you engage in water-related rituals during your stay in Kumbh Mela (e.g., river bathing, water offerings)?

b. I expect to have access to proper sanitation facilities (toilets, hand washing stations, waste disposal) during Kumbh Mela, and I believe they will be adequate for all the pilgrims without overcrowding or long lines

c. I plan to keep my temporary accommodation clean and actively engage in efforts to reduce waste at my site during Kumbh Mela

d. I plan to segregate my waste (dry vs wet) before disposing of it during Kumbh Mela

e. I will try to judiciously use the water supplied to me during Kumbh Mela so as not to

stress the water resources of the local communities in Prayagraj

f. Pilgrims, including myself, are responsible for maintaining the cleanliness and sanctity of the rivers at Prayagraj during Kumbh Mela /

g. I expect to use adequate toilet facilities during Kumbh Mela

h. I am concerned about the quality of water after performing my rituals at Kumbh Mela

i. I believe that my water-related rituals might contribute to water pollution during Kumbh Mela

j. I believe that the waste I generate during Kumbh Mela could affect the water quality at Prayagraj

k. I support initiatives that aim to reduce the environmental impact of water-related rituals during Kumbh Mela

l. I am confident in my understanding of water quality and its importance for rituals at Kumbh Mela

m. I anticipate using an appropriate amount of water during my stay at Kumbh Mela for both daily needs and rituals

n. I understand that throwing flowers, oil, and other products (including plastics) as part of my rituals could affect the water quality

o. I understand the difference between blue and green dustbins, and how waste should be segregated

p. I am aware that the Ganga River is one of the most polluted rivers in the world, and how this might impact Kumbh Mela

q. I have a reliable source of drinking water planned during my stay at Kumbh Mela

r. The availability of clean water for ritual purposes is crucial for my participation in Kumbh Mela

s. I believe that proper waste disposal and sanitation are important for maintaining the spiritual sanctity of Kumbh Mela

t. Religious and spiritual leaders should actively promote water conservation, waste management, and environmental sustainability during the Kumbh Mela

u. The socio-cultural and spiritual aspects of the Kumbh Mela should be balanced with efforts to maintain a clean and sustainable environment

v. I am satisfied with the infrastructure provided by the government and authorities to ensure access to clean water for my daily requirements during Kumbh Mela

w. I am satisfied with the cleanliness and hygiene in the camps where I will stay during Kumbh Mela

x. I believe that the government and authorities are taking adequate steps to ensure the availability of clean and accessible toilets at key sites during Kumbh Mela

Stakeholder: FLOATING POPULATION

c. I believe that the sanitation facilities provided during the Kumbh Mela will be adequate to handle the large influx of people

d. I believe that the water supply during the Kumbh Mela will be sufficient for the pilgrims' needs

e. I feel that the waste management systems in place during Kumbh Mela 2025 will be effective in minimizing environmental impact

f. I trust that the public health authorities will be well-prepared to prevent sanitation- related health risks at the event

g. I believe that the water provided for drinking during Kumbh Mela 2025 will meet the necessary quality standards

h. I expect that adequate access to clean water will be available in public areas during Kumbh Mela 2025

i. I am confident that the availability of safe bathing areas (such as for the ritual bath in the river) will be sufficient and sanitary

j. I believe there will be adequate facilities for handwashing and hygiene, including soap and water, during Kumbh Mela 2025

k. I expect that the waste collection points at Kumbh Mela 2025 will be strategically placed to ensure ease of access for the crowd

l. I trust that the waste management strategies at Kumbh Mela 2025 will have minimal environmental impact

m. I expect there will be a sufficient number of waste disposal bins and recycling options throughout the Kumbh Mela sit

n. I believe that the Kumbh Mela 2025 will have clear guidelines and initiatives for reducing plastic waste

o. I feel that public health concerns regarding waterborne diseases will be adequately addressed during Kumbh Mela 2025

p. I trust that sanitation measures during Kumbh Mela 2025 will prevent the outbreak of diseases related to poor hygiene

q. I believe that the event organizers will ensure that the sanitation practices are aligned with public health safety protocol

r. I expect that public health experts will be actively involved in monitoring and improving water quality and sanitation throughout the event

s. I feel that water, waste, and sanitation management at Kumbh Mela 2025 will set a positive example for future large-scale events

t. I believe that the overall environmental and public health impact of Kumbh Mela 2025 will be manageable with proper water and sanitation management strategies

u. I believe the Kumbh Mela 2025 organizers have sufficiently planned for waste disposal in high-traffic areas

v. I trust that the water provided for drinking during Kumbh Mela 2025 will meet the necessary quality standards

w. I believe that the waste collection points at Kumbh Mela 2025 will be strategically placed to ensure ease of access for the crowd

x. I believe that the Kumbh Mela 2025 organizers should plan sufficiently for waste disposal in high-traffic areas

y. I believe that Kumbh Mela 2025 should ensure that water quality meets the necessary standards for drinking

z. I believe that adequate access to clean water should be available in all public areas during Kumbh Mela 2025

aa. I think that the Kumbh Mela should prioritize safe and sanitary bathing areas for the ritual bath in the river

bb. I believe there should be sufficient facilities for handwashing and hygiene, including soap and water, during Kumbh Mela 2025

cc. I feel that the waste segregation (biodegradable vs non-biodegradable) system should be efficient at Kumbh Mela 2025

Stakeholder: RELIGIOUS AND SPIRITUAL LEADERS

a. I expect to have easy access to clean and safe water for my spiritual practices during the Kumbh Mela

b. I believe that the quality of water used for ritual bathing will be important for both spiritual purification and public health during the Kumbh Mela

c. The availability of clean water for ritual purposes (e.g., bathing, water offerings) will be crucial for my participation in the Kumbh Mela

d. I believe that the government and authorities will provide sufficient access to clean and

safe water sources for spiritual rituals during the Kumbh Mela

e. I expect to see improvements in sanitation facilities (e.g., toilets, waste disposal) at the Kumbh Mela compared to previous events

f. I believe that waste generated during the Kumbh Mela will affect water quality

g. I anticipate facing difficulties in accessing sanitation facilities during the Mela due to overcrowding or long line

h. I believe that the authorities will make efforts to maintain cleanliness and hygiene in the camps where I will stay during the Kumbh Mela

i. I think the socio-cultural and spiritual aspects of the Kumbh Mela should be balanced with efforts to maintain a clean and sustainable environment

j. Considering millions of pilgrims attend the Kumbh Mela, I estimate that a significant amount of water will be consumed for bathing rituals alone

k. I estimate that pilgrims will consume around 2 liters, 5 liters, or more water per day for drinking during the Kumbh Mela

l. I expect to have easy access to clean and potable water for drinking and spiritual practices during the Kumbh Mela

m. I believe that handwashing stations with soap and water will be readily available and maintained at the Kumbh Mela to ensure hygiene

n. I believe that proper waste disposal and sanitation are important for maintaining the spiritual sanctity of the Kumbh Mela

o. I feel that water-related rituals should not contribute to water pollution during the Kumbh Mela

p. I support initiatives that aim to reduce the environmental impact of water-related rituals during the Kumbh Mela

q. I believe that the availability of proper sanitation facilities (toilets, waste disposal) will be adequate for the large number of spiritual leaders and pilgrims at the Kumbh Mela

r. I believe that the authorities will do enough to ensure the availability of clean and accessible toilets at key sites during the Kumbh Mela

s. I expect there to be sufficient emphasis on hygiene and sanitation in the camps where religious leaders will stay during the Kumbh Mela

t. I am aware that there will be waste separation practices (e.g., recycling, biodegradable waste disposal) at the Kumbh Mela to reduce environmental impact

u. I believe that environmental sustainability efforts (e.g., water conservation, waste

management) will align with the spiritual practices at the Kumbh Mela

v. I believe that religious leaders like myself have a responsibility to promote cleanliness and waste management among pilgrims during the Kumbh Mela

w. I believe that religious and spiritual leaders should set an example by actively participating in water and waste conservation efforts during the Kumbh Mela

x. I believe that the sacredness of water is linked not only to its spiritual significance but also to its preservation in the natural environment during the Kumbh Mela

y. I believe that the quality of water at the Kumbh Mela is important for both my spiritual practices and my health.

During Phase II and Post-Phase

Stakeholder: ENVIRONMENTAL AND SOCIAL ORGANISATIONS (NGOs)

a. To what extent were you aware of the specific actions taken by NGOs to address sanitation issues (e.g., mobile toilets and hand-washing stations) during the Kumbh Mela?

b. To what extent do you agree that environmental organizations were well-informed about the environmental impacts of poor water and sanitation management at the Kumbh Mela?

c. To what extent do you believe NGOs had a clear understanding of how the floating population affected water and waste management (e.g., plastic bottles, food wrappers, and religious offerings) during the Kumbh Mela?

d. To what extent were you aware of the initiatives implemented by environmental organizations to educate pilgrims about water conservation and sanitation during the Kumbh Mela? /

e. To what extent do you agree that NGOs working during the Kumbh Mela had effective strategies for monitoring water quality and sanitation practices (e.g., mobile water quality testing kits) in real time?

f. To what extent do you believe environmental organizations were knowledgeable about the role of cultural practices in shaping pilgrims' hygiene and sanitation behaviors (e.g., using soaps, oils) during the Kumbh Mela? /

g. To what extent did NGOs actively monitor sanitation and hygiene practices at the Kumbh Mela to ensure they met environmental standards? /

h. To what extent did environmental and social organizations play a key role in supporting the Prayagraj Mela Authority in managing waste and sanitation (e.g., portable toilets and hand-washing stations) during the Kumbh Mela?

i. To what extent do you believe waste management practices during the Kumbh Mela were insufficient to manage the scale of the event's waste generation? /

j. To what extent do you think the cultural practices of pilgrims at the Kumbh Mela had a direct negative impact (e.g., soaps, oils, and chemicals during their baths) on water sanitation in the region?

k. To what extent do you believe the floating population during the Kumbh Mela led to significant strain on the local sanitation infrastructure (e.g., overflowing toilets, inadequate cleaning schedules)?

l. To what extent did you notice a visible decline in water quality in the Ganges due to poor sanitation practices during the Kumbh Mela?

m. To what extent do you believe social and environmental organizations should take a more active role in improving sanitation (e.g., community-led initiatives such as regular clean-up drives) during the Kumbh Mela?

n. To what extent do you believe NGOs and environmental organizations should collaborate with the Prayagraj Mela Authority to promote water conservation (e.g., awareness campaigns) during the Kumbh Mela?

o. To what extent do you believe the government should allocate more resources for improving sanitation and waste management during the Kumbh Mela? /

p. To what extent do you think there should be stronger regulations to enforce proper waste disposal and water hygiene practices (e.g., fines for littering or improper disposal of plastic, religious offerings) during the Kumbh Mela?

q. To what extent do you think local environmental and social organizations should be more involved in educating pilgrims about hygiene and sanitation during the Kumbh Mela?

r. To what extent do you believe sanitation and hygiene (e.g., portable toilets and handwashing stations) should be a priority focus for NGOs working during the Kumbh Mela?

s. To what extent do you think social organizations should promote sustainable waste management practices (e.g., waste segregation bins) and water conservation (e.g., water- efficient taps) as part of the Kumbh Mela experience?

t. To what extent do you believe religious leaders should have been actively involved in promoting better sanitation practices among pilgrims during the Kumbh Mela?

u. To what extent do you think the religious significance of the Kumbh Mela can be aligned with efforts to protect local water bodies and improve hygiene? /

v. To what extent do you believe religious beliefs around water conservation and cleanliness can be leveraged to encourage pilgrims to adopt better sanitation practices?

OPEN ENDED QUESTIONS

w. From your perspective, what was the most significant environmental impact of the Maha Kumbh Mela on local water resources and sanitation systems, and how do you perceive its long-term effects on Prayagraj's infrastructure?

x. What is your organization's attitude towards the management and involvement of the local

y. community in waste disposal, sanitation, and water conservation during the Kumbh Mela? Do you believe there were sufficient efforts in engaging the pilgrims and locals in sustainable practices?

z. Can you share what strategies and educational programs your organization implemented or supported to raise awareness among pilgrims and locals about water conservation, waste

aa. management, and hygiene during the Kumbh Mela?

bb. How do you think religious beliefs and cultural practices during the Kumbh Mela influenced the environmental and sanitation behavior of the pilgrims? Were there specific religious practices that facilitated or hindered sanitation and waste management efforts? /

PERCEPTION OF FLOATING POPULATION

a. To what extent did the influx of pilgrims during the Kumbh Mela affect the quality of bathing water in Prayagraj (e.g., contamination from soaps, oils, human waste)?

b. To what extent did the large number of pilgrims during the Kumbh Mela contribute to the pollution of the Ganges and other local water bodies?

c. To what extent do you believe it was important to have safe drinking water facilities (e.g., multiple RO plants, Water ATMs, Bottled Water Distribution) available at key locations during the Kumbh Mela?

d. To what extent did the current waste management infrastructure in Prayagraj handle the

waste

e. To what extent were sanitation facilities (e.g., toilets, washing stations) sufficient during the Kumbh Mela?

f. To what extent you agree that waste management was a joint responsibility between local residents, authorities, and pilgrims during the Kumbh Mela?

g. To what extent you agree that local residents were involved in organizing waste collection points during the Kumbh Mela?

h. To what extent you agree that waste disposal practices (e.g., plastic, food wrappers, and non-biodegradable waste) were strictly enforced during the Kumbh Mela to prevent pollution?

i. To what extent you agree that pilgrims were educated on the proper ways to dispose of waste (e.g., throwing garbage in designated bins, avoiding littering in the river) during the Kumbh Mela? /

j. To what extent you agree that local authorities implemented enough handwashing stations at key locations during the Kumbh Mela? /

k. To what extent did you believe that the pollution in the Ganga ji through pollutants such as plastic, food wrappers, and religious offerings occurred during the Kumbh Mela?

l. To what extent did you believe that preserving the environment and water resources during the Kumbh Mela was a moral and religious duty? /

m. To what extent did you believe that the cleanliness of the Ganges and surrounding areas was important for maintaining the spiritual integrity of the Kumbh Mela?

n. To what extent did you believe that religious rituals (e.g., bathing in the Ganges) should be supported by sustainable water and waste management practices during the Kumbh Mela?

o. To what extent did you actively participate in local cleanliness drives or waste management efforts around the Kumbh Mela area?

p. To what extent did you regularly use proper waste disposal methods (e.g., trash bins, composting) in your neighborhood during the Kumbh Mela?

q. To what extent did you encourage your family and fellow pilgrims to maintain hygiene and cleanliness during the Kumbh Mela? /

r. To what extent were you aware of the potential health risks associated with poor sanitation and water management (e.g., waterborne diseases, the spread of infections, and vector-borne diseases) during the Kumbh Mela? /

s. To what extent did you practice hygiene practices, such as handwashing, to prevent the

spread of diseases during the Kumbh Mela? /

t. To what extent did you know the methods of properly disposing of waste (e.g., biodegradable vs. non-biodegradable) during the Kumbh Mela?

OPEN ENDED QUESTIONS

u. How would you describe your experience with the availability and quality of water during the Kumbh Mela, and how do you think it impacted your overall well-being?

v. What do you think are the long-term effects of the Kumbh Mela on the local water bodies and sanitation systems in Prayagraj? How do you feel about the role of pilgrims in managing waste and maintaining hygiene during the event?

w. Can you explain how you managed waste and sanitation during your visit to the Kumbh Mela? What measures did you take to ensure proper hygiene, and were you aware of any waste management facilities available to you?

x. In your opinion, how do religious beliefs and practices during the Kumbh Mela influence the way water, sanitation, and hygiene are perceived and practiced among pilgrims? Are there any cultural practices related to cleanliness that you follow?

y. During your participation in the Kumbh Mela, what specific behaviors or actions did you take to ensure cleanliness and hygiene, especially in areas with high footfall? Would you be willing to follow these practices in your daily life after returning home?

PERCEPTION OF GOVERNMENT OFFICIALS AND AUTHORITY

a. To what extent did the Prayagraj Mela Authority actively monitor sanitation facilities to ensure they met the required standards (e.g., minimum acceptable guidelines for sanitation facilities) throughout the Kumbh Mela?

b. To what extent was the Prayagraj Mela Authority responsible for ensuring that the sewerage systems (e.g., setting up temporary sewage treatment plants (STPs) and ensuring regular maintenance) were regularly maintained and functioning during the event?

c. To what extent did you perceive that the floating population during the Kumbh Mela significantly impacted the local water quality (e.g., people bathing in the Ganges) and availability (e.g., use of water for drinking, cooking)?

d. To what extent did you perceive that the waste management systems were insufficient (e.g., overload of waste bins, number of temporary toilets) to handle the large volume of waste generated by pilgrims during the Kumbh Mela?

e. To what extent did you perceive that the Kumbh Mela caused noticeable environmental degradation (e.g., use of soaps, oils, and religious offerings like flowers, plastic) in water bodies like the Ganges due to improper sanitation practices?

f. To what extent did you notice an increase in waterborne diseases (cholera, dysentery, and diarrhea) during the Kumbh Mela, mainly due to sanitation and hygiene issues?

g. To what extent did you perceive that the current sewerage system (e.g., temporary sewerage infrastructure, which may have been quickly set up but not properly maintained, resulting in blockages) in Prayagraj was underprepared to handle the increased load during the Kumbh Mela?

h. To what extent did you perceive that there was a significant gap between the sanitation infrastructure requirements and what was actually in place for the Kumbh Mela?

i. To what extent did you perceive that pilgrims' cultural practices (e.g., religious offerings like flowers, plastic items) around water use during the Kumbh Mela had a direct impact on local water resources?

j. To what extent do you think that the wastewater management infrastructure during the Kumbh Mela needs to be strengthened to minimize pollution in the Ganges?

k. To what extent do you believe that improving sanitation and waste management should have been the top priority for the Prayagraj Mela Authority during the Kumbh Mela?

l. To what extent do you agree that the Prayagraj Mela Authority should have allocated more resources for sustainable water conservation practices (e.g., low-flow toilets and water-saving taps) during the Kumbh Mela?

m. To what extent do you support the idea of using technology (e.g., sensor equipped trash bins, mobile apps to track the cleanliness and availability of toilets) to monitor and improve sanitation systems during the Kumbh Mela?

n. To what extent do you agree that the Prayagraj Mela Authority should have collaborated more with local communities and pilgrims (e.g., promoting reusable bags and eco-friendly offerings) to ensure proper hygiene and waste management?

o. To what extent do you believe there was a strong need for the Prayagraj Mela Authority to implement waste segregation systems (e.g., biodegradable and non-biodegradable waste) for better management during the Kumbh Mela?

p. To what extent do you think the Prayagraj Mela Authority should have enforced stricter regulations on waste disposal (e.g., regular patrols to monitor and penalize individuals) during the Kumbh Mela to prevent contamination of local water resources?

q. To what extent were you aware of the specific sanitation measures (e.g., portable toilets

at key locations to prevent open defecation and reduce contamination of the Ganges) in place to prevent water contamination during the Kumbh Mela?

r. To what extent do you agree that the Prayagraj Mela Authority had a clear plan to address the sanitation challenges (e.g., mobile toilets and hand- washing stations) posed by the floating population during the Kumbh Mela? /

s. To what extent were you aware of the strategies in place to manage wastewater and its safe disposal (e.g., temporary wastewater treatment plants and mobile sewage treatment units) during the Kumbh Mela?

t. To what extent do you believe the Prayagraj Mela Authority informed pilgrims about safe hygiene and sanitation practices (e.g., information pamphlets and displaying posters) during the Kumbh Mela?

u. To what extent do you believe the authorities were well aware of the potential risks related to waterborne diseases (e.g., cholera, dysentery, and diarrhea) during the Kumbh Mela?

v. To what extent do you agree that the Prayagraj Mela Authority had a comprehensive understanding of the impact of cultural practices on water and waste management (e.g., using soaps and oils, and disposing of religious offerings such as flowers, incense, and plastic materials) during the Kumbh Mela?

w. To what extent do you think the Prayagraj Mela Authority should have collaborated with religious leaders and organizations to educate pilgrims about the importance of sanitation and water conservation during the Kumbh Mela?

x. To what extent do you agree that the Prayagraj Mela Authority should have ensured that the religious significance of the Kumbh Mela aligned with efforts to protect the environment, including promoting sustainable water and sanitation practices?

y. To what extent do you believe the Prayagraj Mela Authority should have involved religious organizations more actively in promoting hygiene and sanitation among pilgrims during the Kumbh Mela?

OPEN ENDED QUESTIONS

z. How do you perceive the overall impact of the Maha Kumbh Mela on the local water systems and sanitation infrastructure? Were there any significant challenges in maintaining water quality and waste management during the event?

aa. What is your attitude towards the involvement of pilgrims in water conservation, waste disposal, and sanitation practices during the Kumbh Mela?

bb. Do you think more can be done to improve their engagement and responsibility?

cc. What strategies and systems were put in place to manage water usage and sanitation during the Kumbh Mela? How effective were these strategies in ensuring the safety of water resources and the proper disposal of waste?

dd. Considering the religious and cultural significance of the Kumbh Mela, how do you believe religious beliefs and practices influence the behavior of pilgrims in relation to water, sanitation, and hygiene? Were there any specific cultural practices that affected waste management efforts?

ee. What behavior changes or actions were observed among the local population and pilgrims in relation to hygiene and sanitation during the Kumbh Mela? Do you think these behaviors were sustainable, and how can they be reinforced for future events?

PERCEPTION OF INFRASTRUCTURE AND SERVICE PROVIDERS

a. Adequate steps were taken to prevent over-extraction of water from groundwater, local rivers, and reservoirs during the event

b. The current water supply infrastructure (e.g., mobile water storage tanks, water ATMs, government tap water system) was adequate to meet the needs of pilgrims during Kumbh Mela 2025

c. There was an adequate amount of maps and signage for locating water facilities for easy access

d. Hand washing stations were placed near food stalls, toilets, and other high-use areas for easy access

e. The infrastructure ensured accessible clean water facilities (e.g., government tap water system, mobile toilets, bio-toilets, FRP toilets, hand washing stations) for elderly, children, and differently-abled individuals

f. The storage tanks for drinking water were cleaned and maintained once a day to ensure hygiene

g. Bathing ghats and associated pipelines were inspected frequently to prevent blockages or leaks

h. Measures were in place to quickly address breakdowns or malfunctions in water infrastructure

i. The frequency of wastewater collection and disposal was sufficient to prevent any accumulation at event sites

j. Wastewater infrastructure, such as tanks and treatment plants, was inspected frequently

for smooth operations

k. Hygiene-related waste (e.g., diapers, menstrual waste) was disposed of using proper collection and treatment methods

l. The wastewater from toilets was treated before being released into the environment

m. The frequency of toilet cleaning was sufficient to maintain hygiene and prevent foul odors

n. The frequency of septic tank emptying and maintenance was sufficient to prevent overflow during Maha Kumbh

o. The sources of water used for drinking, sanitation, and hygiene at Maha Kumbh were well-documented and regularly teste

p. The infrastructure team was aware of the energy consumption involved in water pumping, treatment, and distribution and actively worked to optimize energy use

q. Backup water sources and storage facilities were mapped and available for quick deployment in case of disruptions

r. The infrastructure (Septic tanks, portable toilets, Mobile Wastewater Collection Units, STPs) was designed to handle large volumes of wastewater during peak time without failure

s. The methods for collecting and disposing of human waste from sanitation facilities were clearly defined and followed

t. There was a structured schedule for septic tank emptying and maintenance to prevent overflow

u. I believe that ensuring access to safe water and sanitation for millions of pilgrims is a fundamental responsibility to uphold the religious and cultural significance of Maha Kumbh

v. I believe that effective waste and wastewater management during Maha Kumbh is crucial for protecting the sacred rivers and their religious importance

w. I reported any issues (such as clogged toilets or overflowing waste bins) to authorities instead of ignoring them

x. I avoided improper disposal of waste materials (e.g., plastic, food waste) into drainage or sanitation systems to prevent blockages

y. I support the equitable distribution of water across different sectors to prevent shortages

z. I am willing to advocate for regular inspections and timely repairs of water infrastructure to avoid system failures

PERCEPTION OF LOCAL RESIDENTS

a. To what extent do you believe that the cleanliness of water (e.g., drinking water and bathing in the river) became a significant concern for local

b. residents during the Kumbh Mela?

c. To what extent do you believe the present waste management infrastructure (e.g., solid waste collection, recycling efforts) in Prayagraj was sufficient to handle the large number of pilgrims during the Kumbh Mela?

d. To what extent do you believe the condition of the river Ganges during the Kumbh Mela significantly impacted the health (e.g., cholera, diarrhea, and typhoid) of the local population?

e. To what extent do you believe local residents perceived the Kumbh Mela as an event that brought positive impacts (e.g., infrastructure improvements and awareness about cleanliness) on water quality and sanitation?

f. To what extent do you believe the waste generated by pilgrims during the Kumbh Mela significantly affected the local waste management systems?

g. To what extent do you believe the current condition of water and sanitation issues as a result of the Kumbh Mela helped to grow the awareness of the local population about these issues?

h. To what extent do you believe that the government and authorities acted adequately in addressing water and sanitation issues during the Kumbh Mela?

i. To what extent did the Kumbh Mela help you understand the importance of waste segregation, such as separating biodegradable materials from non-biodegradable?

j. To what extent do you think local residents took responsibility in managing water and waste during the Kumbh Mela?

k. To what extent do you support the idea of organizing regular community clean-up initiatives to collect waste and improve sanitation during the Kumbh Mela?

l. To what extent do you believe that the local community's attitude towards water and waste management improved due to more resources being allocated (e.g., sanitation facilities, waste collection bins) by the government during the Kumbh Mela?

m. To what extent did you have sufficient knowledge about the waterborne diseases (e.g., cholera, diarrhea, and typhoid) that can be caused by poor sanitation during the Kumbh Mela?

n. To what extent were you aware of the methods available to the local community for

treating and purifying water (e.g., UV purifiers, or chlorine tablets) during the Kumbh Mela?

o. To what extent did you know where clean drinking water stations (e.g., water tankers, water ATMs, or tap stands) were located during the Kumbh Mela?

p. To what extent were you knowledgeable about how waste management systems (e.g., location of waste bins, clearance of bins, and their further disposal) were set up during the Kumbh Mela?

q. To what extent did you understand that improper waste disposal during the Kumbh, such as dumping plastic, food waste, and religious offerings into the river, has polluted the Ganges and other wetlands nearby?

r. To what extent do you believe that religious practices and rituals during the Kumbh Mela included a focus on water conservation and cleanliness?

s. To what extent do you feel that the teachings of religious leaders played a key role in promoting better sanitation and waste management practices during the Kumbh Mela?

t. To what extent do you believe that sacred rituals related to the river emphasized the importance of maintaining water quality and proper waste disposal during the Kumbh Mela?

u. To what extent did you make efforts to maintain hygiene and cleanliness in public spaces during the Kumbh Mela?

v. How actively did you participate in or support waste management activities during the Kumbh Mela to ensure a cleaner environment?

Annexure H: Stakeholder Consultation on Evaluating Complexities and Recommendations for WaSH Services at Maha Kumbh 2025

Project	**IPSA-Kumbh Project — "Mapping the Impact of Floating Population on Sewerage during Maha Kumbh 2025"**
Venue	Hindustani Academy, Prayagraj
Date	13 August 2025
Time	10:00 AM – 3:00 PM



टेरी स्कूल ऑफ एडवांस्ड स्टडीज़, नई दिल्ली द्वारा आयोजित कार्यशाला का आयोजन

स्पष्ट आवाज

प्रयागराज। हिंदुस्तानी अकादमी, प्रयागराज में किया गया। यह कार्यशाला आईपीएसए-कुंभ परियोजना के अंतर्गत आयोजित की गई है, जिसका विषय है "Mapping Impact of Floating Population on Sewerage during Maha Kumbh 2025"। यह परियोजना राष्ट्रीय स्वच्छ गंगा मिशन (NMCG), जल शक्ति मंत्रालय, भारत सरकार द्वारा समर्थित है। इस परियोजना को अंतरराष्ट्रीय और राष्ट्रीय स्तर के प्रतिष्ठित संस्थानों द्वारा मिलकर संचालित किया गया है, जिनमें होक्काइडो विश्वविद्यालय जापान, आईआईटी बीएचयू, आईआईटी रुड़की और टेरी स्कूल ऑफ एडवांस्ड स्टडीज (TERI SAS), नई दिल्ली, शामिल है। इस कार्यशाला में अतिथि के रूप में डॉ. अभिनव पाठक, एस.डी.एम., प्रयागराज नैनी प्राधिकरण (पीएमए); डॉ. आनंद के. सिंह, स्वच्छता प्रमुख, पीएमए; डॉ. कुमुद दुबे, वैज्ञानिक, आई.सी.एफ.आर.ई., प्रयागराज; श्रीमती वैशाली शुक्ला, पीएमए; श्री सलेश मिश्रा, नायब तहसीलदार, पीएमए; डॉ. राम अवतार, होक्काइडो विश्वविद्यालय जापान; तथा डॉ. टी.के. राहू, सहायक प्रोफेसर, सी.एन.जी. डिग्री कॉलेज, इलाहाबाद विश्वविद्यालय, ने अपने अनुभव और ज्ञान साझा किए। । टेरी एसएएस, नई दिल्ली से प्रोफेसर शालीन सिंगल ने महाकुंभ 2025 जैसे विशाल धार्मिक जनसागम में WaSH services के मूल्यांकन एवं प्रबंधन हेतु एक विशिष्ट रूपरेखा के विकास की महत्ता पर प्रकाश डाला। सुश्री ऐश सिंह, जिला परियोजना अधिकारी, जिला गंगा समिति, राष्ट्रीय स्वच्छ गंगा मिशन (NMCG), जल शक्ति मंत्रालय; तथा आई.आई.टी. बी.एच.यू., आई.आई.टी. रुड़की और टेरी एसएएस के शोधकर्ताओं ने भी महाकुंभ 2025 के विभिन्न पहलुओं पर अपने विचार प्रस्तुत किए। टेरी एसएएस, नई दिल्ली से डॉ. रामगोपाल फुकन, श्रीमती निश्चिंत और डॉ. वंदिका चौधरी ने विश्लेषण हेतु DPSIR (Driver-Pressure-State-Impact-Response) दृष्टिकोण को प्रस्तुत किया तथा कार्यशाला के दौरान हितधारकों के साथ परामर्श सत्र आयोजित किया।

पूर्वोत्तर रेलवे

खुली ई–निविदा सूचना:
(Two Packet System)

भारत के राष्ट्रपति की ओर से मंडल रेल प्रबन्धक / इंजीनियरिंग / पूर्वोत्तर रेलवे / लखनऊ द्वारा निम्नलिखित कार्यों हेतु आनलाईन 'खुली ई–निविदायें आमंत्रित की जाती है जिसका विवरण नीचे निम्नवत है:–

Figure H.1 Report of Stakeholder Consultation Workshop published in a leading regional newspaper

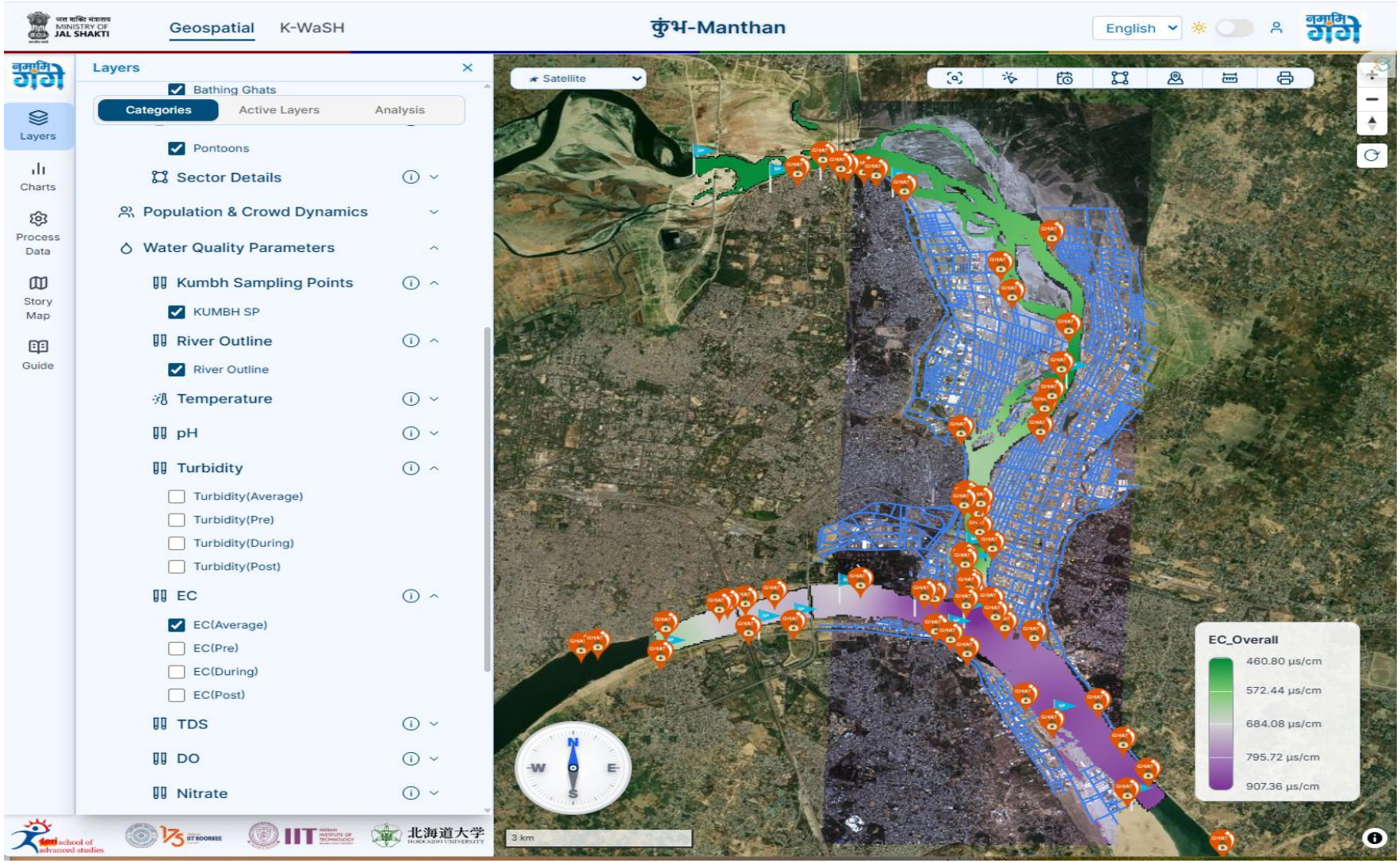
The robustness and operational viability of the Kumbh WaSH (Water, Sanitation, and Hygiene) framework were subjected to a rigorous process of verification and validation through an intensive stakeholder consultation convened on 13 August 2025 at the historic Hindustani Academy, Prayagraj, under the aegis of the IPSA-Kumbh project a consortium- driven endeavour by Hokkaido University, IIT-BHU, IIT-Roorkee, and TERI SAS designed to map the cascading impacts of a gigantic floating population on sewerage networks, water quality, and hygienic sustainability during the Maha Kumbh 2025. This consultation was not a mechanical exercise but an epistemic crucible where empirical insights from ground-level sanitation operatives, governance architects from the Prayagraj Mela Authority (PMA), experts from Public Health Department (Prayagraj), academic researchers, and civil society representatives were amalgamated to stress-test the conceptual integrity and pragmatic

elasticity of the K-WaSH framework. At the heart of this intellectual exercise lay the DPSIR (Drivers–Pressures–State–Impact–Response) model, which was unanimously validated as a methodologically resilient heuristic, capable of mapping the intricate cause–effect continuums that govern WaSH outcomes in a congregation of this magnitude. The stakeholders affirmed that the framework's enumeration of cultural and demographic drivers ranging from ritual bathing and Akhara processions to the staggering density and temporal rhythm of the floating population was not only exhaustive but also sensitive to the sociocultural pulse of the Mela.

The identified pressures, encompassing surges in sewage load, the proliferating detritus of plastic and ritual waste, and the diurnal variability of crowd movement, were recognised as credibly modelled, with the explicit consideration of peak bathing days lending robustness to predictive analytics. The "state" of the system, as represented through real-time water quality indices collected by Jal Nigam and NMCG, as well as high-resolution satellite imagery employed by IIT-Roorkee to map sanitation infrastructure distribution, was adjudged faithful reflection of ground realities, thus reinforcing the model's empirical validity (Figure 1).

Further, experts from IIT-BHU exhorted that longitudinal monitoring of biogeochemical stressors and ecosystem health indices be integrated to enhance predictive fidelity and allow anticipatory interventions to pre-empt ecological tipping points. The framework's emphasis on a multilateral response architecture combining state-led governance, community participation, and volunteer-driven service delivery was lauded as operationally viable and aligned with PMA's adaptive governance ethos, which privileges informal yet agile service deployment mechanisms over rigid hierarchies. Validation exercises, consequently, did not merely corroborate theoretical soundness but assessed its real-world tractability, confirming that the K-WaSH framework merges seamlessly with PMA's contingency planning protocols, emergency response frameworks, and post-sunset crowd-management strategies, thereby strengthening the normative case for its formal institutionalization within official SOPs. The technological skeleton of the framework notably predictive modelling spatio-temporal infrastructure mapping was hailed as indispensable for operational planning, with experts recommending the establishment of integrated decision-support dashboards at PMA command centres, capable of fusing crowd-flow analytics, water-quality telemetry, and facility occupancy data for pre-emptive resource allocation to risk-prone sectors, such as congested ghats during main *snans* The behavioral and sociological dimension of WaSH services was the integral part of the consultation reaffirmed the centrality of *sewa bhaav* (service mentality) and the catalytic role.

Annexure I: IPSA-Kumbh project dashboard (Kumbh-Manthan)





IPSA-Kumbh: Mapping Impact of Floating Population on Sewerage during Maha Kumbh 2025

National Mission for Clean Ganga (NMCG) Ministry of Jal Shakti
Government of India

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