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Assessing the Environmental Impact of Heavy Metal Contamination in Water, Sediments, and Aquatic Vegetation of River Yamuna in Delhi

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Abstract

Objective: The 22 Km Delhi stretch is a most polluted region of the Yamuna River. The current study was conducted to determine the physio-chemical and biological parameters of Yamuna River water along with heavy metals in water, sediment, and aquatic plants in Delhi. **Methods:** The water physio-chemical and heavy metals in sediments as well as aquatic plants were determined by standard procedures. **Findings:** The values of total dissolved solids (TDS), turbidity, phosphate (PO_4), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), Nickel (Ni) and lead (Pb) in water samples varied from 544 to 1134 mg L^{-1}, 8 to 53 NTU, 0.11 to 1,46, 2.6 to 8.4, 3.2 to 28.4, 30 to 280, 0,36 to 1.45, 0.16 to 0.41, 0.02 to 0.14, BDL to 0.06, 0.03 to 0.09 and 0.02 to 0.08 mg L^{-1}, respectively. The results confirmed that TDS, turbidity, PO_4, Fe, Zn, Ni and Pb values surpassed the acceptable limit of BIS (2012) in all the water samples. The seven downstream sites showed a higher BOD5 level than prescribed by WHO (5mg/l). The Water Quality Index (WQI) ranged from 74 to 278, indicating that the water quality of downstream sites, after Wazirabad, was not found suitable for drinking purposes and fish culture. The enrichment factor (EF) for Zn (1.18-13.7), Cu (1.53-10.9, Ni (2.84-9.02), and Pb (1.36-8.99) was found to be quite high in the sediments. The aquatic plant *Ranunculus sceleratus* had high accumulations of Ni (246 mg kg^{-1}), Pb (276 mg kg^{-1}), and Zn (154 mg kg^{-1}) metals, whereas Cu (236 mg kg^{-1}) and Cr (40 mg kg^{-1}) were found to be maximum in *Eicchornia crassipes*. All the samples of plants surpassed the threshold level of Cr, Ni and Pb. **Novelty :** The outcome of this study shows that the Yamuna River is badly polluted in the Delhi region. It is pertinent to create a robust wastewater treatment facility for the entire Delhi region before discharging into the Yamuna River.

Keywords: Heavy Metals; River Yamuna; Sediment; Aquatic Vegetation; Enrichment Factor

1 Introduction

River water is used for various activities, including cleaning as well as disposal of waste in developing countries like India. The wastewater discharge from cities and industries, contaminates the river water with organic and inorganic pollutants, affecting humans and ecosystems worldwide [1]. The sewage wastewaters from cities are the major source of organic pollutants loads in rivers. The sediments, which absorb heavy metals, are used to estimate the metal pollution in the rivers' water along with their path. The sediments contains a higher amount of heavy metals as compared to the water column due to the tendency of metals to accumulate in the bottom [2]. These heavy metals move rapidly from the water column to the sediments, while some portion of these heavy metals can be accumulate into the biota from the sediments [3]. The heavy metals from sediments and water are taken up, through active and passive absorption, by aquatic plants. The main sources of heavy metals are mining, industrial processing, agricultural run-off, and sewage, as well as weathering and erosion of heavy metals from geological sources into the river system [4].

The water quality index (WQI), which provides a single number for water quality, measures how suitable water is for diverse uses. The policymakers can take the help of WQI in the proper implementation of the management plan of any water body [5]. Several studies have evaluated the water quality index (WQI) as well as heavy metals in water, sediments, and macrophytic plants of various rivers in terms of WQI [3,6–9].

Yamuna River became one of the most polluted rivers in the world due to the recent industrial revolution and significant population growth in the last five decades. The main causes of its current condition are domestic wastewater and industrial effluents flowing through numerous major and minor drains [4]. As per Census (2011), the population of Delhi is approximately 16,700,000. Total wastewater generated in Delhi is about 3267 MLD, including 218 MLD from industrial sources. Out of this, 2365 MLD is discharged into the Yamuna River. A total of 2330 MLD was treated in the sewage treatment facility, but 937 MLD discharge were without any treatment into the river [10]. The river water quality is impaired by the 22 major drains, which carry a large part of household and industrial wastewater that is directly discharged into the river. The presence of industrialization and heavy urbanization in Delhi city initiated the present study to evaluate the pollution level in various components in the Yamuna River at Delhi stretch. The heavy metals level in Yamuna water was evaluated by several researchers [6,7], however, they only looked at the water. While from the water, heavy metals accumulation occurred in sediments and aquatic vegetation with time. There was limited studies in the literature that examined the heavy metal concentrations in the water, sediments, or aquatic vegetation in the Yamuna River [11,12].

It is therefore, the present study was conducted on the Delhi stretch of the Yamuna River. The main objectives of study were (1) To measure the concentrations of heavy metals namely, iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), and lead (Pb) in water, sediments, and macrophytic plants, and determination enrichment factor (2) Assessment of the water quality index (WQI) by using most common water parameters.

2 Methodology

2.1 Study area and sampling site description

The total area of Delhi is 1485 sq. km with 77.12E longitude and 28.38 N latitude and it is the capital of India. Palla village of Delhi is the entering point of Yamuna in the capital and Okhla is the last point. The total length of the Yamuna River stretch in Delhi is 22 km from Palla to Okhla. The sampling locations were selected based on distance and approachability criteria. In the current study, nine different sampling sites were selected in the Delhi region during the winter season. Palla village (entering point of Yamuna in Delhi) (S1), Wazirabad (point from where water extracted for Delhi water supply) (S2), Inter-State Bus Terminal Kashmiri Gate(I.S.B.T) (S3), Yamuna Ghat (S4), LohaPul Gandhi Nagar (S5), Indraprastha (S6), Raj Ghat (S7), DND flyover (S8), Kalindi Kunj (S9) were the sampling sites. All the sampling locations were approximately 2 km apart from each other.

2.2 Water, sediments, and aquatic plants sampling

The grab water samples were collected in 2 liters of jerry cans in duplicates and kept in an icebox at 4°C before further processing and analysis. The sediments from 0-15cm depth were collected with the help of a steel corer having a tube length of 20 cm and diameter of 10 cm. The sediments were collected from 10x10 meters of area from each site. The samples were homogenized and composite samples were stored in bottles. In the laboratory, an oven at 110 °C was used to dry the sediment samples. The pestle and mortar were used to make powdered sediments, before further analysis. The plants growing just inside the river bank were randomly collected in triplicate from each site and stored in paper bags. The aquatic plants namely, *Spirogyra, Ranunculus sceleratus, Tagetes erecta (Marigold), Eichhornia crassipes (Water hyacinth), Croton sparsiflourus, Lithospermum* *arvense, Portulaca meridiana* were collected and identified. The plants were dried at 80 °C in the oven and ground to obtain powdered material in the laboratory.

2.3 Water physio-chemical analysis

From each site, water parameters such as DO, pH, EC and TDS were measured at the site. The pH, EC, and TDS were measured by Systronics water and soil testing kit Model No. 371, while DO was estimated by the Wrinkler method. In the laboratory, water samples were filtered by using a Millipore filtering system and analyzed according to standard methods [13]. BOD was measured by 5 days BOD test at 20 °C, while COD was determined by the open reflux method using ferrous ammonium sulphate as a titrant. Flame photometer model No. EP 902 was used to determine Na and K. EDTA titration method was used to measure Ca and Mg. A Colorimetric method using stannous chloride was used to analyze total phosphorus. Bicarbonate and chloride were measured by titration method using HCl and $AgNO_3$, respectively. Sulphate was determined by the turbidity method by using barium chloride. All the water samples were analysed in triplicate using analytical grade chemicals.

2.4 Heavy metals analysis

The organic matter interference was removed by acid digestion before the determination of heavy metals. Water samples were digested by taking a 100ml sample and 20 ml 1:1 HNO_3. For the release of mineral elements from sediments wet oxidation of samples was carried out using 10ml HNO_3 and 5ml concentrated HCl for 1gm of dried sediments. The aquatic plants were wet digested by using 20 ml concentrated HNO_3 and 5 ml of $HClO_4$ for 1gm of dried plant material. The digestion of all samples was carried out by heating at 80 °C in a water bath till dryness in fume hood chamber. After completion of digestion, double distilled water was added and filtered through *Whatman no. 42 filter paper*. The final volume of all the samples was 50 ml makeup with distilled water. The heavy metals, Fe, Cu, Zn, Cd, Ni, Pb, and Cr were determined by Polarized Zeeman Hitachi *Atomic Absorption Spectrophotometer (AAS) (model No. Z6100)*. All samples were analyzed in triplicate. Analytical grade (AR) chemicals were used throughout the study. Certified stock solutions (Merck) of 1000 mg L^{-1} were used for the preparation of heavy metals working standards.

- **Enrichment factor (EF)**

The world average of the metals in soils was used as a background value for the determination of enrichment factors (EF) for each of the heavy metals in the sediments.

$$Enrichment\ factor = \frac{Heavy\ metals\ in\ sediments}{background\ value\ of\ heavy\ metals\ in\ sediments} \tag{1}$$

- **Water Quality Index (WQI)**

The water physiochemical data was used to determine the weighted arithmetic water quality index (WQI) by using Microsoft Excel 2007 version. The WQI was evaluated by using the most common water parameters viz., pH, total dissolved solids (TDS), total hardness (TH), chloride, turbidity, sulphate (SO_4), biological oxygen demand (BOD), dissolved oxygen (DO) and heavy metals. The weighting unit for each parameter was calculated as prescribed by Singh et al [3]:

$$Wi = K\sum \frac{1}{S_{standard}} \tag{2}$$

Where $S_{standard}$ denotes the ith parameter maximum permissible limit, and K denotes the constant of proportionality, computed by using Equation 2.

$$K = \frac{1}{\sum \frac{1}{S1} + \frac{1}{S2} + \cdots + \frac{1}{Sn}} \tag{3}$$

Where the number of parameters denoted by n

The water parameters quality rating scale (Qi) of ith parameter was carried out by Equation 3.

$$Qi = \frac{Q_{actual} - Q_{ideal}}{S_{standard} - Q_{ideal}} * 100 \tag{4}$$

Where,Q_{actual} = Water sample i^{th} parameter evaluated concentration, Q_{ideal} = i^{th} parameter ideal value in pure water, and Q_{ideal} = 0, except DO = 14.6 mg L^{-1} and pH = 7.

The WQI was computed by using the values of Wi and Qi in Equation 4.

$$WQI = \frac{\sum_{i=1}^{i=n} WiQi}{\sum Wi} \tag{5}$$

3 Results and Discussion

3.1 Physio-chemical water quality

A total of nine water samples were collected and analyzed from the Yamuna River in the Delhi region. The results of physio-chemical water quality are depicted in Table 1. The pH value in the surface water of Yamuna River was alkaline in all the samples, ranging from 7.28 to 8.2,5 with a mean value of 7.8. Generally, fluctuation in pH value at different sampling sites was attributed to factor like the removal of CO_2 by photosynthesis through bicarbonate degradation [8]. Variation in EC and TDS were observed minimum of 825 μmho cm^{-1} and 544 mgL^{-1} at Palla village (S1) and a maximum of 1890 μmhocm^{-1} and 1134 mgL^{-1} at DND flyover (S8), respectively. The TDS mainly contributed by organic salts, dissolved gases, and organic matter in dissolved form. The TDS was remarkably increased from 628 at Wazirabad (S2) to 1084 mgL^{-1} at I.S.B.T Kashmiri Gate (S3). It could be due to the mixing of Najafgarh drain water in the Yamuna River. The Yamuna water was not impacted by sewage or drain water till Wazirabad. The previous study conducted on the Yamuna River in the Delhi region by Bhattacharya et al. [14] showed that TDS ranged from 233 to 667 mgL^{-1}, which was lesser compared to the present study, demonstrating the increase in sewage contamination over time. Turbidity varied from 8 to 53 NTU. The pollution of water quality is indicated by turbidity particularly due to drainage. The higher level of turbidity in the present study, suggests that particles causing turbidity have a chance to contain pathogenic organisms and could be creating potential health hazards. The cations like sodium (Na), potassium (K), calcium (Ca), magnesium Mg, and anions namely bicarbonates (HCO_3), chlorides (Cl), sulphate (SO_4) varied in the following range 88-207, 5-22, 43-72, 21-49, and 49-127, 120-298, 42- 98 mg L^{-1}, respectively, where total hardness (TH) varied from 193-370 mg L^{-1}. A TH greater value than 80 mg L^{-1} in water coagulates soap, hence cannot be used for domestic purposes. The value of phosphate (PO_4) varied between 0.11 to 1.46 mg L^{-1}. The higher level of phosphate in the water body could cause excess growth of phytoplankton, and unwanted biological changes with turbid water [8]. The study reveals that the concentration of dissolved ions rose as one moved away from the Palla village entry point. The TDS, turbidity, and PO_4 values surpassed the acceptable limit of BIS [15] in all the water samples. While Na in 11%, TH in 89%, Mg in 55%, Cl in 55% samples were above the acceptable limit of BIS.

The dissolved oxygen (DO), biological oxygen demand (BOD5), and chemical oxygen demand (COD) were between 2.6-8.4, 3.2-28.4, and 30-280 mg L^{-1}, respectively. The minimum DO level was 2.6 mg L^{-1} at Indraprastha (S7). After Wazirabad, DO levels showed a downward trend while BOD5 levels showed an upward trend, indicating that almost the whole study area has low oxygen levels, unsuitable for supporting aquatic life. Joshi et al. [16] pointed out that untreated sewage contributed about 70% of the pollution in rivers, which results in low DO and high BOD values. The organic pollution from municipal or industrial discharge was measured by the BOD and COD of the receiving water. The BOD value of unpolluted natural water has less than 5 mg L^{-1} [17]. In the present study, the BOD5 value after Wazirabad (S2) was greater than 5mgL^{-1} at all the downstream sites. The growth of bacteria and other organisms, supported by the presence of the organic compounds in water, consumed the available oxygen in decomposition and contributed to the higher value of BOD5 and COD [14]. The four downstream samples, DO values were less than 4mg L^{-1} as well as higher BOD values in all samples (> 2), indicating that Yamuna water was not suitable for wildlife and fisheries, as it was even not match the D class criteria of river water classification prescribed by Central Pollution Control Board (CPCB) [10]. The CPCB (2006) has categorized five major classes A to E for river water quality based on their use. The possible sources of high physio-chemical parameters were caused by discharge from municipal sewage, runoff from urban and agricultural land, leachate from solid waste dumping site, low levels of dilution (no water is allowed to flow from Tajewala barrage during summer and winter) and industrial discharges. After connecting the Shahdara drain, the DO value from Wazirabad to Okhla barrage ranged from 0.5 to 3.6 mg L^{-1}, which was less than the prescribed limit of 5mg/l. The finding of the present study is also concurrent with the study conducted by Dutta et al. [18] on the Nag River and associated drains that flow through the Nagpur city of Maharashtra. They highlighted that Nag River and associated drain showed the TDS, Cl^-, PO_4^{3-}, BOD, COD, and Na^+ values exceeded the prescribed limits of BIS (2012) and WHO (2011). The DO levels ranged from 0.32 to 5.82 mg L^{-1} for all the sampling locations, indicating the suffocating environment for aquatic life.

Table 1. Physiochemical parameters of Yamuna water samples collected from different sites

Parameters	S1	S2	S3	S4	S5	S6	S7	S8	S9	Mean (Range)	BIS (2012) Acceptable limit
pH	8.25	7.5	7.28	8	7.8	7.88	7.77	7.93	7.81	7.8 (7.28-8.25)	6.5-8.5
EC (μmhocm^{-1})	825	952	1610	1225	1706	1760	1746	1819	1230	1430 (825-1819)	–
TDS (mgL^{-1})	544	628	1084	794	1120	1110	1130	1134	790	926 (544-1134)	500
Turbidity (NTU)	8	8	38	14	40	14	20	53	17	23.5 (8-53)	1
DO (mg L^{-1})	8.4	7.3	5.0	4.8	4.0	3.4	2.6	2.8	2.8	4.5 (2.6-8.4)	–
BOD (mg L^{-1})	3.2	4	17.4	18.2	18.6	19.2	19	24.2	28.4	16.9 (3.2-28.4)	–
COD (mg L^{-1})	30	50	120	150	150	180	160	220	280	148 (30-280)	–
Na (mg L^{-1})	88	164	135	141	198	207	204	201	205	171 (88-207)	200
K (mg L^{-1})	5	12	19	21	21	23	22	22	20	18.3 (5-22)	–
TH (mg L^{-1})	230	193	340	350	326	335	370	255	270	296 (193-370)	200
Ca (mg L^{-1})	48	43	67	72	62	62	68	68	56	60 (43-72)	75
Mg (mg L^{-1})	27	21	42	22	48	44	38	49	28	35 (21-49)	30
SO_4 (mg L^{-1})	68	61	77	45	78	87	98	89	42	72 (42-98)	200
Cl (mg L^{-1})	170	120	275	142	298	256	284	270	199	233 (120-298)	250
HCO_3 (mg L^{-1})	52	49	92	127	115	102	110	113	62	91 (49-127)	–
PO_4 (mg L^{-1})	0.19	1.46	0.11	1.30	1.04	0.28	0.33	0.30	0.15	0.58 (0.11-1.46)	0.1

3.2 Heavy metals in water, sediments, and aquatic Plants

The river water, sediments, and aquatic plants heavy metals (Fe, Zn, Cu, Cr, Ni, and Pb) concentration has been summarized in Table 2. The heavy metals concentration in sediments and aquatic plants was much higher (500 to 1000 times) as compared to water concentration, indicating the adsorption by sediments and bioaccumulation by aquatic plants.

The concentrations of Fe, Zn, Cu, Cr, Ni, and Pb in river water varied between 0.363 to 1.451, 0.162 to 0.412, 0.020 to 0.144, BDL to 0.068, 0.030 to 0.096, and 0.020 to 0.084 mgL^{-1}, respectively. The maximum concentrations of Fe, Ni, and Pb were found at Kalindi Kunj (S9), while Cu and Cr were at the DND flyover (S8), and Zn was at Indraprastha, (S6), respectively. The heavy metals concentration increased by many folds in downstream sampling locations in comparison to upstream locations. In case of Cu and Cr, 44% and 22% of the water samples surpassed the drinking water acceptable limit (0.05 mgL^{-1}) of BIS[15]. The Fe. Zn, Ni, and Pb concentrations were above the acceptable level in all the water samples. Heavy metals works in industrial areas of Delhi could be the main attribution factor in downstream sites. The finding of this study is in good agreement with the outcome of Perihar et al[19] study conducted on iron and copper heavy metals in the Yamuna River at the Delhi region. They also reported the water iron and copper concentration was more than the prescribed BIS (2012) limit. Similarly, Sharma et al.[1] also reported the higher values of various heavy metals in Delhi Yamuna water in comparison to the BIS (2012) limit. However, most of the study conducted on heavy metals in Yamuna at Delhi is limited to the water component. The present study evaluated the levels of heavy metals in sediments and aquatic vegetation in addition to looking at the water.

The Fe, Zn, Cu, Cr, Ni, and Pb concentrations in sediments ranged between 766 to 1191, 112 to 849, 21.4 to153, 9.6 to 28.1, 44.7 to 162, and 34 to 224 mg kg^{-1}, respectively. The geological occurrence of Fe metal is quite high, the world average of Fe in uncontaminated soils is 4600 mg/kg, which is much higher than other metals[20]. Due to such a high background concentration in sediments, Fe concentration in sediments was found below the background level, and enrichment factor (EF) varied between 0.16-0.26. The highest Zn concentration was found at Raj Ghat (S7). Zn exceeded the background concentration (62 mg kg^{-1}) in all the samples. The enrichment factor (EF) for Zn ranged between 1.81-13.7. The background concentration of Cu, Cr, Ni, and Pb in soils is 14, 42, 18 and 25 mg kg^{-1} [22,23]. All the samples showed higher values than the background values for Cu, Ni, and Pb, while value for Cr in all sediment samples was within the background value. The enrichment factor (EF) was lesser than one in the case of Cr, while 1.53 to 10.9 for Cu, 2.48-9.02 for Ni, and 1.36-8.99 for Pb, indicating industrial clusters related to heavy metals works are dominated in the Delhi region. Singh et al.[24] conducted the study on the Hindon River in Muzaffarnagar Region, Uttar Pradesh . The findings indicate that the enrichment factors in sediment samples were extremely high for Ni (28373) and Pb (10568) in Hindon River. Mehra et al.[21] studied the Cr concentration in Yamuna sediments during the year 2000 in the Delhi region. They reported 48 to 108 mg kg^{-1} concentration of Cr in Yamuna sediments. The concentration of Cr in the present study was lesser as compared to Mehra et al.[21]. It could be due to the more stringent rule regarding Cr

Table 2. Water, sediment and aquatic plant heavy metals content in Yamuna River

Heavy metals	Water (mg L^{-1})				Sediments (mg Kg^{-1})					Aquatic plants (mg Kg^{-1})			
	Mean	Min.	Max.	BIS (2012) Standards	Mean	Min.	Max.	Background concentration in soils	Enrichment Factor (EF) range	Mean	Min.	Max.	Safe limit in plants
Fe	0.632	0.363	1.451	0.3	1021	766	1191	4600[a]	0.16-0.26	919	443	2250	–
Zn	0.294	0.162	0.412	5.0	286	112	849	62[b]	1.81-13.7	83.8	5.19	154	100[c]
Cu	0.068	0.020	0.144	0.05	62.7	21.4	153	14[b]	1.53-10.9	80.8	12.5	236	25[c]
Cr	0.030	BDL	0.068	0.05	15.8	9.61	28.1	42[b]	0.22-0.67	15.9	2.40	40.1	0.5[c]
Ni	0.074	0.030	0.096	0.02	101	44.7	162	18[b]	2.48-9.02	141	60.5	246	5[c]
Pb	0.051	0.026	0.084	0.01	76.5	34.0	224	25[b]	1.36-8.99	110	12.6	276	10[c]

BDL= below detectable limit [a] Lo and Fung[19] [b] Alloway[20] [c] Allen[21]

producing waste and replacement of Cr electroplating with Zn plating because of the hazardous nature of chromium. Bhuyan and Bakar[2] recorded the Ni and Pb concentrations in the range of 11.3 to 22.5 and 6.3 to 15 mg kg^{-1}, respectively in the sediment of Halda River, Chittagong, Bangladesh.

The Fe, Zn Cu, Cr, Ni and Pb concentrations in aquatic plants ranged between 443 to 2250, 5.19 to 154, 12.5 to 236, 2.4 to 40.1, 60.5 to 246, and 12.6 to 276 mg kg^{-1}, respectively. The *Ranunculus sceleratus* showed higher concentrations of Fe, Ni and Pb, where Zn was found maximum in Marigold, Cu, and Cr was found maximum in *Eicchornia crassipes* at I.S.B.T Kashmiri Gate. The Zn, Cu, Cr, Ni, and Pb safe limit in plants is 100, 25, 0.5, 05, and 10 mg kg^{-1} as quoted by Allen[25]. All the samples of plants surpassed the threshold level of Cr, Ni and Pb, while 78% of samples exceeded the Cu threshold level. Maria Cavadas Morais Couto et al.[26] reported that Zn concentration ranged between 16 to 653 mg kg^{-1} in aquatic plants of Ave River lower basin, Portugal. Similarly, Al-Afify and Abdel-Satar[27] evaluated the heavy metals in two native aquatic plants (*Ceratophyllum demersum and Eichhornia crassipes*) in Rosetta Branch of Nil River, Egypt. They noted that these plants effectively accumulated the Cd in comparison to other heavy metals.

3.3 Water Quality Index (WQI)

The WQI was computed by using eight parameters and heavy metal concentrations in water. The standards prescribed by Bureau of Indian Standards (BIS, 2012) and Indian Council of Medical Research (ICMR) were used for the calculation of WQI. The classification of river water based on the WQI score has been summarized in Table 3. The evaluated WQI of nine sites in the Delhi region Yamuna water is presented in Figure 1. The WQI was found between 72.84 to 278.5. The highest value of WQI was observed at Kalindi Kunj (S9), while the lowest value was observed at Wazirabad (S2). The WQI of the first two sites, Palla village (S1) and Wazirabad (S2) was found to be in the range of poor category indicating that the river also received organic pollution from the Haryana stretch. The water of these two locations can be suitable for bathing and irrigation purposes. The WQI sharply increased at I.S.B.T Kashmiri Gate with a value of 184. It could be due to the discharge of Najafgarh drain wastewater into the river Yamuna upstream of this site.

Table 3. WQI value indicating water quality classification (Dutta et al.[18])

WQI value	Water quality status
0-25	Excellent
26-50	Good
51-75	Poor
75-100	Very poor
> 100	Unsuitable for drinking use and fish culture

The WQI constantly showed an increasing trend from Wazirabad (S2) to downstream locations till Kalindi Kunj (S9) near Okhla. Downstream from Wazirabad, Yamuna is just like an open sewer, which receives treated and untreated wastewater 22 drains from Delhi. The BOD and DO were the main contributing parameters, which impacted on the water quality and enhanced the WQI. It can also be concluded that Yamuna water downstream from Wazirabad is not suitable for drinking use and fish culture. A similar study with high WQI has been conducted by Dutta et al.[16] on the Nag River at Nagpur, Maharashtra.

They reported the WQI ranged from 32.67 to 3991.03. They also emphasized that high WQI may be due to elevated levels of BOD. The natural flow rate was minimal after Wazirabad in Yamuna because the water in Wazirabad barrage is collected for water supply and nominal water is allowed to flow in downstream from this place. This is another possible reason for the increased pollution after Wazirabad in Delhi.

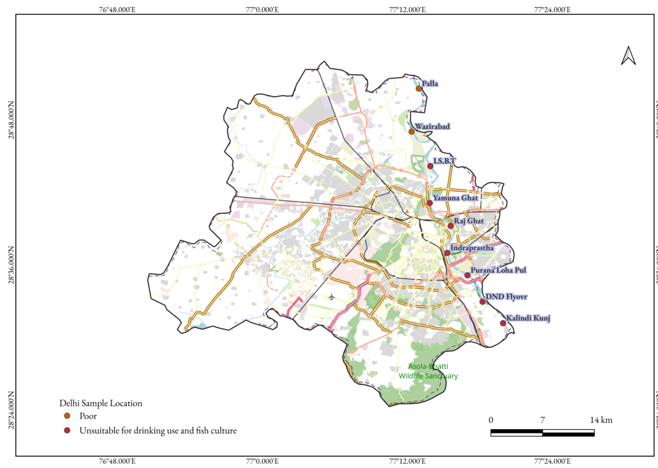

Fig 1. Water Quality Index at various sites

4 Conclusion

The physio-chemical properties as well as heavy metals content in Yamuna water in the Delhi region were evaluated in the current study. Simultaneously, heavy metals content in sediments and accumulation in aquatic plants were also determined. The detection of heavy metals in water, sediments, and aquatic plants makes this study more advantageous. The TDS, turbidity, PO_4 values exceeded the prescribed BIS level in all the water samples, whereas the TH value exceeded in 8 samples, Mg, and Cl values exceeded in 5 samples. The mean BOD (16.6 mg L^{-1}) and COD (148 mg L^{-1}) values were found to be quite higher, inclined in sites downstream from Wazirabad. The low value of DO and high value of BOD demonstrated that Yamuna water does not even fulfill the D classification criteria of CPCB (2006). The average concentrations of Fe, Cu, Cr, Ni, and Pb were 0.63, 0.06, 0.03, 0.07, and 0.05 mg L-1, respectively, exceeding the BIS (2012) limits. The Yamuna sediment results revealed that Zn, Cu, Ni, and Pb concentrations were found higher as compared to the background level indicating the contamination from industrial discharges, which was supported by high enrichment factors for these metals. The higher concentrations of heavy metals were found in *Ranunculus sceleratus and Eicchornia crassipes*, suggesting that these plants are good accumulators. The WQI of seven downstream sites was quite high, suggesting that water was not suitable for drinking and fish culture.

In summary, it is demonstrated that Yamuna water in Delhi stretch present in an alarming condition. The waste waters from the 22 drains discharge in Yamuna ware the main contributing factor. The study suggests that a more robust wastewater management plan is needed for Delhi, in terms of wastewater treatment technologies for the entire city, before discharging the water in the Yamuna River.

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