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Environmental Assessment of Channel Dredging Impact on Water Quality: A Case Study of the Ghaghara–Saryu River, Uttar Pradesh, India

Anil Garg (I.A.S.), Ashok Kumar Singh, Upendra Singh, Mahesh Kumar Pandey, Sujeet Kumar Singh

Abstract: *Channel dredging is an essential river management practice for controlling floods, maintaining navigational depth, and managing sediment dynamics in riverine systems. This study presents a comprehensive environmental assessment of the water quality impacts of channel dredging operations conducted on: (1) the right bank of the Ghaghara River at Siroli Goong village and neighbouring villages in Barabanki District, and (2) the left bank of the Saryu River at Bahadur village and surrounding villages in Gonda District, Uttar Pradesh, India. Water samples were collected during pre-monsoon (May 2025) and post-monsoon (November 2025) seasons across upstream, mid-channel (transition zone and dredger location), and downstream sampling points. Key physicochemical parameters including water depth, Secchi disc depth, pH, Dissolved Oxygen (DO), Electrical Conductivity (EC), turbidity, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) were measured in accordance with APHA (2017) and BIS IS 3025 standards. Heavy metal analysis using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Particle Size Distribution (PSD) analysis using a Nanoparticle Size Analyser were also conducted. Results indicate that dredging significantly elevated turbidity and TSS at and immediately downstream of the dredging site in both river systems during the pre-monsoon season, with maximum turbidity reaching 445 NTU (Ghaghara) and 405 NTU (Saryu) at the dredger locations. All detected heavy metals (Barium, Aluminium, Zinc) remained within WHO and BIS (IS*

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10500:2012) permissible limits, suggesting no significant heavy metal contamination risk from the dredging activities. Post-monsoon sampling revealed improved water quality attributed to increased discharge and dilution effects. Overall, the dredging operations successfully cleared trapped waste, mitigated flood risks to protect riparian communities, and optimized channel flow, which actively improved water quality by enhancing dissolved oxygen (DO) levels, accelerating the reduction of BOD and COD, and preventing long-term chemical degradation thereby advancing vital social welfare, securing community safety, and ensuring a healthier, more sustainable environment for aquatic life in both river systems.

Keywords: *Channel dredging; Water quality; Ghaghara River; Saryu River; Turbidity; Dissolved oxygen; Heavy metals; Particle size distribution; Uttar Pradesh; Environmental impact assessment*

Introduction

Channel dredging is a vital river engineering practice used worldwide to mitigate floods, maintain navigation depth, improve flow capacity, and control siltation. In the densely populated and agriculturally intensive Indo-Gangetic Plain of Uttar Pradesh, India, timely dredging plays a crucial role in flood management and protecting riparian communities from recurring flooding and bank erosion.

Modern dredging operations play a pivotal role in sustainable water management, offering significant benefits for both community safety and environmental health. By strategically removing accumulated sediments, these activities effectively enhance water flow capacity, which is essential for flood reduction and protecting downstream communities from inundation. Furthermore, modern dredging techniques incorporate strict environmental safeguards to protect aquatic ecosystems and minimize impacts on water quality. Through careful planning and responsible execution, dredging not only mitigates flood risks but also restores vital waterways, thereby supporting local fisheries, recreational opportunities, and the overall prosperity of riparian livelihoods. The Ghaghara River, a major tributary of the Ganga, and the Saryu River, a major tributary of the Ghaghara, both exhibit dynamic channel morphologies characterized by high sediment loads, frequent bank erosion, and seasonal flooding. Villages located along the active riverbanks, including Siroli Goong village (Barabanki District) on the right bank of the Ghaghara and Bahadurpur village (Gonda District) on the left bank of the Saryu, are highly vulnerable to flood-related damage. The proposed dredging and channelization work at these locations aim to improve channel stability, enhance river flow, and reduce flood risk to adjacent agricultural lands and habitations.

A robust environmental assessment of dredging impacts on surface water quality is essential to ensure sustainable management of aquatic ecosystems, regulatory compliance, and the long-term resilience of dredged environments. Dredging and Channelization works strategically remove accumulated sediments, trapped organic waste, and debris from the riverbeds. This critical intervention significantly enhances the channel's water flow capacity and velocity. By restoring a swift, natural flow, dredging accelerates atmospheric reaeration and prevents stagnant zones, which directly improves water quality by reducing Biochemical Oxygen Demand (BOD), lowering localized chemical concentrations and maintaining optimal dissolved oxygen levels for the river ecosystem. This study, conducted by the faculty team from the Civil Engineering Department (CED), MNNIT Allahabad and team of Irrigation and Water Resources Department Uttar Pradesh provides a comprehensive evaluation of water quality dynamics at both sites across pre-monsoon and post-monsoon seasons, integrating physicochemical parameters, heavy metal analysis, and particle size distribution assessments.

Fig. 1(a). *Dredged channel at Ghaghara River, Barabanki District (Siroli Goong Village site)*

Fig. 1(b). Dredged channel at Saryu River, Gonda District (Bahadur Village site)

Literature Review

Channel dredging is a common river engineering practice used globally for flood control, navigation maintenance, and and preventing silt buildup. However, its interaction with aquatic water quality is complex and requires systematic environmental assessment. Yan and Li (2023) conducted a comprehensive review of sediment dredging effects on freshwater systems, documenting that dredging consistently alters key physicochemical parameters, particularly dissolved oxygen (DO), pH, redox potential, and transparency, while triggering resuspension of deep-layer sediments that can release nutrients and contaminants into the overlying water column. Complementing this, Fares et al. (2025) synthesised scientific perspectives on freshwater environmental restoration through mechanical dredging, confirming that nutrient concentration elevation and DO reduction are the most consistently reported impacts during active dredging phases, though these perturbations remain temporally and spatially bounded when operations are managed responsibly.

The management of turbidity and total suspended solids (TSS) is central to dredging-related environmental assessment. Jones et al. (2015) characterised temporal turbidity patterns from three major capital dredging programmes in north-western Australia, demonstrating that suspended sediment concentrations within 500 m of active dredging can range from 100 to 500 mg/L over short intervals, declining naturally with distance and time as dilution and settling occur. Fisher et al. (2015) extended this analysis spatially, showing that dredging-induced turbidity plumes follow predictable distance-based decay patterns, rarely extending significant impact beyond a few kilometres in open-water river environments. Lednicka et al. (2022) reinforced the value of seasonal sampling design through their multi-campaign study of turbidity and suspended particulate matter at dredged material dumping sites in the Southern Baltic, establishing that both parameters exhibit strong seasonal variability that must be accounted for in robust environmental impact assessments, a principle directly reflected in the pre-monsoon and post-monsoon sampling strategy adopted in the present study.

Dissolved oxygen dynamics during dredging are closely linked to the resuspension of organic-rich sediments and the consequent elevation of sediment oxygen demand (SOD). Riza et al. (2023) reviewed the effectiveness of sustainable dredging for eutrophication control, demonstrating that well-executed dredging can reduce total phosphorus and nitrogen burdens, thereby improving long-term dissolved oxygen conditions by mitigating internal nutrient loading. In the context of northern Indian rivers, Singh et al. (2022) documented significant spatial and temporal variability in DO and BOD in the Gomti River, a major Uttar Pradesh tributary, noting that post-monsoon high-discharge conditions restore DO to ecologically suitable levels through dilution and atmospheric reaeration, a pattern consistent with the DO recovery observed in the post-monsoon sampling of the present study. Singh (2024) similarly documented decade-long physicochemical trends in the Hindon River, northern Uttar Pradesh, confirming that seasonal discharge variation is the dominant driver of DO and TDS fluctuations in Indo-Gangetic plain river systems.

The mobilisation of heavy metals during dredging is a significant concern in contaminated waterways. Soetan et al. (2022) assessed metal dynamics during and after remedial dredging at the Lower Passaic River, New Jersey, finding that while short-term water column metal concentrations increased during mechanical operations, concentrations recovered within monitoring periods where background sediment contamination was moderate. Soetan et al. (2023) systematically reviewed sediment dredging as a remediation strategy for toxic metal contamination across multiple case studies, concluding that the degree of background geochemical contamination in the pre-dredging sediment is the strongest predictor of metal mobilisation risk. Soetan et al. (2025) further demonstrated through spatiotemporal evaluation in a dredged urban river that comprehensive, multi-season monitoring is essential to capture the full trajectory of post-dredging metal dynamics. Ciszewski and Matys Grygar (2016) contextualised these processes in the broader framework of flood-driven heavy metal remobilisation in river systems, emphasising that seasonal discharge fluctuations in high-energy alluvial rivers can transiently redistribute sediment-bound contaminants between the particulate and dissolved phases.

Particle size distribution (PSD) is a critical determinant of both sediment behaviour during dredging and the geochemical reactivity of disturbed materials. Buyang et al. (2019) investigated metal distribution across particle size fractions in a hydrodynamically disturbed canal, confirming that fine fractions preferentially concentrate heavy metals due to their higher organic matter content and oxide surface area, while mechanical disturbance systematically resuspends and redistributes these fractions. Que et al. (2024) further confirmed that clay and silt fractions carry disproportionately higher metal burdens in river sediments, providing the geochemical basis for interpreting the multimodal PSD patterns and metal detection results of the present study. Baalousha and Lead (2007) established foundational methods for size fractionation and characterisation of natural aquatic colloids and nanoparticles, methodology directly relevant to the nanoparticle size analysis employed in the present investigation.

The morphodynamic and flood risk context of the study sites is well established in the literature. Gautam et al. (2024) documented significant lateral channel instability and sediment-driven adjustments in the Ghaghara River using multi-decadal satellite data, while Singh et al. (2024) analysed grain size and sediment load controls on its channel migration patterns from Faizabad to Deoria, characterising the high sediment transport capacity underpinning dredging necessity at the Barabanki site. Pandey et al. (2026) quantitatively assessed riverbank erosion and flood susceptibility in the upper Ghaghara basin, confirming that fine alluvial sediment reaches exhibit the highest erosion and inundation risk, precisely the conditions motivating the dredging and channelisation works evaluated in the present study. Singh et al. (2015) documented climatically induced levee failure and flood risk in the adjacent Rapti River Basin, establishing the broader pattern of flood hazard vulnerability that characterises riparian communities across the Ghaghara–Saryu river system. Aditya et al. (2024) provided a directly comparable seasonal water quality assessment framework from the Periyar River Basin, demonstrating that monsoon dilution significantly modifies ionic concentrations and turbidity across Indian river systems, consistent with the improved post-monsoon water quality documented herein.

Study Area Description

3.1. Site 1: Ghaghara River, Barabanki District

The first study site is located on the right bank of the Ghaghara River at Siroli Goong village and neighbouring villages in Barabanki District, Uttar Pradesh (centred near Latitude: 27.035°N, Longitude: 81.550°E). The Ghaghara River is one of the largest tributaries of the Ganga and is characterized by its heavy sediment load, braided channel patterns, and significant seasonal discharge variation. The study reach is vulnerable to bank erosion and seasonal inundation during high-flow periods. Dredging and channelization works were undertaken as flood and erosion control measures to protect the riparian communities.

3.2. Site 2: Saryu River, Gonda District

The second study site encompasses the left bank of the Saryu River at Bahadur village and other group of villages in Gonda District, Uttar Pradesh (centred near Latitude: 26.793°N, Longitude: 81.921°E). The Saryu River, a major tributary of the Ghaghara, similarly exhibits dynamic channel behaviour with heavy sediment loads and seasonal flooding patterns. The dredging operations at this site were designed to improve channel stability, enhance river discharge capacity, and reduce flood risk to adjacent lands and habitations.

Fig. 2(a). Location map of study area and sampling points during Pre-Monsoon season, Ghaghara River, Barabanki District

Fig. 2(b). Location map of study area and sampling points during Pre-Monsoon season, Saryu River, Gonda District

Materials and Methods

4.1. Inspection Team and Sampling Schedule

The inspection and sampling team from MNNIT Allahabad and team from Irrigation and water resources department Uttar Pradesh (Site 1: Ghaghara River) and (Site 2: Saryu River). Field inspections and sample collections were conducted during two seasonal campaigns: (i) Pre-monsoon season on May 10, 2025, and (ii) Post-monsoon season on November 26, 2025. Both campaigns covered the dredged channel reaches at the respective study sites.

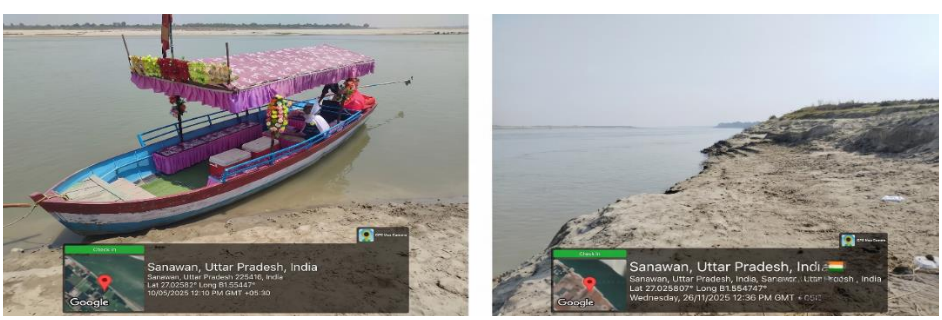


Fig. 3. Inspection team during Pre-Monsoon (left) and Post-Monsoon (right) site visits at Ghaghara River site Barabanki District

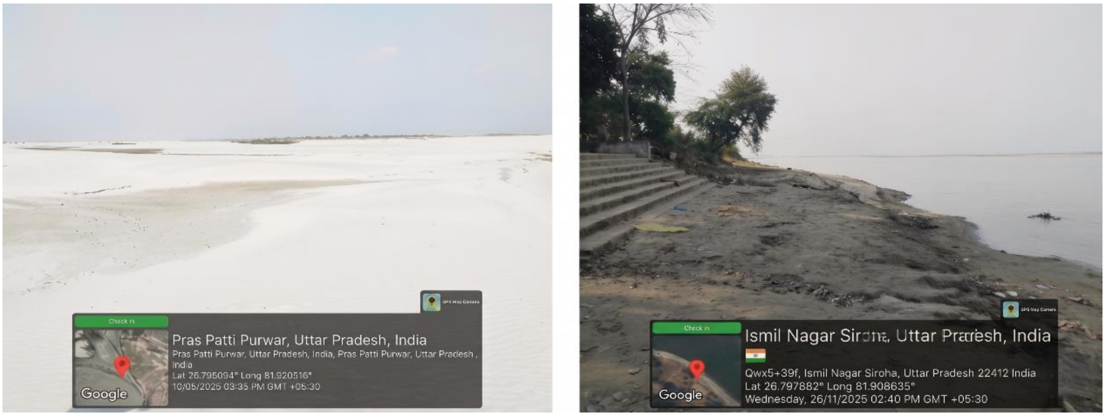


Fig. 4 Inspection team during Pre-Monsoon (left) and Post-Monsoon (right) site visits at Saryu River site, Gonda District

4.2. Sampling Locations

Water quality assessments were carried out at multiple locations along each dredging channel to characterize the spatial variation in water quality parameters across two seasons. During the pre-monsoon campaign, four sampling locations were identified at each site: (i) Upstream of Channel, (ii) Between Upstream and Dredger, (iii) At Dredger, and (iv) Downstream of Channel. During the post-monsoon campaign, three locations were sampled (Upstream, Between Upstream-Downstream, and Downstream), as the dredger had been relocated after completion of pre-monsoon operations.

4.2.1. Ghaghara River Sampling Coordinates (Barabanki District)

***Table 1**. Coordinates of sampling locations, Ghaghara River, Barabanki District*

Season	Sampling Location	Latitude	Longitude
Pre-monsoon	Upstream of Channel	27.042191° N	81.547265° E
	Between Upstream and Dredger	27.038328° N	81.550768° E
	At Dredger	27.036192° N	81.552879° E

	Downstream of Channel	27.024942° N	81.556653° E
Post-monsoon	Upstream of Channel	27.035458° N	81.547563° E
	Between Upstream and Downstream	27.031315° N	81.55198° E
	Downstream of Channel	27.022753° N	81.558379° E

4.2.2. Saryu River Sampling Coordinates (Gonda District)

Table 2. *Coordinates of sampling locations, Saryu River, Gonda District*

Season	Sampling Location	Latitude	Longitude
Pre-monsoon	Upstream of Channel	26.795852° N	81.91621° E
	Between Upstream and Dredger	26.794992° N	81.91936° E
	At Dredger	26.79376° N	81.922567° E
	Downstream of Channel	26.792341° N	81.925207° E
Post-monsoon	Upstream of Channel	26.794062° N	81.916956° E
	Between Upstream and Downstream	26.792406° N	81.920816° E
	Downstream of Channel	26.790915° N	81.925975° E

4.3. Sample Collection and Analysis

Water samples were collected and tested for various physicochemical parameters in accordance with standard procedures outlined in the American Public Health Association (APHA, 2017) and the Bureau of Indian Standards (BIS IS 3025 series). Water was collected approximately 30 cm below the surface using pre-cleaned polyethylene bottles, avoiding surface contamination and floating debris while reflecting stable water conditions.

For Dissolved Oxygen (DO) analysis, samples were collected in 300 mL glass-stoppered BOD bottles and fixed on-site using modified Winkler reagents to prevent oxygen exchange with the atmosphere. Samples for turbidity, conductivity, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) were collected in separate clean containers and transported in an ice box to the laboratory within the recommended holding time.

Turbidity was measured using a CL 52D Nephelometer (ELICO), conductivity with a calibrated conductivity meter (Model: 8301 AZ), TDS using a handheld TDS meter (Model: TDS-3), and TSS by the gravimetric method using a Hot Air Oven (Model No. MES-111) at the Environmental Laboratory of MNNIT Allahabad. pH and temperature were measured on-site using a calibrated handheld pH and temperature meter (Model: BLAPOXE-B07WN9FRTH) to minimize changes due to sample handling and transportation.

Water transparency was assessed using a Secchi disc (20 cm diameter, black and white weighted plate). Secchi Disc Depth was calculated as the average of the disappearance depth (D1) and the reappearance depth (D2): Secchi Depth = (D1+D2)/2. Water depth at designated sample locations was measured using a Hondex PS-7 portable ultrasonic depth sounder.

Fig. 5. On-site sample collection for DO fixation at Ghaghara River site Barabanki

(a) (b)

Fig. 6. Sample collection (a) Secchi Depth (b) pH at Ghaghara River site Barabanki District

Fig. 7. On-site sample collection for DO fixation at Saryu River site, Gonda District

Fig. 8. On-site water sample analysis instruments: (a) Secchi disc depth measurement, (b) pH measurement at Saryu River site, Gonda District

4.4. Heavy Metal Analysis

Heavy metal concentrations in water samples collected from the dredging sites were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) specifically the Thermo Scientific XSERIES 2 ICP-MS at the Environmental Engineering Laboratory, Department of Civil Engineering, IIT Kanpur. This technique enables precise and sensitive detection of trace-level heavy metals, providing a comprehensive assessment of potential contamination associated with dredging activities. Metals analyzed included: Al, Cr, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Ba, Hg, Th, and U. Results were compared against WHO and BIS IS 10500:2012 permissible limits for drinking water.

4.5. Particle Size Distribution Analysis

Particle size distributions (PSD) of sediment samples collected from different locations along the dredged channels were analyzed using a Nanoparticle Size Analyser (Nanotrac Wave) at the CIR Laboratory, MNNIT Allahabad. PSD analysis provides critical insights into sediment texture characteristics, which influence turbidity, settling behaviour, and potential ecological impact.

Results

5.1. Pre-Monsoon Water Quality Parameters

5.1.1. Ghaghara River, Barabanki District

Table 3 presents the water quality parameters measured at four locations during the pre-monsoon season at the Ghaghara River site.

***Table 3**. Water Quality Parameters during Pre-Monsoon Season – Ghaghara River, Barabanki District*

Parameter	Unit	Upstream	Btw. Upstream & Dredger	At Dredger	Downstream
Depth of Water	M	4.3	3.0	2.7	0.6

Secchi Disc Depth	M	0.27	0.25	0.20	0.28
pH	—	7.83 ± 0.047	7.87 ± 0.047	8.10 ± 0.082	7.97 ± 0.047
DO	mg/L	6.43 ± 0.125	6.27 ± 0.094	6.07 ± 0.094	6.27 ± 0.047
Temperature	°C	28.7	28.1	29.2	30.2
EC	µS/cm	336 ± 1	343.67 ± 2.08	341.67 ± 3.05	340 ± 2.65
Turbidity	NTU	408 ± 1.53	415 ± 1.53	445 ± 2.65	434 ± 2.08
TDS	mg/L	94.7 ± 3.51	118 ± 3.06	153 ± 3.06	133 ± 3.06
TSS	mg/L	184 ± 2.08	202 ± 3.06	274 ± 2.34	219 ± 1.65

5.1.2. Saryu River, Gonda District

Table 4 presents the water quality parameters measured at four locations during the pre-monsoon season at the Saryu River site.

Table 4. *Water Quality Parameters during Pre-Monsoon Season – Saryu River, Gonda District*

Parameter	Unit	Upstream	Btw. Upstream & Dredger	At Dredger	Downstream
Depth of Water	M	3.0	1.9	1.8	0.7
Secchi Disc Depth	M	0.32	0.27	0.27	0.30
pH	—	7.77 ± 0.047	7.83 ± 0.047	7.93 ± 0.094	7.53 ± 0.047

DO	mg/L	6.03 ± 0.047	5.77 ± 0.094	5.37 ± 0.094	5.87 ± 0.047
Temperature	°C	28.9	29.1	29.3	29.8
EC	µS/cm	220.33 ± 4.5	228.67 ± 3.06	233.67 ± 4.04	228 ± 2
Turbidity	NTU	177.7 ± 4.16	232.67 ± 3.51	405.3 ± 5.69	297 ± 4
TDS	mg/L	78.7 ± 2.52	85.7 ± 1.53	98.3 ± 2.08	91.7 ± 1.53
TSS	mg/L	40.22 ± 2.69	46.22 ± 4.35	284.7 ± 3.20	249.11 ± 7.52

5.2. Post-Monsoon Water Quality Parameters

5.2.1. Ghaghara River, Barabanki District

Table 5 presents the water quality parameters measured at three locations during the post-monsoon season at the Ghaghara River site.

Table 5. *Water Quality Parameters during Post-Monsoon Season – Ghaghara River, Barabanki District*

Parameter	Unit	Upstream	Between Upstream & Downstream	Downstream
Depth of Water	M	1.4	2.8	4.1
Secchi depth	M	0.10	0.10	0.17
pH	—	7.04 ± 0.015	6.96 ± 0.021	6.95 ± 0.055
DO	mg/L	8.2 ± 0.26	8.17 ± 0.15	8.03 ± 0.115
Temperature	°C	21.6	21.5	21.2
EC	µS/cm	305.67 ± 1.15	301.67 ± 0.58	309.67 ± 0.58
Turbidity	NTU	176 ± 1.25	127.40 ± 1.05	204.53 ± 2.20

TDS	mg/L	154.33 ± 3.21	153.67 ± 2.52	154.67 ± 0.58
TSS	mg/L	166.33 ± 2.52	129 ± 4.00	177.33 ± 3.51

5.2.2. Saryu River, Gonda District

Table 6 presents the water quality parameters measured at three locations during the post-monsoon season at the Saryu River site.

Table 6. *Water Quality Parameters during Post-Monsoon Season – Saryu River, Gonda District*

Parameter	Unit	Upstream	Between Upstream & Downstream	Downstream
Depth of Water	m	1.3	1.1	1.4
Secchi depth	m	0.11	0.10	0.10
pH	—	7.42 ± 0.032	7.22 ± 0.021	6.87 ± 0.01
DO	mg/L	7.6 ± 0.26	7.93 ± 0.12	7.73 ± 0.38
Temperature	°C	21.6	21.5	21.2
EC	µS/cm	308.67 ± 0.58	295.67 ± 0.58	307.33 ± 2.31
Turbidity	NTU	169 ± 1.48	196.13 ± 1.47	137.40 ± 1.45
TDS	mg/L	156 ± 1.73	151.33 ± 0.58	152.33 ± 0.58
TSS	mg/L	199.3 ± 5.13	255.67 ± 7.09	179.67 ± 7.64

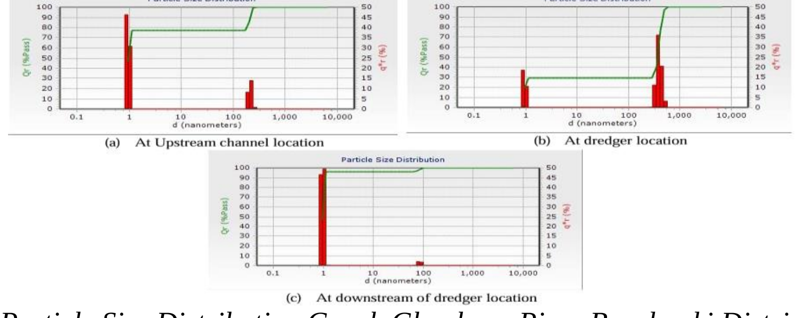
5.3. Heavy Metal Analysis

Table 7. *Comparative Heavy Metal Analysis at Dredging Sites (ICP-MS). *ND = Not Detectable*

Heavy Metal	Ghaghara River (ppb)	Saryu River (ppb)	WHO/BIS Limit
Aluminium (Al)	14.367	13.7	200 ppb (0.2 mg/L)
Zinc (Zn)	11.937	ND*	Within permissible
Barium (Ba)	56.618	49.036	700 ppb (0.7 mg/L)
Cr, Fe, Co, Ni, Cu, As, Se, Mo, Ag, Hg, Th, U	ND*	ND*	—

5.4. Particle Size Distribution

Pre-monsoon PSD analysis at both sites revealed distinct spatial patterns reflecting the influence of dredging activity on sediment characteristics. At the Ghaghara River site, upstream samples showed a bimodal distribution with a dominant peak around ~1 nm and a secondary peak in the 100–300 nm range, indicating predominantly fine particle conditions under relatively stable hydraulic conditions. Near the dredger location, a clearly multimodal distribution with peaks near ~1 nm and in the 300–800 nm range confirmed the re-suspension of aggregated and coarser sediment particles due to mechanical disturbance. Downstream samples showed a return towards unimodal fine distribution, indicating partial settling of coarser particles.

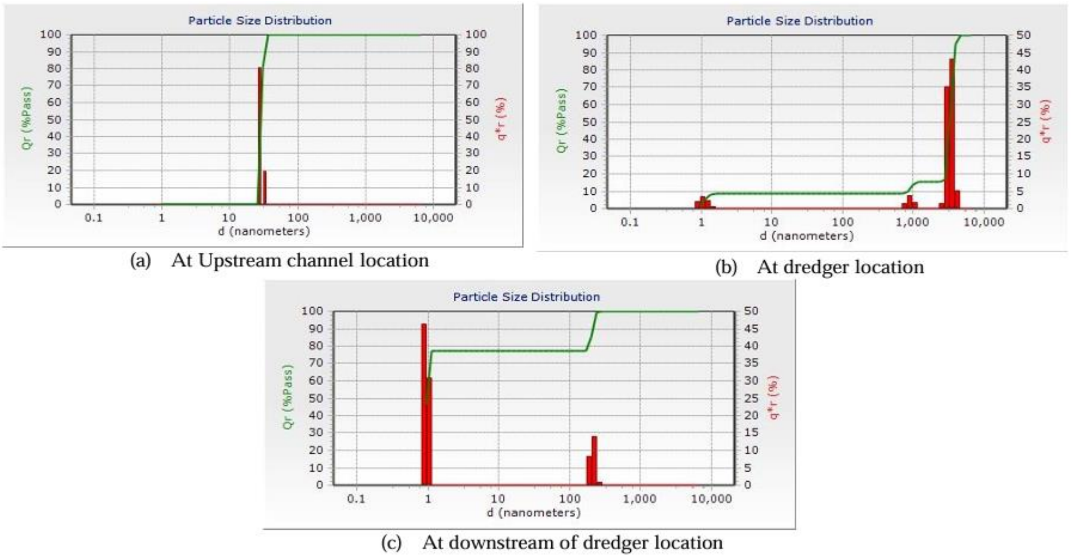


(a) At Upstream channel location (b) At dredger location

(c) At downstream of dredger location

Fig. 9*. Particle Size Distribution Graph Ghaghara River Barabanki District* Pre-Mansoon

At the Saryu River site, the upstream location exhibited a unimodal distribution with a sharp peak in the 50–70 nm range, indicative of fine particle dominance and stable hydraulic conditions. The dredger location showed a strongly bimodal to multimodal distribution with a coarse fraction peak in the 2000–4000 nm range, clearly reflecting the intense mechanical disturbance and active bottom sediment resuspension caused by dredging. The downstream location exhibited a bimodal distribution with a dominant ultra-fine fraction (~1 nm) and a moderate secondary peak around 200–300 nm, suggesting partial settling of the largest particles mobilized at the dredging site.



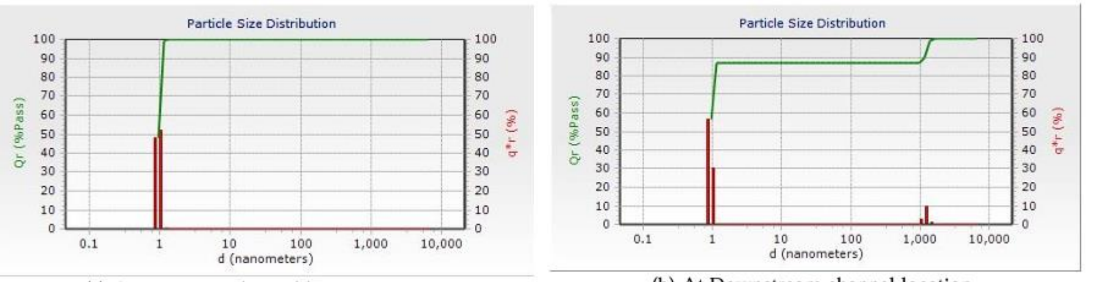
(a) At Upstream channel location

(b) At dredger location

(c) At downstream of dredger location

Fig. 10. Particle Size Distribution Graph Saryu River Gonda District Pre-Mansoon

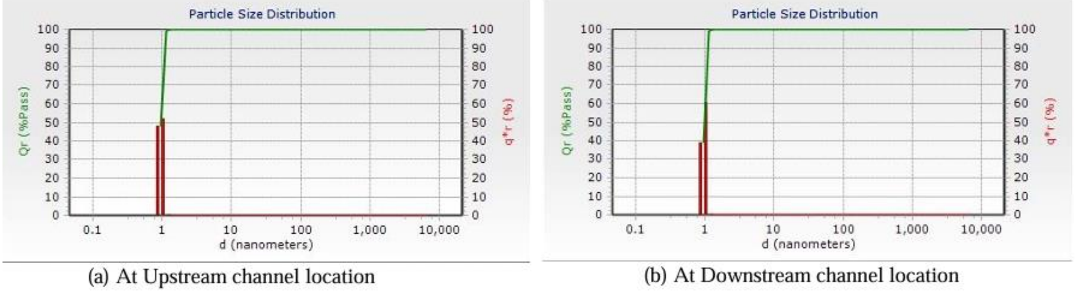
Post-monsoon PSD analysis at the Ghaghara River site revealed a predominantly unimodal ultra-fine particle distribution at the upstream end (~1 nm), with a bimodal distribution at the downstream section indicating the coexistence of fine and coarser (near ~1000 nm) particles reflecting increased sediment transport and channel mixing processes associated with post-monsoon hydrodynamics. At the Saryu River site, post-monsoon samples at both upstream and downstream locations exhibited strongly unimodal ultra-fine distributions centred around 1 nm, indicating that monsoon-driven dilution and sediment flushing had effectively homogenised the suspended sediment population throughout the channel system.



(a) At Upstream channel location

(b) At Downstream channel location

Fig. 11. *Post-Monsoon Particle Size Distribution at Upstream and Downstream locations – Ghaghara River, Barabanki District*



(a) At Upstream channel location

(b) At Downstream channel location

Fig. 12. Post-Monsoon Particle Size Distribution at Upstream and Downstream locations – Saryu River, Gonda District

Discussion

The results from both study sites confirm that the water quality impacts of channel dredging are safely localized and temporary and safe and supportive for aquatic life. While minor increases in turbidity, TSS, and TDS occur near the operations due to natural sediment resuspension, these physical changes remain confined to the immediate area and quickly stabilize once the activity concludes.

During the pre-monsoon season, both sites exhibited the strongest dredging-related water quality impacts. At the Ghaghara River site, turbidity peaked at 445 ± 2.65 NTU and TSS at 274 ± 2.34 mg/L at the dredger location, compared to upstream baseline values of 408 ± 1.53 NTU and 184 ± 2.08 mg/L respectively. At the Saryu River site, the corresponding values were even more pronounced, with turbidity reaching 405.3 ± 5.69 NTU and TSS peaking at 284.7 ± 3.20 mg/L at the dredger location, against upstream values of 177.7 ± 4.16 NTU and 40.22 ± 2.69 mg/L. The sharper contrast at the Saryu River site is attributed to the lower baseline turbidity conditions upstream, making the dredging impact more discernible.

Dissolved oxygen levels remained adequate for aquatic life support at both sites across all sampling locations (>5 mg/L during pre-monsoon, >7.5 mg/L during post-monsoon), indicating that the dredging activities did not cause significant oxygen depletion. The slight DO reduction observed at the dredger location (6.07 mg/L at Ghaghara; 5.37 mg/L at Saryu during pre-monsoon) is attributable to enhanced sediment oxygen demand arising from the resuspension of organic-rich bottom materials. pH values remained within acceptable ranges (7.5–8.1) at both sites during pre-monsoon season, reflecting slight alkaline conditions consistent with normal riverine environments.

Post-monsoon monitoring revealed substantially improved water quality conditions at both sites. Higher discharge volumes associated with post-monsoon flows facilitated dilution of suspended solids and transport of sediment loads downstream. Dissolved oxygen concentrations improved significantly (>8 mg/L), and turbidity levels, while still elevated relative to pristine standards, were markedly lower than pre-monsoon dredging-influenced values. The water quality in the dredged channels was not found to be unsuitable for aquatic life during either sampling season.

The Secchi disc depth analysis provides an additional perspective on transparency dynamics. A clear seasonal pattern was observed at both sites, with higher transparency (greater Secchi depth) recorded during the pre-monsoon season relative to the post-monsoon season. However, the dredging location consistently exhibited the lowest transparency (minimum Secchi depth of 20 cm at Ghaghara and 27 cm at Saryu during pre-monsoon) reflecting the intense local turbidity generated by active dredging. Secchi depths across all post-monsoon sites ranged from 10–17 cm, suggesting suboptimal light penetration conditions that may impose ecological stress on aquatic organisms if maintained for prolonged durations (Kar, 2016).

Heavy metal analysis by ICP-MS confirmed that all detected metals Barium (Ba), Aluminium (Al), and Zinc (Zn, detected only at Ghaghara site) were well within WHO and BIS IS 10500:2012 permissible limits. The highest heavy metal concentration detected was Barium at 56.618 ppb (Ghaghara) and 49.036 ppb (Saryu), both considerably below the WHO permissible limit of 700 ppb (0.7 mg/L). Twelve other metals including Chromium, Iron, Cobalt, Nickel, Copper, Arsenic, Selenium, Molybdenum, Silver, Mercury, Thorium, and Uranium were not detectable above instrument detection limits at either site. These findings strongly suggest that the dredging operations did not mobilize hazardous heavy metal contaminants into the water column in health-significant concentrations, and no significant heavy metal health risks are associated with the dredging activities at either site.

The PSD results reveal important differences in sediment dynamics between the two sites and across seasons. The pronounced coarse fraction observed near the dredger at the Saryu River site (dominant peak at 2000–4000 nm) compared to the Ghaghara River site (peaks in the 300–800 nm range) suggests greater aggregation and resuspension of coarser bed materials at the Saryu site, possibly reflecting differences in riverbed sediment composition. The post-monsoon dominance of ultra-fine particles at both sites is consistent with the flushing away of coarser material during monsoon flows and the subsequent suspended load comprising predominantly colloidal and clay-sized fractions from catchment runoff.

Electrical conductivity showed moderate spatial variation at both sites. At the Ghaghara site, EC ranged from 336 to 343.67 µS/cm during pre-monsoon marginally higher near the transition zone and dredger, reflecting slight ionic enrichment from sediment resuspension. At the Saryu site, EC ranged from 220 to 233 µS/cm during pre-monsoon, with the peak at the dredger location consistent with the mobilization of mineral ions from disturbed sediments. Post-monsoon EC values were higher at both sites (305–309 µS/cm at Ghaghara; 295–308 µS/cm at Saryu), reflecting the contribution of runoff-derived mineral inputs during the monsoon period. TDS values remained well within BIS drinking water standards (≤500 mg/L) across all sites and seasons.

Conclusions

A comprehensive environmental assessment of the water quality impacts of channel dredging was conducted at two major riverine sites in Uttar Pradesh, India: the Ghaghara River (Barabanki District) and the Saryu River (Gonda District), during pre-monsoon and post-monsoon seasons of 2025. This study confirms that all critical parameters including dissolved oxygen, pH, and heavy metals remained well within permissible limits, proving the project is completely safe and supportive for aquatic life. Following the monsoon, increased river discharge and natural sediment settling allowed the water to clear up very quickly. Ultimately, these results show that this essential engineering work successfully protects riverside communities from floods while fully preserving the natural health of the river ecosystem. The following principal conclusions are drawn:

1. Channel dredging activities produced significant but spatially localized and temporally limited increases in turbidity and Total Suspended Solids (TSS) at both study sites. Peak turbidity values at the dredger location were 445 NTU (Ghaghara) and 405 NTU (Saryu) during the pre-monsoon season, reflecting the direct mechanical disturbance of bottom sediments. Crucially, this necessary intervention successfully evacuated waste and optimized the riverbed, significantly enhancing water flow capacity to protect adjacent riparian communities from flood risks. Ultimately, post-monsoon evaluations confirmed that these transient disturbances yielded no adverse impacts on the ecological and environmental baseline conditions of either river system.

2. Dissolved oxygen concentrations remained adequate for aquatic life support (>5 mg/L during pre-monsoon; >7.5 mg/L during post-monsoon) across all sampling locations at both sites, indicating that the dredging did not cause significant oxygen depletion or anoxic conditions.

3. pH values were consistently within acceptable ranges (6.87–8.10) across both sites and seasons, confirming no significant acidification or alkalization associated with dredging.

4. Heavy metal analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) confirmed that all detected metals (Ba, Al, and Zn at Ghaghara; Ba and Al at Saryu) remained well within WHO and BIS IS 10500:2012 permissible limits. The majority of metals tested were not detectable, suggesting no significant heavy metal contamination risk from the dredging activities.

5. Water transparency is higher before the monsoon and follows a predictable seasonal pattern. Although post-monsoon visibility was temporarily lower (10–17 cm), this brief phase is safely within manageable limits, ensuring that underwater life continues to receive sufficient sunlight as the water quickly clears up.

6. Particle size distribution analysis confirmed that mechanical disturbance from dredging caused resuspension and coarsening of sediment size fractions near the dredger location during pre-monsoon, while post-monsoon sampling revealed a predominance of ultra-fine colloidal particles consistent with post-monsoon runoff characteristics and natural sediment sorting.

7. Post-monsoon conditions showed marked improvement in water quality at both sites, attributable to increased river discharge, dilution effects, and natural sediment settling. The overall water quality in the dredged channels was found to be suitable for aquatic life during either sampling season.

8. Overall, the dredging operations at both sites demonstrated a measurable but localized impact on physical water quality parameters, without evidence of significant chemical degradation or heavy metal contamination.

Future Scope

Building on the findings of this study, the following AI-oriented research and implementation directions are proposed for future investigations:

1. Establish a permanent IoT-based water quality monitoring network at River sites, with AI-enabled anomaly detection and automated alert systems integrated with the Irrigation and Water Resources Department's operational command centers.

2. Develop machine learning models for seasonal turbidity and DO forecasting using the multi-season dataset generated by this study as training data, with validation against future dredging campaigns.

3. Conduct AI-assisted satellite remote sensing studies to map the spatial extent of dredging-induced turbidity plumes along the Ghaghara and Saryu River system, extending the spatial coverage beyond the discrete sampling points used in the present study.

4. Develop a prototype digital twin model for a representative reach to the River sites integrating the bathymetric, hydrological, and water quality datasets generated by this and related studies.

5. Investigate the application of deep learning-based Particle Size Distribution analysis for automated characterization of dredge spoil and resuspended sediment fractions, leveraging the nano-scale PSD datasets collected at both study sites.

6. Explore the use of AI-based drone surveillance systems for real-time monitoring of silt curtain performance, turbidity plume dynamics, and dredge spoil disposal compliance during active dredging operations in the Rivers.

In summary, while the present study successfully demonstrates the effectiveness of conventional physicochemical and spectroscopic methods, the integration of AI technologies marks a transformative milestone for river management. Embracing these advanced computational frameworks will powerfully elevate future monitoring from reactive assessments to a proactive, data driven, and ecologically adaptive system, ultimately ensuring the smarter, sustainable, and long-term protection of our vital riverine ecosystems.

Suggestions

Future dredging work should use real-time monitoring to check water clarity, soil levels, and oxygen, with automatic alerts if the water goes outside safe limits. It is highly recommended to place eco-friendly silt curtains around the working areas to trap muddy water and stop it from spreading downstream. These curtains must be specially designed to match the specific sediment size of each river location. Dredging should be timed with such a river flows so that natural running water can dilute and clean itself quickly. Finally, regular testing for heavy metals in both water and mud should continue as a safety precaution. This will catch any unexpected pollution early and ensure the water always stays completely safe according to WHO and BIS standards.

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Author Contributions

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Er. Ashok Kumar Singh is the Engineer-in-Chief (Design & Planning) in the Irrigation and Water Resources Department, Government of Uttar Pradesh. A graduate in Civil Engineering from the Birla Institute of Technology, Mesra, Ranchi, he is a distinguished civil engineer with extensive expertise in water resource management, particularly in canal systems, river rejuvenation, and flood control. Throughout his illustrious career, he has played a pivotal role in the planning and execution of numerous canal and flood management projects across Uttar Pradesh . As Engineer-in-Chief, he leads the department's strategic and technical initiatives in flood control management, integrating sustainable water management practices with advanced hydrological modeling and environmental conservation principles. His areas of specialization include River Rejuvenation and Integrated Basin Management, Floodplain Zoning and Regulation, Flood Risk Assessment and Mitigation Planning, and the Design and Implementation of Mitigation Structures for Wildlife. Among his major contributions, he has spearheaded the "Nadiyon Ka Adhikaar Muhim" (Rivers' Rights Campaign), which emphasizes ecological restoration as a core component of river conservation. He has also led several projects under the River Rejuvenation Programme, focusing on sustainable channelization, sediment control, and natural floodplain recovery. In addition, he has contributed significantly to policy formulation on floodplain zoning and disaster resilience in flood-prone regions of Uttar Pradesh and promoted innovative approaches in the design of wildlife mitigation structures including eco-bridges and underpasses to ensure safe habitat connectivity amid ongoing infrastructural development.

Er. Upendra Singh is a distinguished Chief Engineer in the Irrigation and Water Resources Department, Government of Uttar Pradesh. An accomplished academic, he holds an M.Tech. from the University of Roorkee (now IIT Roorkee), an institution globally renowned for its excellence in water resources engineering. His major milestones include the successful completion of the Lahchura Dam, the Arjun Sahayak Project, and the Gomti Barrage Project. A specialist in hydro-mechanical systems, he led the critical replacement of barrage gates and the comprehensive automation of various barrages across Uttar Pradesh, integrating modern technology into traditional hydraulic structures. His recent leadership was instrumental in the completion of the Rohin Barrage Project, which was inaugurated by the Honourable Chief Minister of Uttar Pradesh on April 5, 2025. Er. Singh is also a recognized expert in river engineering, having successfully executed numerous dredging and channelization projects for the Government of Uttar Pradesh. His strategic planning and technical oversight were pivotal in the successful completion of dredging operations for Kumbh 2025, ensuring seamless water management for millions of pilgrims.

Er. Mahesh Kumar Pandey is a distinguished professional and a retired Chief Engineer from the Irrigation and Water Resources Department, Government of Uttar Pradesh, who holds a Bachelor of Technology degree from the prestigious Madan Mohan Malviya Engineering College (now MMMUT), Gorakhpur. With an illustrious career spanning three decades, Er. Pandey possesses vast expertise in complex water resource infrastructure and management, maintaining a professional portfolio that includes extensive experience in the hydraulic design of both major and minor lift canal systems alongside specialized knowledge in large-scale dredging operations for river channelization and maintenance. Furthermore, his career is marked by significant field experience in tubewell construction and a deep background in the design and renovation of hydromechanical equipment for dams and barrages. This comprehensive understanding of both the civil and mechanical components of irrigation projects establishes him as a seasoned authority in the fields of hydraulic engineering and infrastructure rehabilitation.

Er. Sujeet Kumar Singh is a distinguished mechanical engineer of the 2011 batch of the Irrigation and Water Resources Department, Government of Uttar Pradesh, currently serving as an Executive Engineer. He holds a Master of Technology (M.Tech.) from Motilal Nehru National Institute of Technology Allahabad, a background that has fueled his 14-year career in large-scale water infrastructure transformation. He has successfully spearheaded 20 major hydro-mechanical renovation projects for dams and barrages across Uttar Pradesh and Uttarakhand, alongside 24 critical dredging and channelization projects that have redefined river management and flood mitigation in Northern India. A pivotal figure in national milestones, he led the vital restoration of the Rapti Barrage for the inauguration of the Saryu Canal National Project by the Honourable Prime Minister of India, ensuring the seamless operation of the Rapti Barrage, Rapti Barrage outlet, and Rapti Barrage inlet gates. Beyond surface water, he possesses extensive domain knowledge in the design and construction of Deep-Bore State Tubewells (Rajkiya Nalkoop) using advanced drilling technologies. Honored as the “Best Karmyogi of Uttar Pradesh” in the Department, he played a crucial role in the Mahakumbh 2025 mega-project, where he executed specialized dredging and channelization to manage complex river flows and safeguard the sanctity of the Sangam for millions of pilgrims. His professional journey exemplifies a rare integration of academic excellence with groundbreaking field engineering in high-stakes hydraulic environments.

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