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Application of water quality index and multivariate statistical techniques for assessment of water quality around Yamuna River in Agra Region, Uttar Pradesh, India

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ABSTRACT

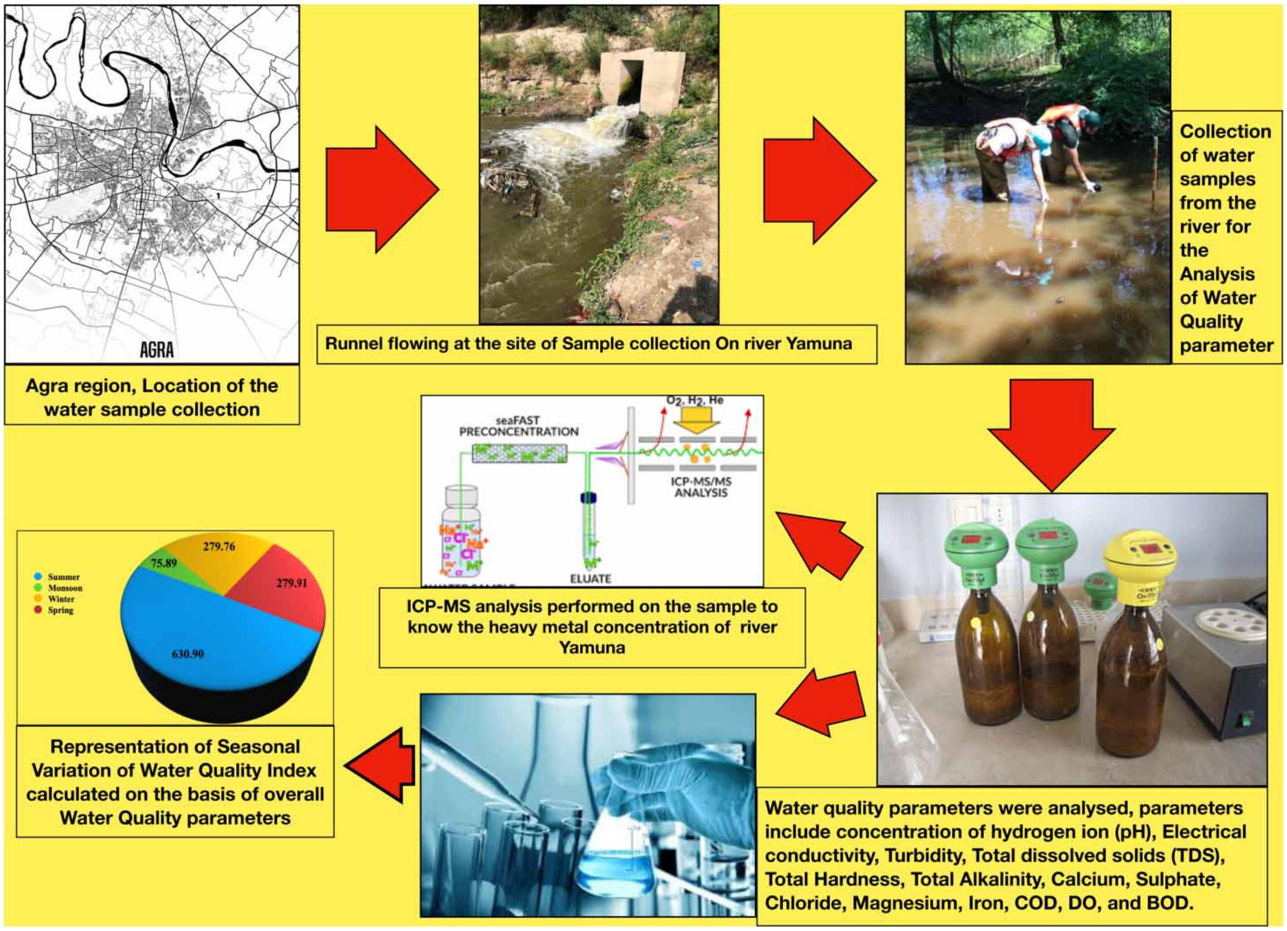
In this research, water quality index and multivariate statistical techniques were carried out on 14 water quality parameters collected quarterly (four times/year) from nine water sources in Agra, Uttar Pradesh, India, for one year (May 2019–April 2020). The water quality parameters included are the concentration of hydrogen ions (pH), Electrical Conductivity, Turbidity, Total Dissolved Solids (TDS), Total Hardness, Total Alkalinity, Calcium, Sulphate, Chloride, Magnesium, Iron, COD, DO, and BOD. The water samples collected show that the mean values of physicochemical parameters are in the range set by WHO and BIS except for hardness in summer (1,680 mg/L), monsoon (832.22 mg/L), winter (1,876.66 mg/L), spring (1,535.55 mg/L); TDS in summer (1,000.33 mg/L), monsoon (683.44 mg/L), winter (1,087.66 mg/L), spring (776.66 mg/L); and sulphate in summer (927.22 mg/L), monsoon (446.77 mg/L), winter (925.77 mg/L), spring (944.88 mg/L), which indicate bad quality of water. The WQI values were calculated for three locations in different weather conditions. WQI values in summer, winter and spring are 630.90, 279.61, 279.91, showing that the river water is not suitable for drinking purposes whereas the WQI value in monsoon is 75.89, showing that water is fit for drinking purposes due to the dilution of the river water. A moderate positive correlation was observed for turbidity with total hardness, iron, total alkalinity, and sulphate. Negative correlation was observed with pH. Moderate correlation was seen with TDS–EC (0.608), TDS–Alkalinity (0.7794), EC–Ca (0.723), and strong correlation was observed for BOD–DO (0.941) and Ca–Mg (0.999). Principal component analysis revealed that five factors were significant (eigenvalue > 0.5) with total variance of 39.43%–85.19% respectively. The ICP-MS study of water samples from point sources indicate the presence of Ni^{2+}, Cr^{6+}, Co^{2+}, Mn^{2+}, Cu^{2+}, and Zn^{2+} ions at higher concentrations.

Key words: BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), ICP-MS (Inductively Coupled Plasma Mass Spectroscopy), Water Quality Index (WQI)

HIGHLIGHTS

- WQI values in summer, winter and spring are 630.90, 279.61, 279.91, showing that the river water is not suitable for drinking purposes.
- WQI value in monsoon is 75.89, showing that water is fit for drinking purposes due to the dilution of the river water.
- ICP-MS detects the presence of metal ions such as Ni^{2+}, Cr^{6+}, Co^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}.
- Multivariate statistical analysis reveals that five parameters are responsible for the high values of WQI.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is the most paramount component on the earth and required by living creatures for their survival. Fresh water has an important role in the development of the natural ecosystem and human advancement. Industrialization and urbanization are continuously increasing the level of by-products in water streams from various production and chemical processes. These toxic secondary products have caused the elevation of water pollution level by unbalancing the natural concentration and parameters of water. River water is a source of many human uses such as irrigation, agriculture, transportation, drinking, fishing, boating, swimming etc. The increasing pollution of river bodies is a major unsettling concern for the world. A river is a running watercourse and it is important to protect and improve the river water quality. River water generally contains natural nutrients which are important for human health and aquatic species. The contamination of river water changes the water quality which may cause algal blooms and aquatic organisms to die.

India is a land of rivers. The huge population of India depends on the river water supply. There are several major rivers and important tributaries in India. Yamuna River is the longest tributary in India. In Indian surroundings, heavy populations reside near river banks and mainly depend on the river water for irrigation, drinking and other household activities. The emerging pollution of river water by toxins discharged from untreated wastewater has caused the imbalance in the water quality.

The contaminated water has devastating effects on the living ecosystem, which causes genetic and functional mutations that transform the physical and chemical functions of living organisms. Water quality parameters play a vital role in governing the overall condition of water and its appropriateness for consumption. The water quality index (WQI) is a single number that generates the water quality by ciphering parameters such as dissolved oxygen, pH, alkalinity, salinity, electrolytes, total hardness, biological oxygen demand (BOD), chemical oxygen demand (COD), etc. The assessment of water quality is from time to time conducted using various techniques. Kazi *et al.* (2009) used multivariate statistical techniques to determine the water quality of Manchar Lake, Pakistan. The authors collected the large dataset for two years on a monthly basis to find out the water quality parameters of the polluted lake. By the use of various analysis methods, this study successfully interpreted the complex datasets. Tawati *et al.* (2018) chose the rainy season to analyze the quality of river water located in Indonesia. It was found that calcium and magnesium were the main contributors to permanent hardness in various river locations. In recent research, Kumar *et al.* (2021) estimated 49 years of data using the WQI of the sacred Ganga River, India. The results revealed that the river water was moderately polluted in the years 2015–2018 but was acceptable for agricultural activity. Adimalla & Qian (2019) assessed the groundwater quality of an agricultural region, South India. After calculating the WQI values, the authors found that 86% of groundwater was nitrate-contaminated and unsafe for drinking use. Chakraborty *et al.* (2021) applied WQI and other statistical testing methods to evaluate the changes in the river water quality of Damodar River, India, during COVID-19 lockdown. The results suggested that the WQI during pre-lockdown and during lockdown periods of the sampling sites were of poor quality. Yamuna river samples of different locations have been subjected to physicochemical parameter analysis (Rout 2017). Sharma & Kansal (2011) analyzed the WQI of Yamuna River to describe the pollution level of the river for a period of ten years (2000–2009). Electrode-based techniques were applied by Dubey 2016 to analyze the status of Yamuna water quality (Dubey 2016). A dataset of 13 sampling sites of Yamuna River has been presented (Yadav & Khandegar 2019). The monitoring of water quality of river water is important for the regulation of pollution control. There are a number of methods for quality assessment such as single factor analysis, artificial neural network, fuzzy mathematics and multivariate statistical approach. Among them, WQI and multivariate statistical techniques are the most prevalent approaches for understanding the spatial and temporal dynamics of the water quality of river water (de Andrade Costa *et al.* 2020). In this research, water quality index and multivariate statistical techniques (PCA) were carried out on 14 water quality parameters collected quarterly (four times/year) from nine water sources in Agra, Uttar Pradesh, India, for one year (May 2019–April 2020).

2. METHODOLOGY

2.1. Study area

Yamuna River is one of the major rivers of the northern plains of India and is the second-largest tributary of the Ganga River, and over 90% of irrigation practices for the growing of crops are performed by Yamuna River water. The overall length of the river is around 1,376 km and it has a drainage system of 366,224 square kilometres. The main depth of the Yamuna River in Delhi is about 18 metres. It originates from Yamunotri and merges with the Ganga at Allahabad, India, where the merging point is known as Sangam. The study area is located in the Yamuna River, Agra district of India, in the state of Uttar Pradesh. The district is emplaced in the extreme southwest corner of Uttar Pradesh, Agra, stretching across latitude 26° 44′ north to 27° 25′ north and longitude 77° 26′ east to 78° 32′ east. Agra is the 33rd most populated city in India. The location map of the research area is shown in Figure 1. Nine water samples were collected on a quarterly basis from Yamuna River, Agra district, from May 2019 to April 2020.

2.2. Sample collection area

The samples were collected from May 2019 to April 2020. Three samples from each location were collected as shown in Figure 2. A total of nine samples was collected in every season. The description of sample codes and location of sites along with their coordinates and the depth is given in Table 1.

2.3. Sample collection, experimental design, and its assay

The samples were analyzed with 14 water quality parameters. The samples were collected in the morning to give enough time to do physicochemical analysis in the laboratory within 24 h of the samples being collected. River water samples were collected in bottles made of polyethylene laved with 15% nitric acid (v/v). The samples were stored in the refrigerator at 4 °C for analysis. During sample collection, quality assurance, control, and analysis methods were maintained. The water samples collected from the river were analyzed for pH, EC, turbidity, TDS, total hardness, alkalinity, COD, BOD, dissolved oxygen (DO), iron (Fe^{2+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), and according to the usual operations and recommended prophylactic measures adopted to avoid adulteration. The physical parameters were analyzed by using a digital meter for pH (LT-16 Labtronics), conductivity by conductivity meter (LT-13 Labtronics), total

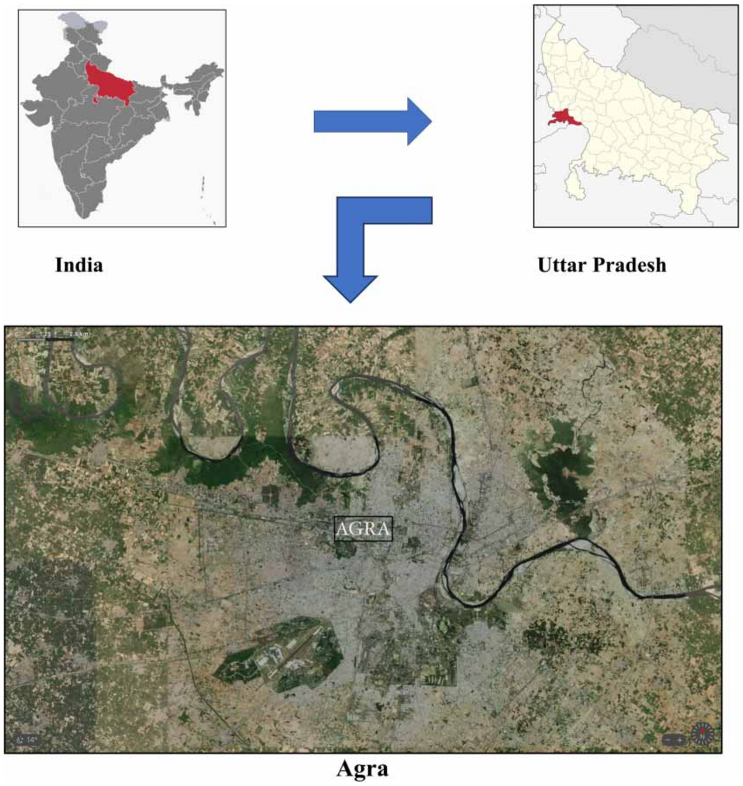


Figure 1 | Location map of the research area.

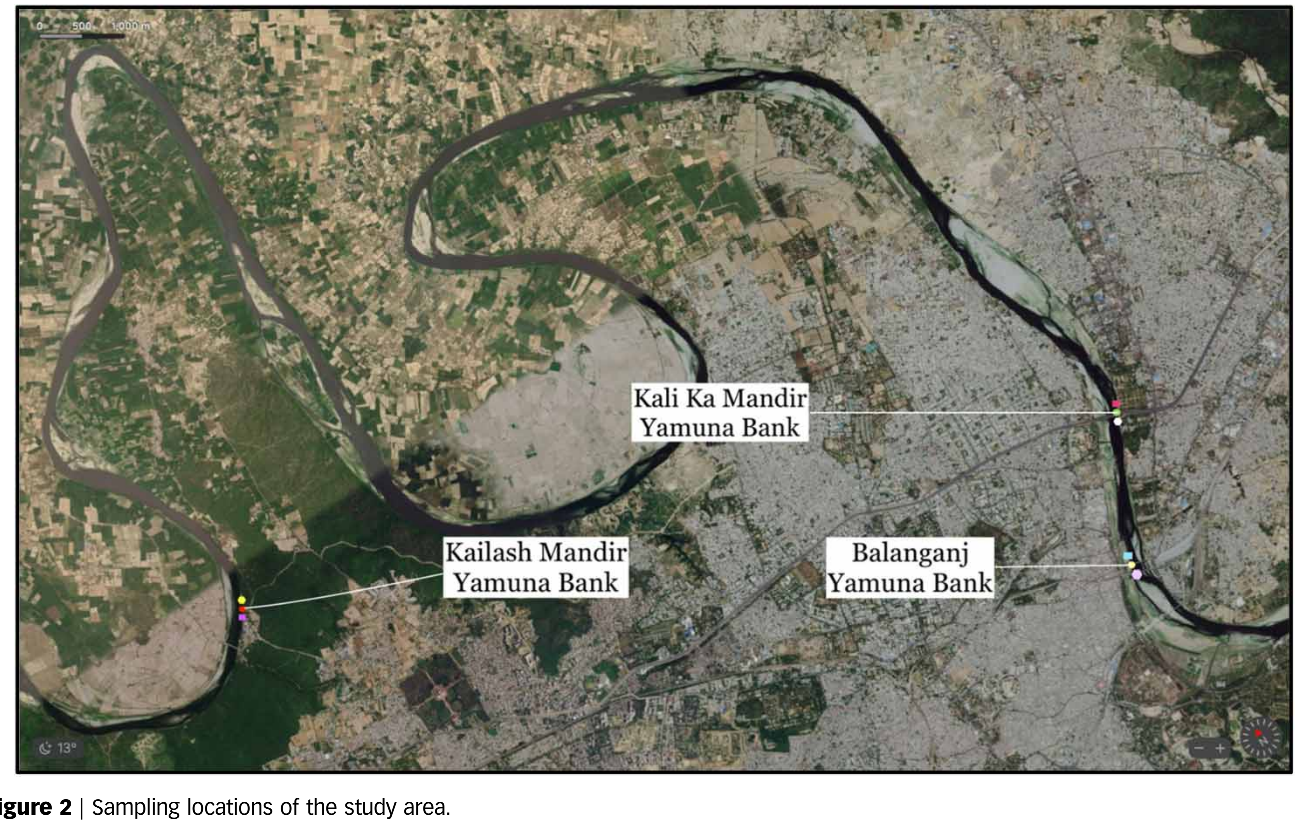


Figure 2 | Sampling locations of the study area.

Table 1 | Co-ordinates and location of sampling at Agra Region, UP, India

Description		Depth	Coordinates	
Sample location	**Sample name**	**cm**	**Latitude**	**Longitude**
Kailash Mandir, Yamuna Ghat	S1	23	27° 23′93.21″N	77° 93′65.07″E
	S2	24	27° 23′94.17″N	77° 93′66.24″E
	S3	23	27° 23′95.79″N	77° 93′66.91″E
Kali ka Mandir, Yamuna Ghat	S4	25	27° 20′54.42″N	78° 03′62.52″E
	S5	22	27° 20′52.56″N	78° 03′6153″E
	S6	26	27° 20′52.55″N	78° 03′59.73″E
Belanganj, Yamuna Ghat	S7	23	27° 19′10.14″N	78° 02′71.78″E
	S8	25	27° 19′09.02″N	78° 02′69.90″E
	S9	23	27° 19′07.14″N	78° 02′70.09″E

dissolved solids by TDS meter (LT-15 Labtronics) and turbidity by turbidity meter (LT-33 Labtronics). Total hardness, alkalinity, calcium, magnesium, iron, and chloride were determined through the titration method while sulphate was determined by gravimetric analysis. The COD was determined by the closed reflux dichromate method, and DO and BOD by iodometric test. The triplicate analysis was carried out using deionized water and the standard procedure given by the APHA manual as mentioned in Table 2.

2.4. WQI method

Water quality index (WQI) is the best tool for giving the details of the overall grade of water (Paun *et al.* 2016), which basically is a process to reduce large numbers and parameters into a single index number. WQI is very effective for understanding water quality findings and is used to judge the appropriateness of water for drinking purposes in major regions in the world. WQI is defined as a rating that reflects the composite influence of different water quality parameters (Sahu & Sikdar 2008). It is calculated assuming that a lower value signifies less deviation from the reported values of water quality parameters and good quality water for human consumption.

Table 2 | Measurement methods for the detection of water quality parameters

No	Parameters	Units	Methods
1	Concentration of Hydrogen Ions (pH)	pH units	pH meter
2	Biological Oxygen Demand (BOD)	mg L^{-1}	Azide modification at 20 °C for 5 days
3	Total Dissolved Solids (TDS)	mg L^{-1}	TDS meter
4	Electrical Conductivity (EC)	μS cm^{-1}	Conductivity meter
5	Iron (Fe)	mg L^{-1}	Titration
6	Total Alkalinity (TA)	mg L^{-1}	Titration
7	Total Hardness (TH)	mg L^{-1}	Herner's method
8	Chloride (Cl)	mg L^{-1}	Titration by silver nitrate
9	Chemical Oxygen Demand (COD)	mg L^{-1}	Reflux dichromate method
10	Calcium (Ca)	mg L^{-1}	Titration by EDTA
11	Sulphate (SO_4^{2-})	mg L^{-1}	Gravimetric method
12	Magnesium (Mg)	mg L^{-1}	Titration by EDTA
13	Dissolved Oxygen	mg L^{-1}	Azide modification at 20 °C for 1st day
14	Turbidity	NTU	Turbidity meter

The following equations are involved to determine WQI:

Ciphering water quality rating:

$$Qn = 10 \times \frac{Vn - Vi}{Sn - Vi} \quad (1)$$

where the values of the above variables are:

Qn = nth parameter of the water quality rating,
Vn = nth parameter of the observed value,
Sn = standard permissible value of the nth parameter, and
Vi = nth parameter of the ideal values.

Unit weight is denoted by Wn:

$$Wn = \frac{K}{Sn} \quad (2)$$

where the above variables are:

Wn = nth parameter of the unit weight,
Sn = nth parameter of the standard value, and
K = proportionality constant.

The above-mentioned K is calculated by the equation:

$$K = \frac{1}{\sum \left(\frac{1}{Sn} \right)} \quad (3)$$

The total WQI is calculated by adding the Qn and Wn linearly:

$$WQI = \frac{\sum Qn\ Wn}{\sum Wn} \quad (4)$$

The water quality of the river water is classified based on the WQI value as shown in Table 3. The mean value of each parameter was taken into consideration quarterly, which showed the overall plight of the river water as well as its quality.

2.5. Multivariate statistical data analysis

For the multivariate statistical data analysis the add-in of Microsoft XLSTAT was used. Principal component analysis (PCA) was used to determine the relationship and difference among the variables on the normalized data scale. This helps to reduce the ambit and complex nature of data having autonomous behaviour. The new variables generated are known as PCs (principal components). The significance of the PCs is measured with the help of eigenvalues calculated while the factor loadings signify the correlations of PCs with the original dataset values (Vega *et al.* 1998; Le *et al.* 2017).

The correlation matrix on the other hand is used to identify the correlations of water quality parameters with other parameters in matrix form. The correlation matrix of the 14 water quality parameters of the 36 samples collected annually was analyzed. Analysis is used to identify and estimate the degree of association involved among multiple parametric variables. Water quality parameters of a region are evaluated in a matrix, which has an important role in determining the influence of the water quality of an area (Bhutiani *et al.* 2018).

2.6. ICP-MS study

Inductively coupled plasma mass spectroscopy (Agilent ICPMS- 7900, IIT Delhi) is the technique where the sample gets ionized with the help of an inductively coupled plasma creating small atoms for detection. This method is used to detect the concentration of the numerable metal ions present in a single sample with a precise result. The concentration value of metal ions present in Yamuna water in the Agra region was analyzed by ICP-MS to detect the concentration of metal ions.

Table 3 | Analytical data of water quality parameters, summer (April–July) 2019

Parameters Sample name	Kailash Mandir Yamuna Ghat			Kali ka Mandir yomuna Ghat			Belanganj Yamuna Ghat					
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**Min**	**Max**	**Mean**
pH	8.36	7.47	8.29	8.48	7.90	7.86	7.29	7.86	7.63	**7.29**	**8.48**	**7.90**
Turbidity (NTU)	11	28	23	16	30	24	17	38	29	**11**	**38**	**24**
TDS (mg/L)	826	623	670	933	1,452	899	1,228	1,366	1,006	**623**	**1,452**	**1,000.33**
EC (μS/cm)	1,135	850	976	1,312	1,382	1,189	1,476	1,804	1,076	**850**	**1,804**	**1,244.44**
BOD (mg/L)	0.81	0.13	0.54	0.88	0.27	0.20	0.27	0.13	0.06	**0.06**	**0.88**	**0.36**
COD (mg/L)	128	352	192	64	192	256	256	160	224	**64**	**352**	**202.66**
Total Hardness (mg/L)	1,560	1,650	1,510	1,155	1,830	1,310	2,030	1,855	2,225	**1,155**	**2,225**	**1,680.55**
Iron (mg/L)	0.16	0.38	0.27	0.27	0.27	0.22	0.38	0.22	0.27	**0.16**	**0.38**	**0.27**
Total Alkalinity (mg/L)	665	420	545	625	750	700	680	750	720	**420**	**750**	**650.55**
Sulphate (mg/L)	889	964	732	720	836	851	1,113	1,280	960	**720**	**1,280**	**927.22**
Chloride (mg/L)	130	87	109	215	167	120	127	150	87	**87**	**215**	**132.44**
Calcium (mg/L)	96.14	156.23	96.14	72.10	132.19	68.10	132.19	112.16	136.20	**68.10**	**156.23**	**111.27**
Magnesium (mg/L)	6.56	9.47	6.56	4.37	8.01	4.131	8.01	6.80	8.26	**4.131**	**9.47**	**6.90**
DO (mg/L)	3.2	1.1	1.9	2.1	0.4	0.9	0.5	0.2	0.1	**0.1**	**3.2**	**1.15**

3. RESULTS AND DISCUSSION

3.1. Analysis of river water

3.1.1. Hydrogen ion concentration (pH)

The pH of any solution gives the strength of the solution and an idea of whether the solution is acidic or alkaline. The pH usually has no direct impact on the health of the human being but an excess of alkalinity in the body by water can lead to gastrointestinal issues and skin irritations. Too much alkalinity may also disturb the body's normal pH, leading to metabolic alkalosis. Figure 3 and Tables 4–7 show the pH values of Yamuna River, Agra, from May 2019 to April 2020. It can be noticed that the river water of the analyzed area was slightly alkaline in the summer and monsoon season (7.71–7.90), while a bit acidic in the winter and spring season (6.37–6.58). The permissible limit of pH required for drinking purposes by WHO is in the range of 7.0–8.5 (Kumar & Puri 2012). However, the alkaline value of the pH may be due to the disposal of industrial waste, domestic waste contamination, and the presence of chemical detergents.

3.1.2. BOD and COD

BOD is the amount of oxygen required to degrade the organic matter present in a given water sample at a particular temperature for a given period with the help of micro-organisms, whereas COD is the amount of dissolved oxygen that is required for any organic matter present in the water to be oxidized. Taking into consideration the mean value of the locations quarterly as shown in Figure 3 and Tables 4–7, it can be seen that the BOD value varied as 0.36 mg L^{-1} (summer), 2.92 mg L^{-1} (monsoon), 1.89 mg L^{-1} (winter) and 2.07 mg L^{-1} (spring). The obtained values are very low compared with the WHO standard of 5.0 mg L^{-1} (Kumar & Puri 2012) at which they become a threat to aquatic life due to the inadequate amount of oxygen supply. The low value of BOD may be attributed to organic substances and bacterial load in the river Yamuna. The mean yearly values of Yamuna River for COD varied as 202.66 mg L^{-1} (summer), 64 mg L^{-1} (monsoon), 89 mg L^{-1} (winter) and 71.11 mg L^{-1} (spring), which are also very low compared with the standard limit set by WHO (250 mg L^{-1}) (Kumar & Puri 2012). Low values of the COD and BOD give an idea of greater toxicity in the river water and indicate the presence of industrial and domestic effluents in the water body; the greater the waste, the less is the oxygen demand. It can also be concluded that the water body has a high amount of detergents in the form of domestic waste (Sharma *et al.* 2014).

3.1.3. Total dissolved solids (TDS), turbidity and EC

The inorganic salts as well as organic material present in the water body determine the TDS of the water, the lower the TDS of the water, the better is the quality of the water. The mean TDS of the water was found to be 1,000.33 mg L^{-1} (summer), 683.44 mg L^{-1} (monsoon), 1,087.66 mg L^{-1} (winter) and 776.66 mg L^{-1} (spring) as shown in Tables 4–7 and Figure 3. These values of TDS are very high compared with the values given by WHO, that is 500 ppm (Kumar & Puri 2012). The high values of TDS are also due to contamination of river water due to domestic waste, industrial discharge, and agricultural

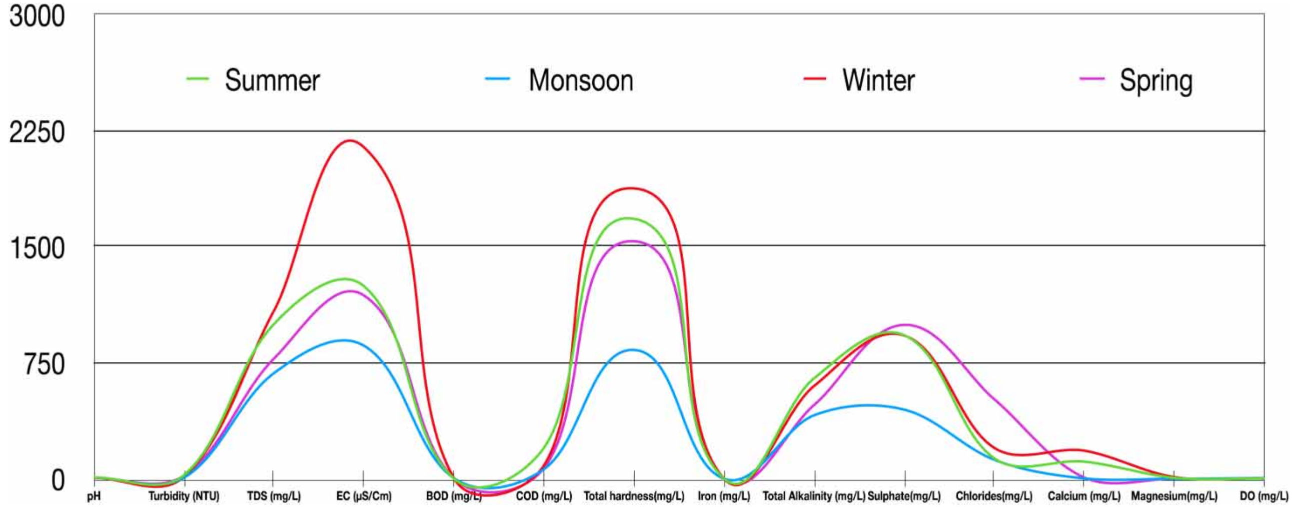


Figure 3 | Seasonal statistical summary of physicochemical parameters in the study.

Table 4 | Analytical data of water quality parameters, monsoon (Aug–Oct) 2019

Parameters	Kailash Mandir Yamuna Ghat			Kali ka Mandir Yamuna Ghat			Belanganj Yamuna Ghat					
Sample name	S1	S2	S3	S4	S5	S6	S7	S8	S9	Min	Max	Mean
pH	7.20	6.90	7.45	7.70	8.63	7.82	7.77	7.91	8.03	**6.90**	**8.63**	**7.71**
Turbidity (NTU)	04	05	03	06	13	07	08	16	11	**3**	**16**	**8.11**
TDS (mg/L)	523	633	412	616	876	703	767	850	771	**412**	**876**	**683.44**
EC (µS/cm)	590	638	609	701	1,180	821	878	1,320	994	**590**	**1,320**	**859**
BOD (mg/L)	2.47	3.27	3.03	2.18	2.40	2.15	4.38	2.32	4.15	**2.15**	**4.38**	**2.92**
COD (mg/L)	96	32	32	128	64	96	32	32	64	**32**	**128**	**64**
Total Hardness (mg/L)	672	820	615	591	985	887	940	1,233	747	**591**	**1,233**	**832.22**
Iron (mg/L)	0.165	0.11	0.165	0.11	0.165	0.22	0.165	0.11	0.165	**0.11**	**0.22**	**0.15**
Total Alkalinity (mg/L)	335	275	490	395	280	505	515	360	535	**275**	**535**	**410**
Sulphate (mg/L)	223	435	311	205	474	365	394	816	798	**205**	**816**	**446.77**
Chloride (mg/L)	101	141	81	155	194	124	126	117	69	**69**	**194**	**123.11**
Calcium (mg/L)	2.0	1.60	1.60	1.60	6.41	3.60	1.20	1.60	1.20	**1.20**	**6.41**	**2.31**
Magnesium (mg/L)	0.12	0.09	0.09	0.09	0.14	0.21	0.07	0.09	0.07	**0.07**	**0.21**	**0.10**
DO (mg/L)	3.8	4.7	4.1	3.8	2.6	4.6	5.5	3.2	5.8	**2.6**	**5.8**	**4.23**

Table 5 | Analytical data of water quality parameters, winter (Nov 2019–Jan 2020)

Parameters / Sample name	Kailash Mandir Yamuna Ghat			Kali ka Mandir Yamuna Ghat			Belanganj Yamuna Ghat					
	S1	S2	S3	S4	S5	S6	S7	S8	S9	Min	Max	Mean
pH	6.3	6.2	6.0	6.7	6.6	6.5	6.5	6.2	6.4	**6.0**	**6.7**	**6.37**
Turbidity (NTU)	04	10	08	05	08	07	16	34	30	**4**	**34**	**13.55**
TDS (mg/L)	842	842	868	974	1,816	947	1,210	1,237	1,053	**842**	**1,816**	**1,087.66**
EC (μS/cm)	1,640	1,694	1,694	2,020	1,858	3,550	2,400	2,350	2,070	**1,640**	**3,550**	**2,141.77**
BOD (mg/L)	2.65	3.46	3.19	0.34	0.13	0.88	2.17	2.58	1.63	**0.13**	**3.46**	**1.89**
COD (mg/L)	96	128	160	64	32	32	65	64	160	**32**	**160**	**89**
Total Hardness (mg/L)	760	695	555	1,465	2,075	1,290	2,800	4,540	2,710	**555**	**4,540**	**1,876.66**
Iron (mg/L)	0.22	0.27	0.22	0.22	0.38	0.16	0.22	0.27	0.22	**0.16**	**0.38**	**0.24**
Total Alkalinity (mg/L)	460	500	450	510	850	635	700	700	600	**450**	**850**	**600.55**
Sulphate (mg/L)	794	839	748	847	1,156	1,333	851	962	802	**748**	**1,333**	**925.77**
Chloride (mg/L)	127.62	141.80	127.62	212.7	383.86	170.16	212.70	226.80	198.52	**127.62**	**383.86**	**200.19**
Calcium (mg/L)	157.51	172.74	146.69	220.44	228.05	240.07	147.49	169.53	148.18	**146.69**	**240.07**	**181.18**
Magnesium (mg/L)	9.54	10.47	8.89	13.36	13.82	14.55	8.94	10.27	8.88	**8.88**	**14.55**	**10.96**
DO (mg/L)	5.0	6.0	6.1	0.5	0.2	1.3	4.1	4.8	3.2	**0.2**	**6.1**	**3.46**

Table 6 | Analytical data of water quality parameters, spring (Feb–March) 2020

Parameters Sample name	Kailash Mandir Yamuna Ghat			Kali ka Mandir Yamuna Ghat			Belanganj Yamuna Ghat					
	S1	S2	S3	S4	S5	S6	S7	S8	S9	Min	Max	Mean
pH	6.54	6.68	6.70	6.26	6.65	6.58	6.65	6.60	6.57	**6.26**	**6.70**	**6.58**
Turbidity (NTU)	24	25	28	10	16	15	11	33	26	**10**	**33**	**20.88**
TDS (mg/L)	771	395	793	793	1,138	965	793	594	748	**395**	**1,138**	**776.66**
EC (μS/cm)	1,200	587	1,210	1,309	1,691	1,418	1,184	882	1,182	**587**	**1,691**	**1,184.77**
BOD (mg/L)	2.72	3.60	2.92	0.88	0	0.74	2.44	2.58	2.78	**0**	**3.60**	**2.07**
COD (mg/L)	64	32	32	32	32	160	32	192	64	**32**	**192**	**71.11**
Total Hardness (mg/L)	1,060	1,765	1,330	2,095	1,185	680	2,140	2,280	1,285	**680**	**2,280**	**1,535.55**
Iron (mg/L)	0.11	0.27	0.22	0.16	0.38	0.22	0.27	0.38	0.22	**0.11**	**0.38**	**0.24**
Total Alkalinity (mg/L)	490	220	475	465	625	515	540	480	485	**220**	**625**	**477.22**
Sulphate (mg/L)	999	1,432	1,197	769	695	1,008	1,127	818	909	**695**	**1,432**	**994.88**
Chloride (mg/L)	510.48	340.32	553.02	553.02	581.38	581.38	538.84	453.76	510.48	**340.32**	**581.38**	**513.63**
Calcium (mg/L)	7.21	10.42	7.28	8.01	10.82	9.21	8.41	8.86	4.80	**4.80**	**10.82**	**8.33**
Magnesium (mg/L)	0.42	0.63	0.43	0.41	0.75	0.26	0.50	0.52	0.29	**0.26**	**0.75**	**0.46**
DO (mg/L)	5.0	6.9	5.6	1.4	0	1.1	4.0	3.8	4.1	**0**	**6.9**	**3.54**

runoff, and are an indicator of harmful contaminants in mineral form. Turbidity of water is defined as cloudiness or haziness of a fluid caused by the large number of individual particles that are generally invisible to the naked eye similar to smoke in the air. Turbidity mean values lie in the range of 24 NTU (summer), 8.11 NTU (monsoon), 13.55 NTU (winter) and 20.88 NTU (spring). The permissibility limit of turbidity given by WHO is 5 NTU (Kumar & Puri 2012). The value of turbidity was found to be high in all the weather conditions due to the presence of clay materials, small inorganic and organic matter, algae, dyes and plankton, coming from agricultural runoff and domestic sewage discharge. The electrical conductivity of water is directly proportional to the number of salts present in the water. As compared with the above TDS values, the mean values of the EC were higher throughout the year, ranging from 859 to 2,141.77 $\mu S\ cm^{-1}$.

3.1.4. Total hardness and total alkalinity

Total hardness gives us an idea about the amount of calcium and magnesium compounds present in water. The alkalinity of water can be defined as the capacity of water to neutralize acid. The mean total hardness of the water varied as 1,680.55 $mg\ L^{-1}$ (summer), 832.22 $mg\ L^{-1}$ (monsoon), 1,876.66 L^{-1} (winter) and 1,535.55 $mg\ L^{-1}$ (spring), comprising 2.31 to 181.18 $mg\ L^{-1}$ of calcium and 0.1 to 10.96 mg/L of magnesium as shown in Tables 3–6 and Figure 3. The permissible limit of hardness given by WHO for the drinking water standard is 600 $mg\ L^{-1}$ (Kumar & Puri 2012). The high value of hardness indicates the presence of cations like Ca^{2+} and Mg^{2+} that can easily reach into the river causing an increase in hardness. The alkalinity values varied as 650.55 $mg\ L^{-1}$ (summer), 410 $mg\ L^{-1}$ (monsoon), 600.55 $mg\ L^{-1}$ (winter) and 477.22 $mg\ L^{-1}$ (spring). The desirable limit given by WHO for alkalinity is 200 $mg\ L^{-1}$ (Kumar & Puri 2012). The values of alkalinity are within the permissible limit except in summer due to less water being in the river and the presence of more solids.

3.1.5. Cations and anions

Major ions that are found in water are mainly derived from deposition by the atmosphere, chemical weathering and anthropogenic waste in rivers from industries and sewage. Chloride is an indicator of the pollution caused by sewage. The permissibility of chloride is 250 $mg\ L^{-1}$ as given by WHO (Kumar & Puri 2012). Chloride in small amounts is consumed by living organisms as well as plants but at higher concentration, it causes toxicity. The recorded values of chloride ions varied as 132.44 $mg\ L^{-1}$ (summer), 123.11 $mg\ L^{-1}$ (monsoon), 200.19 $mg\ L^{-1}$ (winter) and 513.63 $mg\ L^{-1}$ (spring) as shown in Tables 3–6 and Figure 3. The high value of chloride ions in the spring is due to the high value of hardness in this season indicating the presence of harmful associated cations discharged from corroded pipes. The recorded values of sulphate ranged from 446.77 to 994.88 $mg\ L^{-1}$ and those are way beyond the permissible limit (250 $mg\ L^{-1}$) (Kumar & Puri 2012). Sulphate is found in water naturally as a result of the leaching of gypsum. Due to industrial and domestic waste the concentration of sulphate in water increases. It was found in our study that the concentration of sulphate was high throughout the year. Magnesium, calcium and sulphate are directly related to the total hardness of the water. In the present study, it was found that the high concentration of these metals increased the total hardness. The value of iron ranged from 0.15 to 0.27 $mg\ L^{-1}$ in river water, which was less than the 0.3 $mg\ L^{-1}$ permissible limit. The rainwater that came into contact with the soil not only increased the iron concentration of the river water, but also increased the groundwater iron concentration.

3.2. Water quality index (WQI)

Consumption of contaminated water has a bad impact on both living humans and the aquatic ecosystem. As shown in Tables 8 and 9 and Figure 4, the identified water quality index of the river Yamuna, Agra, came out to be 630.90 in summer, 75.89 in monsoon, 279.76 in winter and 279.91 in spring, and the values of WQI suggest that most of the river water is not fit for any use. The water quality in July was found unsuitable for human consumption, and same applies for the winter and spring seasons. However due to the dilution factor in the rainy season, the quality of water became good. It can be thus concluded that the water quality depends on season variations and degraded drastically in some months. The unacceptable value of WQI is due to agricultural runoff, cattle bathing, domestic waste decontamination, and excessive discharge of chemical detergents. This means that in this area the best products generated are not treated well and are not completely disposed of in the water body. Inputs of sewage and household waste from the town are thought to make a significant contribution to the contamination and the increase in the WQI.

Table 7 | Relative weight of each parameter

Parameters	Seasons	Mean sample value *Vn*	*Sn* standard	1/*Sn*	*K*	*Wn* = *K* ÷ *Sn*	Ideal value *Vi*	*Qn*	*Wn* × *Qn*
pH	Summer	7.90	8.5	0.11764706	3.98473654	0.468792534117647	7	150	70.31
	Monsoon	7.71						89.87	42.13
	Winter	6.37						−29.57	−13.86
	Spring	6.58						−21.87	−10.25
Turbidity	Summer	7.90	1	1.00000000	3.98473654	3.98473654	0	−104.34	−415.79
	Monsoon	8.11						−114.06	−454.51
	Winter	13.55						−107.96	−430.22
	Spring	20.88						−105.03	−418.51
TDS	Summer	1,000.33	500	0.00200000	3.98473654	0.00796947308	0	−199.93	−1.59
	Monsoon	683.44						−372.56	−2.96
	Winter	1,087.66						−185.08	−1.47
	Spring	776.66						−280.72	−2.23
Conductivity	Summer	1,244.44	1,500	0.00066667	3.98473654	0.00265649102	0	486.94	1.298
	Monsoon	859						134	0.355
	Winter	2,141.77						−333.72	−0.88
	Spring	1,184.77						375.84	0.99
BOD	Summer	0.36	5	0.20000000	3.98473654	0.796947308	0	7.75	6.18
	Monsoon	2.92						140.38	111.87
	Winter	1.89						60.77	48.43
	Spring	2.07						70.64	56.30
COD	Summer	202.66	20	0.05000000	3.98473654	0.199236827	0	−110.94	−22.10
	Monsoon	64						−145.45	−28.97
	Winter	89						−128.98	−25.69
	Spring	71.11						−139.13	−27.72
Total Hardness	Summer	1,680.55	200	0.00500000	3.98473654	0.0199236827	0	−113.50	−2.26
	Monsoon	832.22						−131.63	−2.62
	Winter	1,876.66						−111.92	−2.23
	Spring	1,535.55						−114.97	−2.29
Iron	Summer	0.27	0.3	3.33333333	3.98473654	13.2824551333	0	900	11,945.20
	Monsoon	0.15						100	1,328.24
	Winter	0.24						400	5,312.98
	Spring	0.24						400	5,312.98
Alkalinity	Summer	650.55	200	0.00500000	3.98473654	0.0199236827	0	−144.39	−2.87
	Monsoon	410						−195.23	−3.88
	Winter	600.55						−149.93	−2.98
	Spring	477.22						−172.14	−3.42
Sulphate	Summer	927.22	200	0.00500000	3.98473654	0.0199236827	0	−127.50	−2.54
	Monsoon	446.77						−181.04	−3.60
	Winter	925.77						−127.55	−2.54
	Spring	994.88						−125.16	−2.49
Chloride	Summer	132.44	250	0.00400000	3.98473654	0.01593894616	0	112.65	1.79
	Monsoon	123.11						97.02	1.54
	Winter	200.19						401.90	6.40
	Spring	513.63						−194.82	−3.10
Calcium	Summer	111.27	75	0.01333333	3.98473654	0.053129820533	0	−306.78	−16.29
	Monsoon	2.31						3.17	0.16
	Winter	181.18						−170.63	−9.06
	Spring	8.33						12.49	0.66
Magnesium	Summer	6.90	30	0.03333333	3.98473654	0.132824551333	0	29.87	3.96
	Monsoon	0.10						0.33	0.04
	Winter	10.96						57.56	7.64
	Spring	0.46						1.55	0.20

(*Continued.*)

Table 7 | Continued

Parameters	Seasons	Mean sample value *Vn*	*Sn* standard	1/*Sn*	*K*	$Wn = K \div Sn$	Ideal value *Vi*	*Qn*	$Wn \times Qn$
Dissolved Oxygen	Summer	1.15	6.5	0.15384615	3.98473654	0.613036390769	0	21.49	13.17
	Monsoon	4.23						186.34	114.23
	Winter	3.46						113.81	69.77
	Spring	3.54						119.59	73.31
						19.0044586726843			

Table 8 | Water quality classification based on WQI value

Class	WQI value	Water quality status
A	<50	Excellent
B	51–100	Good
C	101–200	Poor water
D	201–300	Very poor water
E	>300	Water unsuitable for drinking

Table 9 | WQI of the sites from April 2019 to March 2020

Season	WQI	Water quality status
Summer	630.90	Water unsuitable for drinking
Monsoon	75.89	Good
Winter	279.76	Very poor water
Spring	279.91	Very poor water

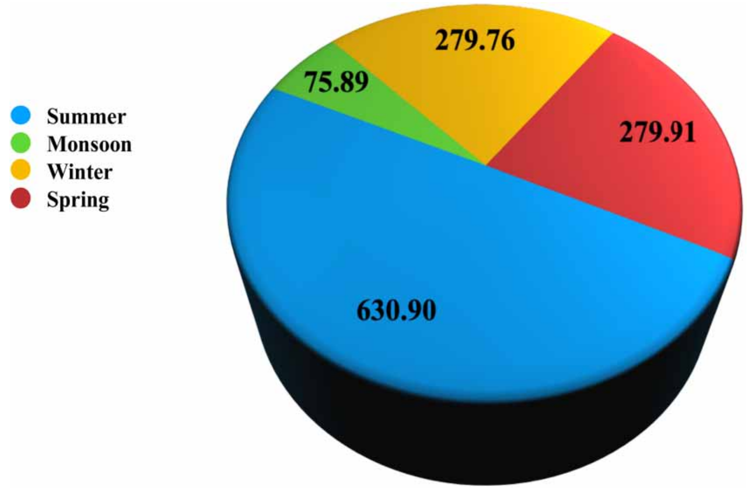


Figure 4 | Representation of seasonal variation of water quality index.

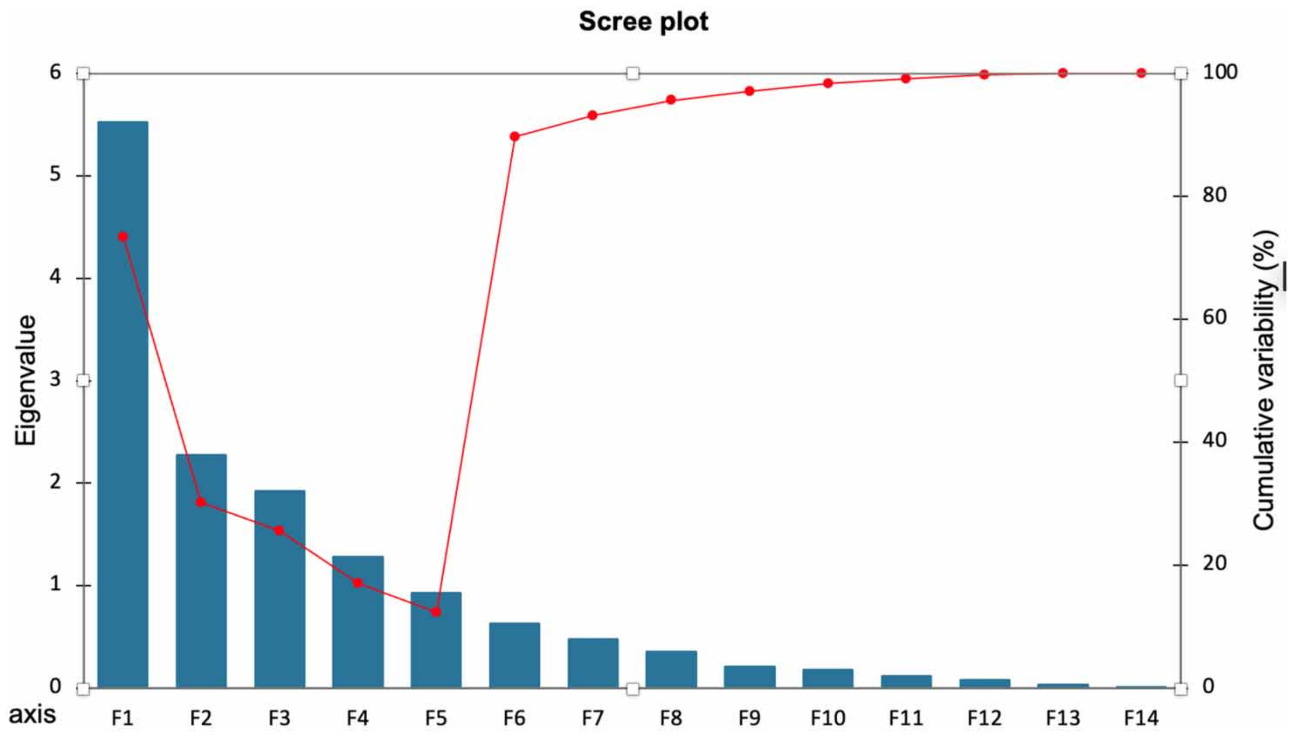


Figure 5 | Scree plot for eigenvalue of each component.

Table 10 | Factor loadings of the experimental data

	F1	F2	F3	F4	F5
pH	−0.171	0.819	0.029	−0.110	0.399
Turbidity (NTU)	0.431	0.023	0.678	0.382	0.316
TDS (mg/L)	0.806	−0.064	−0.082	−0.311	0.233
EC (µS/cm)	0.686	−0.435	−0.405	−0.124	0.092
BOD (mg/L)	−0.729	−0.449	−0.154	0.354	0.189
COD (mg/L)	0.389	0.620	0.214	0.471	−0.280
Total Hardness (mg/L)	0.617	−0.275	0.286	0.246	0.401
Iron (mg/L)	0.596	0.045	0.398	0.182	−0.391
Total Alkalinity (mg/L)	0.809	0.098	−0.022	−0.196	0.283
Sulphate (mg/L)	0.604	−0.405	0.290	0.125	−0.024
Chloride (mg/L)	0.009	−0.586	0.618	−0.433	−0.213
Calcium (mg/L)	0.812	−0.059	−0.498	0.225	−0.129
Magnesium (mg/L)	0.811	−0.048	−0.497	0.228	−0.124
DO (mg/L)	−0.657	−0.474	−0.140	0.476	0.144
Variability (%)	**39.437**	**16.236**	**13.734**	**9.155**	**6.633**
Eigenvalue	**5.521**	**2.273**	**1.923**	**1.282**	**0.929**
Cumulative (%)	**39.437**	**55.673**	**69.407**	**78.562**	**85.196**

3.3. Multivariate analysis

Principal Component Analysis (PCA) helps in determining the patterns in data and expressing the data in such a manner to determine the difference and similarity between the variables. PCA is helpful in graphical representation and identification of ecological aspects of environmental systems. A PC is defined on the basis of those factors whose variance have eigenvalue greater than 0.5. The scree plot presented in Figure 5 presents the eigenvalue for each of the given PCs. The basic structure of the study is analyzed by this technique. A gradual change in the slope was observed after the fifth PC. Table 10 represents the factor loadings of five principal components. F1 contributed an eigenvalue of 5.521 with 39.43% variance highly contributed by TDS, BOD, Total Alkalinity, Calcium and Magnesium whereas EC, Total Hardness, Iron, Sulphate and DO had moderate participation in F1. F2 explains a variance of 16.23%, which is significantly contributed by pH and moderately by COD and Chloride, with the eigenvalue of 2.27. The principal component F3 represents an eigenvalue of 1.93 with a

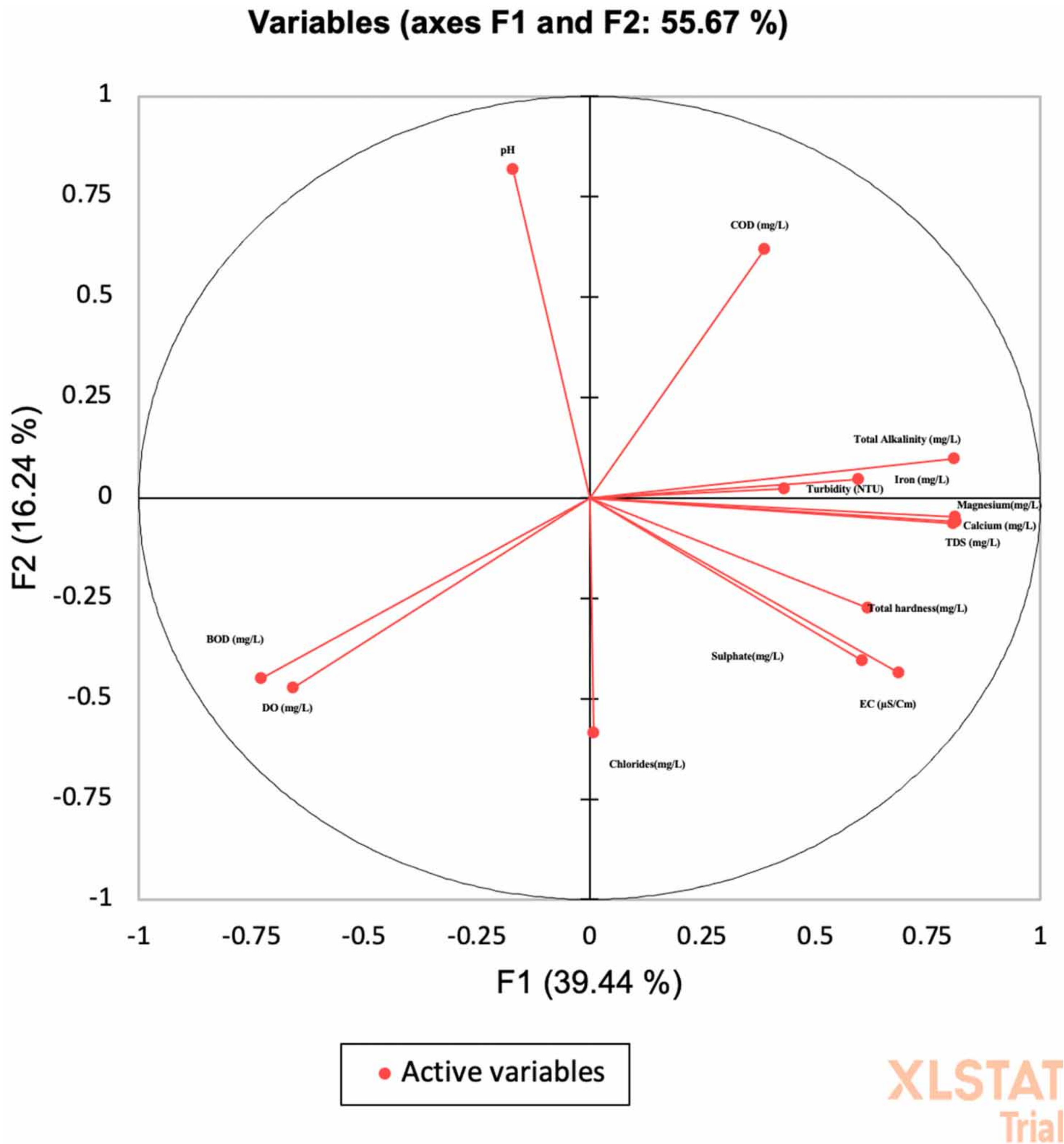


Figure 6 | Factor analysis diagram of principal components.

Table 11 | Pearson Correlation Matrix between various parameters

	pH	Turbidity (NTU)	TDS (mg/L)	EC (μS/cm)	BOD (mg/L)	COD (mg/L)	Total Hardness (mg/L)	Iron (mg/L)	Total Alkalinity (mg/L)	Sulphate (mg/L)	Chloride (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	DO (mg/L)
pH	1													
Turbidity (NTU)	0.031449623	1												
TDS (mg/L)	−0.086234025	0.233670455	1											
EC (μS/cm)	−0.422484993	0.055842178	0.608254315	1										
BOD (mg/L)	−0.198940459	−0.254450158	−0.532226576	−0.29322201	1									
COD (mg/L)	0.220647021	0.438051222	0.068114373	−0.128199091	−0.478185495	1								
Total Hardness (mg/L)	−0.242312905	0.587741721	0.456581572	0.396618633	−0.25421466	0.102763085	1							
Iron (mg/L)	−0.167429836	0.380776293	0.379837047	0.104906141	−0.430738243	0.430258493	0.398741303	1						
Total Alkalinity (mg/L)	0.040343521	0.302778534	0.794495771	0.517229506	−0.584752062	0.233706346	0.480779851	0.405422719	1					
Sulphate (mg/L)	−0.317795246	0.496091738	0.387990546	0.467905817	−0.288772228	0.089500332	0.427829105	0.384056972	0.361550306	1				
Chloride (mg/L)	−0.49460615	0.18906421	0.07369624	0.050465794	−0.034716198	−0.342819549	0.141623004	0.198009236	−0.02441	0.34860668	1			
Calcium (mg/L)	−0.25800799	0.067510123	0.588441108	0.72393867	−0.444666061	0.290337984	0.379494861	0.363680627	0.557222092	0.414014142	−0.323368583	1		
Magnesium (mg/L)	−0.243657977	0.06774648	0.581210903	0.715775039	−0.449765907	0.293867461	0.37922146	0.363218488	0.561725561	0.411952565	−0.330736798	0.999253609	1	
DO (mg/L)	−0.249164558	−0.190421036	−0.55007661	−0.268856989	0.941804646	−0.389811096	−0.19151263	−0.371810209	−0.545131672	−0.190201666	−0.035137293	−0.351143663	−0.350429658	1

variance of 13.73% contributed mostly by Tufbidity and Chloride. F4 on the other side has an eigenvalue of 1.28 and represents a variance of 9.15% and has no contribution from the parameters. The same as the previous factor loading, PC 5 (F5) shows a variance of 6.63% with eigenvalue of 0.92 and no contribution by any of the parameters. Figure 6 shows the relationship of F1 vs F2 and their level of relationship to each other.

In Table 11 of the correlation matrix, a moderate positive correlation was seen for turbidity with total hardness, iron, total alkalinity, and sulphate. In the case of pH, negative correlation was identified comparing with all the parameters. TDS showed a moderate positive correlation with EC and total alkalinity. BOD showed high correlation with the DO but the rest of the parameters were negatively correlated. Calcium showed high positive correlation with Magnesium.

3.4. Analysis of metal concentration in the river by ICP-MS

The metal ion concentration in the river water was analyzed by ICP-MS and it was observed that the concentration of metal ions such as nickel (Ni^{2+}), chromium (Cr^{6+}), cobalt (Co^{2+}), manganese (Mn^{2+}), copper (Cu^{2+}), and zinc (Zn^{2+}) have a high

Table 12 | ICP-MS data of Yamuna River

Element	Mass	I STD	Tune mode	Cone.	Units	RSD (%)	CPS	Ratio	Det.	Time (sec)	Rep
Li	7		No gas	22.466	ppb	2.3	627,625.86		Pulse	0.1000	3
B	11		No gas	1,789.455	ppb	2.7	17,071,644.51		Analog	0.1000	3
P	31		No gas	46,501.617	ppb	2.2	120,679,581.37		Analog	0.1000	3
K	39		No gas	56,847.773	ppb	3.3	2,499,309,340.36		Analog	0.1000	3
Li	7		He	27.278	ppb	2.1	2,453.61		Pulse	0.1000	3
B	11		He	1,748.344	ppb	1.0	135,740.84		Pulse	0.1000	3
Na	23		He	744,244.421	ppb	0.1	1,135,392,980.76		Analog	0.1000	3
Mg	24		He	99,664.727	ppb	0.4	110,167,974.93		Analog	0.1000	3
Al	27		He	102.198	ppb	3.2	53,513.92		Pulse	0.1000	3
P	31		He	48,257.880	ppb	1.2	1,296,312.67		Analog	0.1000	3
K	39		He	50,135.550	ppb	1.1	36,962,311.56		Analog	0.1000	3
Ca	43		He	12,848.811	ppb	1.5	404,386.13		Pulse	0.1000	3
Ca	44		He	23,039.980	ppb	1.0	6,889,855.57		Analog	0.1000	3
Cr	52		He	3.190	ppb	3.0	32,773.79		Pulse	0.1000	3
Mn	55		He	265.460	ppb	1.4	1,722,582.87		Analog	0.1000	3
Fe	56		He	193.888	ppb	1.1	1,770,894.22		Analog	0.1000	3
Co	59		He	0.945	ppb	3.1	14,788.10		Pulse	0.1000	3
Ni	60		He	17.032	ppb	1.8	67,651.39		Pulse	0.1000	3
Cu	63		He	6.520	ppb	1.7	70,077.28		Pulse	0.1000	3
Zn	66		He	85.921	ppb	1.2	134,991.27		Pulse	0.1000	3
Ga	71		He	0.070	ppb	28.1	216.68		Pulse	0.1000	3
As	75		He	10.708	ppb	1.2	11,902.80		Pulse	0.3000	3
Se	78		He	1.756	ppb	8.1	197.78		Pulse	0.3000	3
Sr	88		He	2,470.323	ppb	1.1	22,354,891.33		Analog	0.1000	3
Zr	90		He	0.131	ppb	9.7	1,843.5 4		Pulse	0.1000	3
Mo	95		He	2.197	ppb	2.1	14,812.49		Pulse	0.1000	3
Ag	107		He	2.366	ppb	10.0	1,416.82		Pulse	0.1000	3
Cd	111		He	0.154	ppb	3.8	526.70		Pulse	0.1000	3
In	115		He	0.000	ppb	264.6	−3.33		Pulse	0.1000	3
Sn	118		He	0.128	ppb	5.5	870.11		Pulse	0.1000	3

value of metal ions in the river as shown in Table 12. The presence of these metals can be from both point and non-point sources.

4. CONCLUSION

Water has always been the major contaminating body of the ecosystem. Being a universal solvent, inorganic as well as organic material becomes soluble in water easily. In the above study, it was concluded that most of the water of the river Yamuna has a range of physicochemical parameters above the permissibility level, which makes the water toxic as well as unfit for use. Further, the WQI analyzed the physicochemical parameters and gave a brief idea about the water quality index of the river Yamuna pre- and post-monsoon. We need to take action against the severe water pollution that the river is facing. According to a report of WHO it was found that most of the rivers of India have a deteriorated quality. The toxicity of water directly or indirectly enters the food chain, which is the major cause of many health problems. The water samples collected show that the mean values of physicochemical parameters are in the range set by WHO and BIS except for hardness in summer (1,680 mg/L), monsoon (832.22 mg/L), winter (1,876.66 mg/L), spring (1,535.55 mg/L); TDS in summer (1,000.33 mg/L), monsoon (683.44 mg/L), winter (1,087.66 mg/L), spring (776.66 mg/L); and sulphate in summer (927.22 mg/L), monsoon (446.77 mg/L), winter (925.77 mg/L), spring (944.88 mg/L), which indicate the bad quality of the water. It is very important to monitor sewage and industrial, and domestic waste treatment and disposal to minimize the pollution level of the water bodies so that it does not affect the chemical and physical composition of potable water. The water quality index (WQI) is the best tool for giving the details of the overall grade of water, which basically is a process to reduce large numbers and parameters into a single index number and is also very effective for understanding the water quality findings. The WQI values were calculated for three locations in different weather conditions. WQI values in summer, winter and spring are 630.90, 279.61, 279.91, showing that the river water is not suitable for drinking purposes, whereas the WQI value in monsoon is 75.89, showing that water is fit for drinking purposes due to the dilution of the river water. Applied multivariate statistics gave a broader picture of the data provided by the analytical techniques. Applied PCA saw reduction in the variance percentage, and F4, F5 showed no contribution from the parameters, as also in the correlation matrix. Thus WQI and the multivariate statistical technique gave a highly informative study regarding the water quality of the river Yamuna which can be beneficial for the administration to implement better action plans.

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CONFLICT OF INTEREST

There is no conflict of Interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Adimalla, N. & Qian, H. 2019 Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. *Ecotoxicology and Environmental Safety* **176**, 153–161. https://doi.org/10.1016/j.ecoenv.2019.03.066.

Bhutiani, R., Ahamad, F., Tyagi, V. & Ram, K. 2018 Evaluation of water quality of River Malin using water quality index (WQI) at Najibabad, Bijnor (UP) India. *Environment Conservation Journal* **19** (1–2), 191–201.

Chakraborty, B., Roy, S., Bera, A., Adhikary, P. P., Bera, B., Sengupta, D., Bhunia, G. S. & Shit, P. K. 2021 Eco-restoration of river water quality during COVID-19 lockdown in the industrial belt of eastern India. *Environmental Science and Pollution Research* **28**, 25514–25528. https://doi.org/10.1007/s11356-021-12461-4.

de Andrade Costa, D., Soares de Azevedo, J. P., dos Santos, M. A. & dos Santos Facchetti Vinhaes Assumpção, R. 2020 Water quality assessment based on multivariate statistics and water quality index of a strategic river in the Brazilian Atlantic Forest. *Scientific Reports* **10**, 22038. doi:10.1038/s41598-020-78563-0.

Dubey, R. S. 2016 Assessment of water quality status of Yamuna river and its treatment by electrode based techniques. *International Journal of Engineering Sciences and Research Technology* **5** (2), 448–455.

Kazi, T. G., Arain, M. B., Jamali, M. K., Jalbani, N., Afridi, H. I., Sarfraz, R. A., Baig, J. A. & Shah, A. Q. 2009 Assessment of water quality of polluted lake using multivariate statistical techniques: a case study. *Ecotoxicology and Environmental Safety* **72** (2), 301–309. https://doi.org/10.1016/j.ecoenv.2008.02.024.

Kumar, M. & Puri, A. 2012 A review of permissible limits of drinking water. *Indian Journal of Occupational and Environmental Medicine* **16** (1), 40–44. https://doi.org/10.4103/0019-5278.99696.

Kumar, A., Taxak, A. K., Mishra, S. & Pandey, R. 2021 Long term trend analysis and suitability of water quality of River Ganga at Himalayan hills of Uttarakhand, India. *Environmental Technology & Innovation* **22**, 101405. https://doi.org/10.1016/j.eti.2021.101405.

Le, T. T. H., Zeunert, S., Lorenz, M. & Meon, G. 2017 Multivariate statistical assessment of a polluted river under nitrification inhibition in the tropics. *Environmental Science and Pollution Research* **24**, 13845–13862. https://doi. org/10.1007/s11356-017-8989-2.

Paun, I., Cruceru, L. V., Chiriac, F. L., Niculescu, M., Vasile, G. G. & Marin, N. M. 2016 Water quality indices – methods for evaluating the quality of drinking water. In: *Proceedings of the SIMI 2016 International Symposium 'The Environment and the Industry'*, pp. 395–402. https://doi.org/10.21698/simi.2016.0055.

Rout, C. 2017 Assessment of water quality: a case study of river Yamuna. *International Journal of Earth Sciences and Engineering* **10** (2), 398–403. https://doi.org/10.21276/ijee.2017.10.0239.

Sahu, P. & Sikdar, P. K. 2008 Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environmental Geology* **55**, 823–835.

Sharma, D. & Kansal, A. 2011 Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000–2009). *Applied Water Science* **1** (3–4), 147–157. https://doi.org/10.1007/s13201-011-0011-4.

Sharma, P., Meher, P. K., Kumar, A., Gautam, Y. P. & Mishra, K. P. 2014 Changes in water quality index of Ganges River at different locations in Allahabad. *Sustainability of Water Quality and Ecology* **3–4**, 67–76. https://doi.org/10.1016/j.swaqe.2014.10.002.

Tawati, F., Risjani, Y., Djati, M. S., Bagio & Leksono, A. S. 2018 Analysis of physico-chemical properties of Sumber Maron River in Malang, Indonesia during dry season. *Resources and Environment* **8** (3), 148–154.

Vega, M., Pardo, R., Barrado, E. & Debán, L. 1998 Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Research* **32** (12), 3581–3592.

Yadav, A. & Khandegar, V. 2019 Dataset on assessment of River Yamuna, Delhi, India using indexing approach. *Data in Brief* **22**, 1–10. https://doi.org/10.1016/j.dib.2018.11.130.

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