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ORIGINAL ARTICLE

Evaluation of surface water quality using hydro-chemical, bacteriological characters and water quality index: a case study on sacred ponds of Kurukshetra, Haryana, India

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Abstract

Regular monitoring of water quality of surface waters is essential for the sustainable management of human health. The present investigations looked at the physico-chemical and bacteriological analyses of surface water from five different locations in Kurukshetra district, Haryana (India). Water samples obtained from selected monitoring sites (S1–S5) in 2021 during monsoon and post-monsoon season were tested for physico-chemical characteristics, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients, total bacterial count, and fecal coliform. The results showed that major physico-chemical characteristics, COD, BOD, nutrients like ammonia, orthophosphate, and sulfate were all over the permissible range of Bureau of Indian Standards. Pearson correlation coefficient was used to determine the relationship between the water quality parameters. The presence of fecal coliform and a high MPN index (43 to < 2400 in monsoon and 41 to < 2400 in post-monsoon season) are depicted by bacteriological examination. The ionic statistical analysis and the data plotted on the ternary phase diagram reveal that the surface water chemistry is mainly due to contributions from agriculture and anthropogenic sources. One of the most widely used methods for detecting and evaluating surface water contamination is the water quality index (WQI). Over the course of study period, 13 physico-chemical characteristics were evaluated to determine the surface water quality index of sample locations. The water quality index of S2 (35.458 in monsoon and 26.615 in post-monsoon) and S3 (40.694 in monsoon and 35.935 in post-monsoon) was good, but the water quality index of S5 (264.111 in monsoon and 229.922 in post-monsoon) and S1 (81.458 in monsoon and 65.380 in post-monsoon) was very poor and unfit for consumption in both seasons because it receives the most domestic effluents, sewerage water from adjoining villages, religious activity, and other solid waste material, rendering it unfit for any consumption and extremely harmful to aquatic biodiversity. The results demonstrate that water bodies are experiencing stress as a result of inputs through point and non-point pollution sources and require additional attention, implementation, and management techniques to protect water quality of these sites.

Keywords Coefficient of correlation · Coliform bacteria · India · Kurukshetra · Physico-chemical parameters · Water quality index

Introduction

Water is the most basic and necessary requirement for life on the planet and is required by all living species for survival, development, reproduction, and other life activities. Water covers around 71% of the Earth's surface, with oceans accounting for 96.5% of all water. Water quality is a growing concern throughout the developing world since everything depends on water, from human health to the correct functioning of an ecosystem (Costanza et al. 2017).

Ponds are the most dynamic and productive freshwater (surface water) ecosystems on the planet, with a staggering

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amount of biological diversity. Ground water recharge is aided by surface water ecosystems, which also support livestock, soil erosion control, water purification, and, most critically, carbon sequestration (Sarma and Saikia 2010; Manoj and Padhy 2015; Nag et al. 2019). Ponds provide a variety of ecological services to humans that are free of charge, such as social, cultural, economic, scientific, medical, and esthetic benefits (Gupta et al. 2012). Despite their importance in the lives of all organisms, ponds are constantly degraded as a result of anthropogenic activities, such as industrialization, urbanization, habitat destruction, and pollution (Mishra et al. 2014; Chen et al. 2019). Religious activities, such as immersion of flour, oil, soap, ash, detergents, floral offerings, and mass bathing, are also among the various types of anthropogenic actions that affect the water quality of a water body (Devi et al. 2019). The deterioration of water quality has far-reaching consequences for humans, animals, and plants. Therefore, monitoring of water quality of these aquatic ecosystems including hydro-chemical and bacteriological characteristics is the basic need for water resource management. The physico-chemical characteristics of water affect how biological life develops and whether people can utilize water directly. The water body's size, purpose, and the features of the area in which it is located all influence how much alteration occurs.

Recently, in addition to field studies for water quality characteristics, researchers use certain software/numerical calculation-based tools for predicting the water availability and sampling site maps. (Ghosh et al. 2015; Behairy et al. 2021; Dillon et al. 2020; Jha et al. 2020; Singh and Noori 2022). The widely used water quality index (WQI) provides policymakers and concerned individuals with information on water quality in a straightforward, consistent, and repeatable unit of measurement (Singh et al. 2013). Using statistical approaches, it is possible to explain correlations between a large number of populations and to condense a huge number of variables into a small number of elements without losing critical information (Nadiri et al. 2013). For evaluating water quality and distributing data on overall water quality, WQI and statistical approaches are extremely effective (Tiwari et al. 2015; Singh et al. 2015; Molekoa et al. 2019; Aydin et al. 2021; Bhat et al. 2021; Slathia and Jamwal 2022). Kurukshetra is Haryana's sacred city, located 160 kms north of Delhi on National Highway 44 (NH44) between latitudes 29° 52′ and 30° 12′ and longitudes 76° 26′ and 77° 04′. Kurukshetra is referred to in the Shrimad Bhagwad Gita as Dharamkshetra, which means "field of righteousness". The holy water bodies of Kurukshetra, Haryana, have enormous religious significance, since people from Haryana and other states are emotionally and spiritually connected to these holy water basins of Kurukshetra. According to WHO, water is responsible for around 80% of all human illnesses. Keeping these facts into consideration, the current study was carried out to determine the impact of religious events and other anthropogenic activities on water quality in terms of WQI in five significant lentic water bodies in Kurukshetra where such anthropogenic activities are undertaken. The scientific investigations are to find the hydrochemistry of surface water in Kurukshetra, Haryana, and classify it in order to assess its suitability for drinking, domestic, irrigation, and bathing, as well as municipal, agricultural, and industrial uses. This research is to highlight the necessity of maintaining acceptable water quality standards in surface water bodies, using sunken water bodies as test locations and it offers baseline data on water quality for the benefit of society, which may also aid in water resource planning of similar water bodies in future.

Materials and methods

Study area

Surface water samples were taken from three stations at each sample locations in and around the Kurukshetra district of Haryana. The places for this study were chosen because they were used as sacred and religious waters and also receive waste from some non-point sources. S-1 (Baan Ganga), S-2 (Braham Sarovar), S-3 (Sannihit Sarovar), S-4 (Jyoti Sarovar), and S-5 (Sunnhedi Pond) are the sample locations depicted in ARC-GIS (Fig. 1).

Sample collection

During 2021, samples from selected sites were collected in 1000 mL high-density polyethylene (HDPE) sample bottles. These bottles were disinfected using 1:1 dilute hydrochloric acid and double distilled water before it can be used. The bottles were rinsed again with the sample to be collected prior to sample collection. Samples were collected fortnightly for 2 months in each season. Four visits were carried out in a season in which water sample were collected from three different stations in triplicate at a particular sampling site. Total of 36 samples were collected from each site and standardized through mean value. Sampling was carried out without adding any preservative.

Physico-chemical analysis

The samples were analyzed for color, pH, TDS, TSS, BOD, COD, hardness, alkalinity, chloride, sodium, potassium, sulfate, calcium, magnesium, ammonia nitrogen, nitrate, and orthophosphate. These water parameters were determined by the methodology given by Garg et al. (2002) and APHA (2017). Methodology used is described briefly in Table 1.

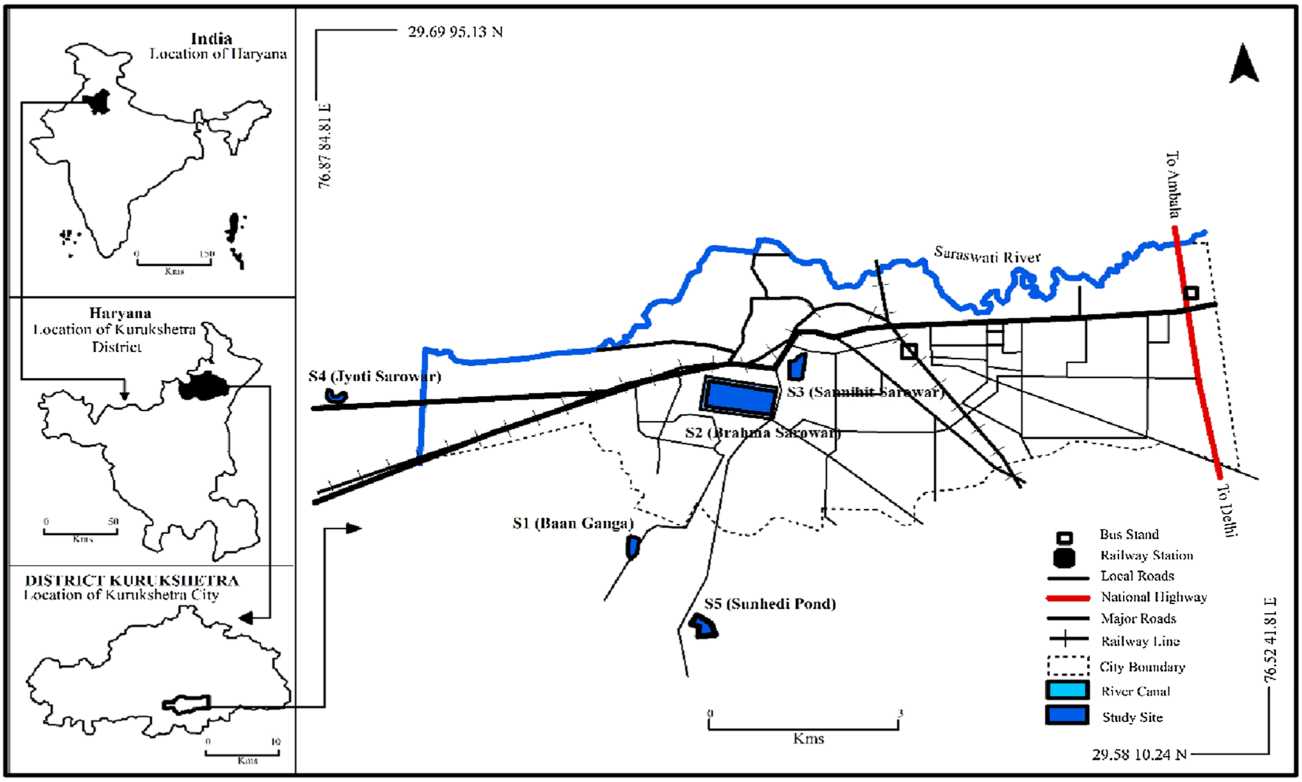

Fig. 1 Study area map (ARC-GIS) showing the surface water sample locations (S1–S5)

Table 1 Water quality parameters, units, BIS standard valve and analytical methods (according to Garg et al. 2002 and APHA 2017)

S. no.	Parameters	Abb	Units	BIS Standards	Analytical methods
1	pH	pH		6.5–8.5	pH meter (SYSTRONICS)
2	Temperature	Temp	°C	–	Digital thermometer
3	Dissolved oxygen	DO	mg L^{-1}	5	Winkler azide titrimetric method
4	Free carbon dioxide	Free CO_2	mg L^{-1}	–	Titrimetric
5	Chemical oxygen demand	COD	mg L^{-1}	10	Potassium dichromate oxidation close reflex, titrimetric
6	Biochemical oxygen demand	BOD	mg L^{-1}	6	Dilution and incubation method (BOD incubator)
7	Carbonates	–	mg L^{-1}	75	Titrimetric
8	Total alkalinity	TA	mg L^{-1}	200	Titrimetric
9	Chlorides	Cl^-	mg L^{-1}	250	Argentometric titration
10	Total hardness	TH	mg L^{-1}	300	EDTA titrimetric method
11	Calcium	Ca	mg L^{-1}	75	EDTA titrimetric method
12	Magnesium	Mg	mg L^{-1}	30	EDTA titrimetric method
13	Sodium	Na	mg L^{-1}	–	Using digital photo flame meter
14	Potassium	K	mg L^{-1}	–	Using digital photo flame meter
15	Sulfate	SO_4^{2-}	mg L^{-1}	200	Spectrophotometric method
16	Total dissolved solids	TDS	mg L^{-1}	500	Filtration and gravimetric
17	Total suspended solids	TSS	mg L^{-1}	–	Filtration and gravimetric
18	Ammonia	NH_3	mg L^{-1}	0.5	Nessler's reagent spectrophotometric
19	Nitrate	NO_3^-	mg L^{-1}	45	Phenol disulfonic acid spectrophotometric
20	Phosphate	PO_4^-	mg L^{-1}	1	Ammonium molybdate spectrophotometric

Microbiological analysis

Using 0.1 ml of acceptable aliquots, the spread plate technique was employed to enumerate total bacterial count using nutritional agar media (HiMedia). The colonies that appeared on agar plate were counted on a digital colony counter after 24–48 h of incubation at 37 °C. The most probable number (MPN) approach was used to analyze indicator bacteria (total coliform and fecal coliform), which involved inoculating 10, 1, and 0.1 ml aliquots of water samples in experimental tubes with MacConkey broth (APHA 1998). The incubation time was 24 h at 37 °C. The generation of acid and gas bubbles in the inverted Durham tube showed positive tubes. A loopful of broth was injected further into brilliant green lactose bile (BGLB) broth from each positive tube, which was incubated for 24–48 h at 37 °C. Durham tubes that produced gas were considered positive, and the total coliform count was calculated as most probable number (MPN) Index. Each positive BGLB tube was tested for total coliform by plating a loopful of broth onto an eosin methylene blue (EMB) agar plate (HiMedia) and that plates were incubated at 37 °C for 24–48 h. The emergence of colonies with a green metallic shine confirmed a positive full test. Based on the completed test, the final fecal coliform count was determined as MPN index.

Calculation of water quality index (WQI)

The water quality index (WQI) was calculated using the standards of drinking water quality recommended by the Bureau of Indian Standards (BIS 2012). The weighted arithmetic index method (Brown et al. 1970) was used for the calculation of WQI of the surface water. The quality rating scale for each parameter Q_p was calculated using the following expression.

$$Q_p = 100\left[V_p - V_o\right] / \left[S_p - V_o\right] \quad (1)$$

(Let's say there are p water quality parameters, and the quality rating or sub index (Q_p) for the pth parameter is a number that reflects the parameter's relative value in contaminated water in comparison to its standard, maximum allowable value).

Q_p is the pth water quality parameter's quality rating, V_p is the mean concentration of the pth parameter, S_p is the pth parameter's standard desired value, V_o is the considering pure water, the ideal value of pth parameter is zero (i.e., 0 for all other except pH and dissolved oxygen) (7.0 and 14.6 mg L^{-1} respectively).

Unit weight was calculated by a value inversely proportional to the recommended standard value S_p of the corresponding parameter.

$$W_p = K/S_p \quad (2)$$

W_p is the unit weight for the pth parameters, S_p is the standard value for the pth parameters, K is the proportionality constant.

The overall WQI was calculated by aggregating the quality rating with the unit weight linearly and then compared with the WQI categories (Table 2).

$$\mathrm{WQI} = \sum Q_p W_p / \sum W_p$$

Statistical analysis

IBM SPSS was used to analyze the data. The differences between sample locations for different parameters were analyzed using one-way analysis of variance (ANOVA). The Duncan test was also used to assess if the data sets were homogeneous. The significance threshold of the tests was set at $p < 0.05$. In order to determine relationship between physico-chemical and bacteriological parameters, the correlation coefficient 'r' was also calculated with the help of IBMSPSS. Ternary phase diagrams showing contribution of individual ions toward the anionic and cationic mass balance were used in Origin 2019b.

Results and discussion

Seasonal variations in physico-chemical parameters

Physico-chemical parameters give an accurate picture of water quality in every sort of water body. The physico-chemical parameters of the analyzed surface water samples of the Kurukshetra district including statistical measures, such as average values and standard error, are given in Tables 3 and 4 of monsoon and post-monsoon season. The outcomes of measurements of various parameters found in water samples were performed through experiments. This detailed information on numerous water quality criteria at different times of the year translates the overall data into a specific

Table 2 The state of water quality according to WQI

Sr. no.	Water quality index level	Water quality status
1	0–25	Excellent water
2	26–50	Good water
3	51–75	Poor water
4	76–100	Very poor water
5	> 100	Unsuitable for drinking

Source: Al-Sabah (2016)

Table 3 Physico-chemical parameters of given sampling sites during 2021 monsoon season

Water parameters	Sampling sites				
	S1 (Baan Ganga)	S2 (Braham Sarovar)	S3 (Sannihit Sarovar)	S4 (Jyoti Sarovar)	S5 (Sunnhedi Pond)
pH	8.9 ± 0.06^{A}	8.36 ± 0.08^{B}	8.82 ± 0.10^{A}	8.80 ± 0.08^{A}	8.2 ± 0.08^{B}
Temp. (°C)	29.3 ± 0.22^{A}	28.27 ± 0.10^{B}	29.53 ± 0.21^{A}	29.72 ± 0.08^{A}	28.07 ± 0.13^{B}
DO (mg L^{-1})	8.26 ± 0.29^{B}	10.13 ± 0.18^{A}	10.60 ± 0.11^{A}	5.13 ± 0.18^{C}	1.13 ± 0.18^{D}
COD (mg L^{-1})	28.89 ± 3.51^{C}	20.44 ± 1.40^{C}	20.67 ± 0.94^{C}	85.56 ± 3.09^{B}	269.73 ± 5.13^{A}
BOD (mg L^{-1})	4.00 ± 0.20^{CD}	4.13 ± 0.18^{C}	3.36 ± 0.24^{D}	10.20 ± 0.20^{B}	18.93 ± 0.35^{A}
C. alkalinity (mg L^{-1})	40.22 ± 1.13^{A}	13.33 ± 0.88^{C}	13.89 ± 0.82^{C}	9.78 ± 0.70^{D}	19.46 ± 0.60^{B}
T. alkalinity (mg L^{-1})	360 ± 7.81^{A}	53.56 ± 2.21^{B}	59.56 ± 2.84^{B}	53.33 ± 1.20^{B}	353.78 ± 11.41^{A}
Chlorides (mg L^{-1})	76.67 ± 0.35^{B}	22.31 ± 1.26^{C}	27.46 ± 0.72^{C}	30.35 ± 0.91^{C}	155.13 ± 7.09^{A}
T. Hardness (mg L^{-1})	231.78 ± 1.61^{B}	123.78 ± 1.84^{CD}	134.44 ± 1.82^{C}	115.11 ± 3.29^{D}	260.22 ± 9.86^{A}
Calcium (mg L^{-1})	18.20 ± 0.46^{D}	26.63 ± 0.58^{B}	27.93 ± 0.34^{B}	24.24 ± 1.03^{C}	33.15 ± 0.36^{A}
Magnesium (mg L^{-1})	45.42 ± 0.44^{B}	13.92 ± 0.49^{D}	16.62 ± 0.50^{C}	12.30 ± 0.86^{D}	78.25 ± 1.49^{A}
Sodium (mg L^{-1})	19 ± 1.16^{B}	3.33 ± 0.88^{D}	5.66 ± 0.88^{D}	10.66 ± 1.20^{C}	29.00 ± 1.15^{A}
Potassium (mg L^{-1})	22.33 ± 1.76^{B}	8.00 ± 0.57^{CD}	4.66 ± 0.33^{D}	13.00 ± 1.54^{C}	384.33 ± 3.48^{A}
Sulfate (mg L^{-1})	213.00 ± 3.21^{B}	113.00 ± 2.08^{E}	126.67 ± 4.05^{D}	180.00 ± 2.30^{C}	328.0 ± 5.29^{A}
TDS (mg L^{-1})	60.44 ± 0.44^{E}	337.78 ± 18.09^{D}	441.11 ± 14.38^{C}	581.44 ± 42.34^{B}	706.78 ± 35.70^{A}
TSS (mg L^{-1})	215.56 ± 8.84^{D}	670.0 ± 55.98^{C}	706.67 ± 14.24^{C}	950.22 ± 22.30^{B}	1319.0 ± 45.06^{A}
Ammonia (mg L^{-1})	0.53 ± 0.03^{B}	0.18 ± 0.01^{C}	0.23 ± 0.012^{C}	0.063 ± 0.002^{D}	1.47 ± 0.026^{A}
Nitrate (mg L^{-1})	0.2 ± 0.022^{B}	0.028 ± 0.005^{C}	0.036 ± 0.002^{C}	0.72 ± 0.05^{A}	0.70 ± 0.03^{A}
Orthophosphate (mg L^{-1})	0.18 ± 0.003^{B}	0.015 ± 0.001^{C}	0.017 ± 0.001^{C}	0.33 ± 0.02^{A}	0.36 ± 0.014^{A}

All values are mean ± S.E of mean

Means with different letters in the same rows are significantly ($p < 0.05$) different (Duncan's multiple range test)

Table 4 Physico-chemical parameters of given sampling sites during 2021 post-monsoon season

Water parameters	Sampling sites				
	S1 (Baan Ganga)	S2 (Braham Sarovar)	S3 (Sannihit Sarovar)	S4 (Jyoti Sarovar)	S5 (Sunnhedi Pond)
pH	9.13 ± 0.04^{A}	8.53 ± 0.06^{C}	9.19 ± 0.08^{A}	8.92 ± 0.02^{B}	8.43 ± 0.10^{C}
Temp. (°C)	28.2 ± 0.12^{A}	26.57 ± 0.28^{B}	26.3 ± 0.29^{BC}	26.72 ± 0.34^{B}	25.52 ± 0.36^{C}
DO (mg L^{-1})	7.20 ± 0.23^{C}	9.13 ± 0.17^{A}	8.27 ± 0.30^{B}	4.20 ± 0.23^{D}	1.00 ± 0.11^{E}
COD (mg L^{-1})	18.0 ± 0.82^{C}	13.56 ± 0.80^{C}	14.44 ± 1.14^{C}	61.56 ± 2.56^{B}	226.0 ± 6.41^{A}
BOD (mg L^{-1})	4.80 ± 0.41^{C}	3.20 ± 0.23^{D}	3.00 ± 0.11^{D}	9.12 ± 0.41^{B}	18.20 ± 0.20^{A}
C. alkalinity (mg L^{-1})	33.78 ± 0.85^{A}	10.22 ± 0.70^{C}	11.44 ± 0.73^{C}	7.89 ± 0.68^{D}	16.8 ± 0.46^{B}
T. alkalinity (mg L^{-1})	313.56 ± 2.44^{A}	49.78 ± 2.27^{B}	53.78 ± 2.29^{B}	47.78 ± 1.31^{B}	323.33 ± 11.14^{A}
Chlorides (mg L^{-1})	78.33 ± 0.28^{B}	28.20 ± 0.60^{C}	34.06 ± 0.60^{C}	34.87 ± 0.72^{C}	161.06 ± 6.90^{A}
T. hardness (mg L^{-1})	212.22 ± 1.35^{B}	103.78 ± 1.84^{D}	113.78 ± 1.71^{C}	103.56 ± 1.97^{D}	235.0 ± 3.92^{A}
Calcium (mg L^{-1})	16.75 ± 0.29^{E}	22.34 ± 0.58^{C}	25.55 ± 0.28^{B}	20.49 ± 0.31^{D}	30.37 ± 0.46^{A}
Magnesium (mg L^{-1})	40.70 ± 0.82^{B}	10.59 ± 0.33^{C}	12.61 ± 0.24^{C}	10.77 ± 0.66^{C}	73.92 ± 1.31^{A}
Sodium (mg L^{-1})	11.66 ± 1.45^{B}	1.00 ± 0.57^{C}	5.66 ± 3.66^{C}	3.33 ± 0.33^{C}	18.0 ± 0.57^{A}
Potassium (mg L^{-1})	13.33 ± 1.20^{B}	2.33 ± 0.33^{C}	4.00 ± 0.57^{C}	2.67 ± 0.66^{C}	290.0 ± 5.77^{A}
Sulfate (mg L^{-1})	189.67 ± 2.02^{B}	80.67 ± 3.48^{E}	97.33 ± 1.33^{D}	165.00 ± 6.80^{C}	307.00 ± 3.00^{A}
TDS (mg L^{-1})	52.0 ± 0.82^{C}	310.67 ± 19.48^{B}	347.78 ± 11.39^{B}	563.11 ± 39.09^{B}	634.0 ± 34.40^{A}
TSS (mg L^{-1})	173.33 ± 8.16^{D}	628.89 ± 54.55^{C}	568.89 ± 17.67^{C}	893.0 ± 16.99^{B}	1179.0 ± 44.66^{A}
Ammonia (mg L^{-1})	0.40 ± 0.012^{B}	0.098 ± 0.007^{D}	0.19 ± 0.007^{C}	0.05 ± 0.003^{E}	1.27 ± 0.03^{A}
Nitrate (mg L^{-1})	0.11 ± 0.007^{C}	0.018 ± 0.003^{D}	0.035 ± 0.003^{D}	0.58 ± 0.032^{A}	0.46 ± 0.024^{B}
Orthophosphate (mg L^{-1})	0.15 ± 0.002^{C}	0.026 ± 0.009^{D}	0.015 ± 0.0003^{D}	0.27 ± 0.014^{B}	0.30 ± 0.012^{A}

All values are mean ± S.E of mean

Means with different letters in the same rows are significantly ($p < 0.05$) different (Duncan's Multiple Range test) level regarding that particular location at a certain moment. Nineteen parameters in all were chosen for examination in this study in two different seasons. The Bureau of Indian Standards made recommendations on the quality of drinking water (2012). This approach is crucial because it may help to determine if access to safe drinking water in underdeveloped nations will still be possible under the same ecological conditions in future. The temperature and the precipitation patterns throughout the course of the year often serve as the primary indicators of seasonal variations in water bodies. The presence of phytoplankton, zooplankton, and contaminants in a surface water body causes the color and odor. The majority of the samples ranged in color from brownish yellow to greenish. S1 had a light yellow color in both seasons, whereas S5 was a turbid blackish yellow color in monsoon and greenish black in post-monsoon. The majority of the samples had an unpleasant odor. The color and the odor of freshwater bodies are indicative of their water quality (Dhanalakshmi et al. 2013). Furthermore, while color does not directly harm aquatic organisms, it does decrease light penetration and restricts aquatic plant development (Olopade 2013). The variation in color of water bodies may be due to the presence of phytoplankton. The darker green color denotes a greater plankton level, whereas the lighter green color denotes a lower plankton level. Due to the dumping of cow dung cakes and other inorganic waste with rain water, S5 has a blackish yellow color. The water's odor might be caused by inorganic and inorganic pollutants in the water.

The sampling location's temperature varied from 28.30 to 29.72 °C in monsoon and 25.52–28.20 °C in post-monsoon season, which were within the acceptable range. Temperature is significant because it influences chemical and biological processes in water and aquatic creatures. At the S4, the highest temperature was recorded in monsoon season and S1 has the highest in post-monsoon season. Higher water temperature was recorded (29.72 ± 0.084 °C) in monsoon season, and lower temperatures (25.52 ± 0.36 °C) were recorded in post-monsoon season. This might be due to a combination of mass bathing and the impact of various effluents dumped into the water body, such as agricultural and household waste. The pH of a solution determines its acidity and basicity. According to BIS (2012), a pH range of 6.5–8.5 is safe for drinking. The pH range of 6.7–8.5 is considered good for aquatic biota growth, whereas the pH range of 7–8.5 is optimal for biological productivity (Bhatnagar and Devi 2013). The average pH of the sampling sites in monsoon ranged from 8.2 ± 0.08 to 8.9 ± 0.06 and 8.43 ± 0.09 to 9.19 ± 0.08 in post-monsoon season. The ranges suggest that the water at the sampling locations was somewhat alkaline. S2 and S5 had pH values that were within the acceptable range in monsoon season and in post-monsoon only at S5 values were observed under acceptable range. However, S1, S3, and S4 had pH values that were above the acceptable range. Higher pH at some locations might be attributed to bicarbonate and calcium and magnesium carbonates in the water. Runoff from urban and rural areas should be the primary source of these pollutants.

Dissolved oxygen is one of the most essential criteria in determining water quality since it impacts flora and fauna survival and dispersal. Oxygen concentration is vital for many creatures immediate needs, as well as the solubility of many nutrients and, as a result, the productivity of aquatic ecosystems (Wetzel and Likens 1990). Temperature, photosynthetic activity, wind movement, the respiratory process of the living on it, pollution load, and other variables all influence the amount of dissolved oxygen in a water body. It varies on a daily basis, seasonally, and with temperature changes (Wavde and Arjun 2010). At S3, the maximum dissolved oxygen was recorded, and at S5, the minimum DO was recorded in monsoon season. In post-monsoon season, S2 had the highest DO, and S5 shows the lowest DO. Most of the locations had DO levels above the BIS allowed limit (2012). Vyas et al. (2007) and Sharma and Kumar (2017) made similar observations.

BOD is a measure of DO require by microbes to oxidize all of the reduced water that is introduced to water bodies (Shah and Joshi 2017). Its greater levels provide a direct indication of the quantity of organic waste present in a certain water body. In the present study, the highest value of BOD was observed in monsoon season. Except for S1, S2, and S3, all of the sites under scrutiny had greater BOD levels than the allowed limit in monsoon season (6 mg L^{-1}). In post-monsoon season, the values at S1, S2, and S3 were within range. In comparison to S4, maximum BOD was recorded at S5, suggesting lower organic load and hence less microbial breakdown at S2 and S3. Natural vegetative detritus, dead and decaying plants and animals, animal feces, and other evident sources of elevated BOD were identified. Other researchers came up with similar conclusions (Bhateria and Jain 2016; Mahajan 2019).

COD is valuable as an indication of organic pollution in surface water since it reflects the presence of all types of organic matter, both biodegradable and non-biodegradable, and hence the degree of pollution in water (Faouzi et al. 2023). The chemical oxygen demand in polluted water is usually quite high. The COD in monsoon season in these five sites ranged from 20.44 ± 1.405 to 269.73 ± 5.13 mg L^{-1}. In post-monsoon season, it ranged from 13.55 ± 0.80 to 226 ± 6.41 mg L^{-1}. The decreasing range of COD is S5<S4<S1<S3<S2, showing their amount of pollution, as a high COD content is an indicator of a high degree of pollution, as supported by Bhatnagar et al. (2016). Carbonate alkalinity varied from 9.79 ± 0.70 to 40.00 ± 1.13 mg L^{-1}, with S1 (40.00 ± 1.13 mg L^{-1}) having the highest value and the rest of the samples having extremely low carbonate concentration in monsoon season. In post-monsoon season,

S1 had the maximum and S4 had the lowest range of carbonate alkalinity. More than half of the water samples had low carbonate levels. Because a higher pH makes a solution more alkaline, less carbonic acid dissociates into carbonate ions, the justification for low carbonate in all of the samples was high pH. Nandal et al. (2020) also made similar observations.

Total alkalinity refers to water's buffering capability, which aids in maintaining its pH (Lodh et al. 2014). The capacity of water to neutralize acids is measured by alkalinity. It is not typically regarded as a contaminant (Sharma and Kumar 2017). S1 (360 ± 7.81 mg L^{-1}) and S5 (323.33 ± 11.13 mg L^{-1}) had the highest alkalinity in monsoon and post-monsoon season respectively, while S4 had the lowest alkalinity in both the seasons. Due to the high rate of decomposition at S1 and S5, which decreases CO_2 and results in the addition of carbonate and bicarbonate ions, the alkalinity level rises (Verma et al. 2012). The total hardness of water is a measurement of its ability to generate soap precipitates and scales when specific anions are present. Total hardness is highly important quality of water from its domestic use point of view. Hard water produces trouble in boilers in enterprises as well as household. The BIS (2012) standard allowable maximum for overall hardness is 300 mg L^{-1}. In monsoon season sample sites, hardness concentrations varied from 115.11 ± 3.28 to 260.22 ± 9.86 mg L^{-1}. Total hardness is higher during monsoon season which may be due to higher concentration of carbonates and bicarbonates added through run-off. The results of the samples were determined to be within the acceptable limit when compared to the ideal limit. Mishra et al. (2014) investigated the quality of groundwater in Rairangpur, Varanasi, and found comparable results, with total hardness values ranging from 146 to 268 mg L^{-1} of total hardness.

Calcium is an essential component for aquatic organisms, and it is found in abundance in all bodies of water (Ahmed et al. 2022). The calcium content in this investigation ranged from 18.20 ± 0.46 to 33.15 ± 0.36 mg L^{-1} in monsoon season and in post-monsoon season the value ranged from 16.75 ± 0.29 to 30.37 ± 0.46 mg L^{-1}. S5 had the highest calcium value in both seasons, whereas S1 had the lowest. The permitted value of calcium for drinking water is 75 mg L^{-1}, according to an Indian guideline (BIS 2012). The permitted limits were met in all of the samples collected. Calcium absorption by living organisms may be to blame for the fall in calcium levels. Magnesium ion concentrations in the sample locations in monsoon season varied from 12.29 ± 0.86 to 78.25 ± 1.47 mg L^{-1}. In post-monsoon season, S2 had the lowest and S5 had the highest value of magnesium. The highest concentrations of magnesium ions were found in S5 in both the seasons and S4 had the lowest value in monsoon and S2 had the lowest value in post-monsoon season. The allowed amount is 30 mg L^{-1}, according to Indian guidelines (BIS 2012). The high content of magnesium might be attributed to rains soaking nutrients into surface water bodies. When the samples were compared to Indian standards, several of them were found to be beyond the acceptable range. Magnesium is frequently associated with calcium in all types of water, but its concentration is generally lower than that of calcium (Venkatasubramai and Meenambal 2007). However, in the current results, the magnesium concentration in water was higher than that of calcium in some of the water samples. This might be because $MgCO_4$ is only partly soluble, causing the magnesium to precipitate as $Mg(OH)_3$ (Alohaly et al. 2016). The phytoplankton population is reduced when magnesium levels are low.

In these specific areas, sodium was the most prevalent cation in surface water, which increases the water's overall salt content. Maximum allowable limit for sodium in drinking water was 200 mg L^{-1}. Concentration of sodium increased from 3.33 ± 0.88 to 29.00 ± 1.15 mg L^{-1} in monsoon season and from 1.00 ± 0.57 to 18.0 ± 0.57 mg L^{-1} in post-monsoon season (WHO 1993). In both the monsoon and post-monsoon seasons, the limit was not exceeded in any of the surface water samples. Humans infrequently suffer negative effects from consuming potassium. The average potassium content during monsoon season ranged from 4.66 ± 0.33 to 384.33 ± 3.48 mg L^{-1} and 2.67 ± 0.66 to 290.0 ± 5.77 mg L^{-1} after monsoon season. In the monsoon season, the concentration of sulfate in surface water ranged from 113.00 ± 2.08 to 328.0 ± 5.29 mg L^{-1}, and in the post-monsoon season, it ranged from 97.331 ± 0.33 to 307.00 ± 3.00 mg L^{-1}. According to BIS 2012, S1 and S5 samples during the monsoon season and S5 during the post-monsoon season were both over the upper desired level of sulfate that is 200 mg $L^{-1.}$ High sulfate concentrations have been linked to laxative effects in humans and respiratory issues in animals (Maiti 1982; Rao 1993; Soubra et al. 2021).

The ionic chemistry of the sampling sites in monsoon and post-monsoon season is given in Fig. 2. Solids in water were defined as suspended and dissolved materials. They are particularly important characteristics for defining the chemical elements of water and they may be thought of as a general set of edaphic relationships that contribute to water body productivity (Szpak et al. 2021). The maximum amount of total dissolved solids that may be tolerated is 500 mg L^{-1} (BIS 2012). TDS levels range from 60.44 ± 0.44 to 706.78 ± 35.70 mg L^{-1} in monsoon season and in post-monsoon season values ranged from 52 ± 0.82 to 634 ± 34.41 mg L^{-1}. It depicts that the sampling sites with TDS values within the permissible limit, with the exception of S4 and S5 (highest) TDS values. This could be due to an increase in dumping of domestic wastes, ashes by pilgrims and higher temperature, which causes an increase in evaporation rate and the accumulation of dissolved salts in the

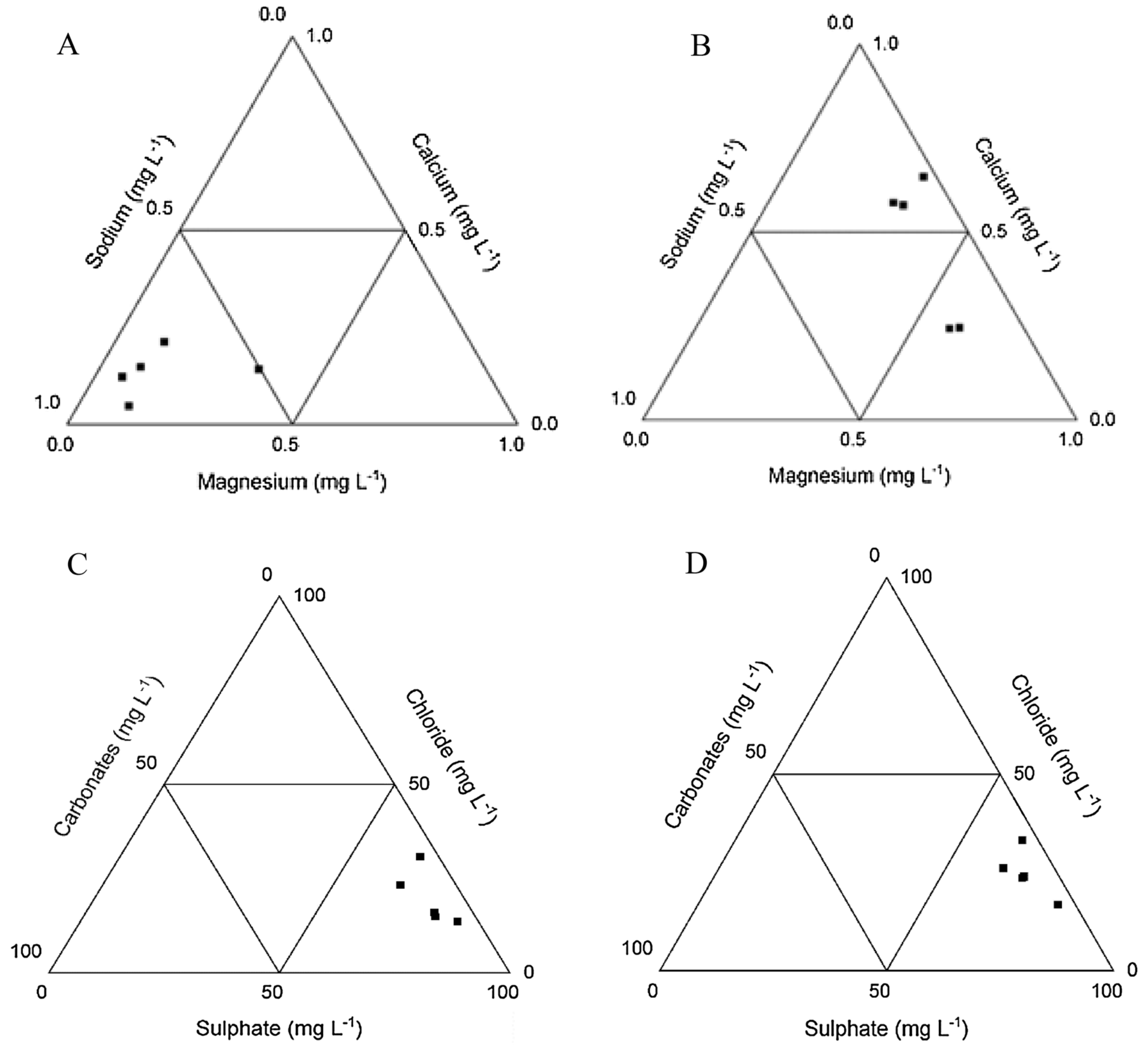

Fig. 2 Ternary diagrams showing contribution of individual ions toward the cationic (**A**, **B**) and anionic (**C**, **D**) mass balance in monsoon and post-monsoon season respectively

water. These results are coincidental with that reported by Zhang et al. (2022).

Chloride is mostly derived from inorganic salts, such as NaCl and KCl, in water, which is primarily derived from soil, animal wastes, and urban wastes (Gopalkrushna 2011). It's also regarded as a key sign of water contamination (Podhade et al. 2020). The quantity of chloride of the samples in monsoon season ranged from 22.31 ± 1.26 to 155.13 ± 7.09 mg L^{-1}. S5 had the highest values for chlorides, whereas S2 had the least. Increased chloride levels showed the existence of calcium and magnesium ion chlorides, which were then responsible for improving the site's overall hardness. In post-monsoon season also, S5 had the highest chloride value and S2 had the lowest chloride value. The maximum levels of ammonia, nitrate, and orthophosphate in monsoon season were determined to be 1.46 ± 0.026, 0.72 ± 0.04, and 37 ± 0.013 mg L^{-1} respectively and in post-monsoon season 1.27 ± 0.029, 0.58 ± 0.032, and 0.30 ± 0.012 mg L^{-1} respectively. Smuleac et al. (2013) found a greater level of nitrates due to the addition of urban garbage, but in the current investigations, agricultural runoff may be the cause of the higher level of nitrates and orthophosphate at the location. Ammonia levels were discovered to be higher at S5, possibly as a result of the influx of residential wastes and sewage water from neighboring villages and cities. Imnatoshi (2012) also found a higher ammonia value because to increasing residential sewage load. Ammonia levels beyond a certain threshold were extremely harmful to fish and other aquatic life in the water body (Bhatnagar and Devi 2013) and show negative correlation with DO (Kalla et al. 2004). Domestic garbage, sewage water from neighboring towns and cities, and other solid waste products contributed to the high levels of nitrate and ammonia.

Table 5 Bacterial assessment of five sampling sites during 2021 monsoon season

Sampling sites	Bacterial plate count (CFU mL^{-1})10^{-6}	MPN index/100 ml
S1(Baan Ganga)	$260.00 \pm 50.33 \times 10^{-6}$	1600 (5, 5, 4)
S2(Braham Sarovar)	$86.67 \pm 14.53 \times 10^{-6}$	43 (5, 1, 1)
S3(Sannihit Sarovar)	$176.67 \pm 24.04 \times 10^{-6}$	140 (5, 3, 2)
S4(Jyoti Sarovar)	$340.00 \pm 52.91 \times 10^{-6}$	345 (5, 4, 4)
S5(Sunhedi Pond)	$566.67 \pm 59.25 \times 10^{-6}$	< 2400 (5, 5, 5)

All values are mean ± S.E of mean

Means with different letters in the same column are significantly ($p < 0.05$) different (Duncan's multiple range test)

Table 6 Bacterial assessment of five sampling sites during 2021 monsoon season

Sampling sites	Bacterial plate count (CFU mL^{-1})10^{-6}	MPN index/100 ml
S1(Baan Ganga)	$241.00 \pm 37.63 \times 10^{-6}$	540 (5, 5, 2)
S2(Braham Sarovar)	$92.667 \pm 16.69 \times 10^{-6}$	41 (5, 0, 2)
S3(Sannihit Sarovar)	$224.67 \pm 32.04 \times 10^{-6}$	110 (5, 3, 1)
S4(Jyoti Sarovar)	$310.00 \pm 26.95 \times 10^{-6}$	350 (5, 5, 1)
S5(Sunhedi Pond)	$726.67 \pm 51.52 \times 10^{-6}$	< 2400 (5, 5, 5)

All values are mean ± S.E of mean

Means with different letters in the same column are significantly ($p<0.05$) different (Duncan's multiple range test)

Seasonal variations in bacterial assessment

Changes in bacterial population abundance can be used to monitor the microbial population of surface water (Xu et al. 2022). Bacteria in surface water denotes not just fecal contamination of the water, but also potential health and environmental risks (Cho et al. 2020). All five sample sites in both the seasons were evaluated during the research period, with both indicator and pathogenic microorganisms being monitored (Tables 5 and 6). When season-wise comparison of surface water bodies was done, it was found that S1, S2, and S4 had high bacterial load due to the addition of organic materials and fecal waste during the monsoon season, whereas S3 and S4 was high during the post-monsoon season because small size of the water body and having cemented floor. Overall average least standard plate count was observed at site S2 indicating less pollution status of the water body due to large size and not having cemented floor.

S5 ($566.67 \pm 59.25 \times 10^{-6}$, < 2400) had considerably higher total count and MPN index in both seasons and S2 had lower ($86.6667 \pm 14.53 \times 10^{-6}$, 43). The larger number of bacteria counted S5 was referred to the area's rapid population expansion, which was aided by the discharge of residential waste containing feces through drains and open defecation along the sample locations. Total counts were often greater than fecal counts during the research period, this might be because fecal counts are a subcategory of overall numbers (Prescott et al. 1996; Mercimek Takci et al. (2023).

Correlation analysis

Study of correlation reduces the range of uncertainty associated with decision making. Pearson correlation coefficient ('r') was calculated to determine the relationship between the water quality parameters depicted in Tables 7 and 8. pH showed negative significant correlation with calcium ($r = -0.766$, $p < 0.01$) in monsoon season. DO also depicted significant negative correlation with COD ($r = -0.917$, $p < 0.01$), chlorides ($r = -0.822$, $p < 0.01$), calcium ($r = -0.858$, $p < 0.01$), magnesium ($r = -0.776$, $p < 0.01$), TDS ($r = -0.700$, $p < 0.01$), TSS ($r = -0.807$, $p < 0.01$), ammonia ($r = -0.889$, $p < 0.01$), and bacterial count ($r = -0.744$, $p < 0.01$) in both seasons depicting that optimum concentration of dissolved oxygen is must to maintain other water quality standards.

Ammonia is strongly and positively correlated with five parameters namely COD {$r = 0.937$ ($p < 0.01$) and $r = 0.584$ ($p < 0.05$) in monsoon and post-monsoon}, T. hardness {$r = 0.892$ and $r = 0.981$($p < 0.01$) in monsoon and post-monsoon}, chlorides {$r = 0.985$ and $r = 0.879$ ($p < 0.01$) in monsoon and post-monsoon}, T. alkalinity {$r = 0.803$ and $r = 0.966$ ($p < 0.01$) in monsoon and post-monsoon} and magnesium{$r = 0.978$ and $r = 0.925$ ($p < 0.01$) in monsoon and post-monsoon}. Nitrates showed strong correlation with COD {$r = 0.769$ and $r = 0.653$ ($p < 0.01$) in monsoon and post-monsoon}, TDS {$r = 0.677$ and $r = 0.759$ ($p < 0.01$) in monsoon and post-monsoon} and TSS {$r = 0.697$ and $r = 0.714$ ($p < 0.01$) in monsoon and post-monsoon}. Bacterial count showed the positive correlation with COD {$r = 0.937$ and $r = 0.974$ ($p < 0.01$) in monsoon and post-monsoon}, T. alkalinity {$r = 0.625$ and $r = 0.640$ ($p < 0.01$) in monsoon and post-monsoon}, chlorides {$r = 0.868$ and $r = 0.917$ ($p < 0.01$) in monsoon and post-monsoon}, T. hardness {$r = 0.683$ and $r = 0.709$ ($p < 0.01$) in monsoon and post-monsoon}, magnesium {$r = 0.806$ and $r = 0.868$ ($p < 0.01$) in monsoon and post-monsoon}, ammonia{$r = 0.814$ and $r = 0.666$ ($p < 0.01$) in monsoon and post-monsoon}, nitrate {$r = 0.868$ and $r = 0.9663$ ($p < 0.01$) in monsoon and post-monsoon} and orthophosphate {$r = 0.904$ and $r = 0.786$ ($p < 0.01$) in monsoon and post-monsoon}. MPN index is strongly correlated with nine parameters, such as COD {$r = 0.767$ and $r = 0.970$ ($p < 0.01$) in monsoon and post-monsoon}, BOD {$r = 0.798$ and $r = 0.731$ ($p < 0.01$) in monsoon and post-monsoon}, T. hardness {$r = 0.975$ and $r = 0.805$ ($p < 0.01$) in monsoon and post-monsoon}, chlorides {$r = 0.970$ and $r = 0.977$ ($p < 0.01$) in monsoon and post-monsoon}, T. alkalinity {$r = 0.953$ and r = 0.745 ($p < 0.01$) in monsoon and post-monsoon}, magnesium

Table 7 Coefficient of correlation among various physico-chemical and biological parameters in monsoon season

	pH	Temp	DO	COD	BOD	C. alkalinity	T. alkalinity	Chlorides	T. hardness	Calcium	Magnesium	TDS	TSS	Ammonia	Nitrate	O-phosphate	B. count	MPN index
pH	1																	
Temp	0.949	1																
DO	0.813	0.730	1															
COD	−0.656	−0.543	−0.917	1														
BOD	−0.238	−0.437	−0.248	0.373	1													
C. Alkalinity	0.299	0.022	0.157	−0.080	0.783**	1												
T. Alkalinity	−0.170	−0.341	−0.441	0.537*	0.885**	0.796**	1											
Chlorides	−0.518	−0.554	−0.822	0.880**	0.679**	0.382	0.862**	1										
T. Hardness	−0.292	−0.437	−0.587	0.638**	0.820**	0.697**	0.983**	0.926**	1									
Calcium	−0.766	−0.588	−0.858	0.683**	−0.264	−0.600	−0.070	0.419	0.109	1								
Magnesium	−0.481	−0.555	−0.776	0.815**	0.726**	0.479*	0.907**	0.992**	0.963**	0.352	1							
TDS	−0.529	−0.250	−0.700	0.731**	−0.331	−0.717	−0.168	0.339	−0.033	0.844**	0.226	1						
TSS	−0.662	−0.415	−0.807	0.828**	−0.165	−0.624	−0.026	0.477*	0.112	0.876**	0.371	0.981**	1					
Ammonia	−0.616	−0.648	−0.889	0.881**	0.607**	0.303	0.803**	0.985**	0.892**	0.536*	0.978**	0.380	0.522*	1				
Nitrate	−0.220	−0.033	−0.468	0.769**	0.236	−0.170	0.289	0.543*	0.304	0.286	0.446	0.677**	0.697**	0.455	1			
O-phosphate	−0.173	−0.050	−0.452	0.771**	0.435	0.065	0.489*	0.652**	0.483*	0.160	0.577*	0.520*	0.565*	0.546*	0.972**	1		
B. count	−0.361	−0.257	−0.744	0.937**	0.425	0.086	0.625**	0.868**	0.683**	0.444	0.806**	0.622**	0.692**	0.814**	0.868**	0.904**	1	
MPN index	−0.344	−0.430	−0.658	0.767**	0.798**	0.578*	0.953**	0.970**	0.975**	0.185	0.980**	0.139	0.278	0.922**	0.506*	0.659**	0.820**	1

**Correlation is significant at the 0.01 level (two-tailed)

*Correlation is significant at the 0.05 level (two-tailed)

Table 8 Coefficient of correlation among various physico-chemical and biological parameters in post-monsoon season

	pH	Temp	DO	COD	BOD	C. Alkalinity	T. Alkalinity	Chlorides	T. Hardness	Calcium	Magnesium	TDS	TSS	Ammonia	Nitrate	O-phosphate	B. count	MPN index
pH	1																	
Temp	0.620**	1																
DO	0.223	0.548*	1															
COD	−0.648	−0.653	−0.864	1														
BOD	−0.501	0.088	−0.411	0.597**	1													
C. Alkalinity	0.308	0.682**	−0.118	−0.039	0.643**	1												
T. Alkalinity	−0.166	0.154	−0.608	0.569*	0.901**	0.797**	1											
Chlorides	−0.481	−0.352	−0.857	0.897**	0.817**	0.389	0.864**	1										
T. Hardness	−0.209	0.047	−0.687	0.641**	0.886**	0.736**	0.994**	0.910**	1									
Calcium	−0.559	−0.948	−0.727	0.739**	0.089	−0.429	0.108	0.556*	0.218	1								
Magnesium	−0.428	−0.251	−0.816	0.839**	0.857**	0.493*	0.916**	0.993**	0.952**	0.477*	1							
TDS	−0.552	−0.843	−0.550	0.725**	−0.048	−0.683	−0.136	0.350	−0.050	0.722**	0.236	1						
TSS	−0.691	−0.873	−0.591	0.813**	0.114	−0.607	−0.012	0.474*	0.075	0.780**	0.367	0.980**	1					
Ammonia	−0.130	0.019	−0.705	0.584*	0.806**	0.740**	0.966**	0.879**	0.981**	0.275	0.925**	−0.112	0.010	1				
Nitrate	−0.279	−0.309	−0.492	0.653**	0.206	−0.237	0.164	0.408	0.193	0.220	0.336	0.757**	0.714**	0.052	1			
O-phosphate	−0.319	−0.181	−0.609	0.758**	0.526*	0.095	0.506*	0.655**	0.522*	0.191	0.613**	0.591**	0.602**	0.381	0.932**	1		
B. Count	−0.461	−0.561	−0.942	0.974**	0.572*	0.075	0.640**	0.917**	0.709**	0.688**	0.868**	0.659**	0.725**	0.666**	0.663**	0.786**	1	
MPN Index	−0.573	−0.508	−0.885	0.970**	0.731**	0.192	0.745**	0.977**	0.805**	0.661**	0.945**	0.540*	0.649**	0.761**	0.535*	0.720**	0.969**	1

**Correlation is significant at the 0.01 level (two-tailed)

*Correlation is significant at the 0.05 level (two-tailed)

{$r = 0.980$ and $r = 0.945$ ($p < 0.01$) in monsoon and post-monsoon}, ammonia {$r = 0.922$ and $r = 0.761$ ($p < 0.01$) in monsoon and post-monsoon}, orthophosphate {$r = 0.659$ and $r = 0.720$ ($p < 0.01$) in monsoon and post-monsoon}, and bacterial count {$r = 0.820$ and $r = 0.969$ ($p < 0.01$) in monsoon and post-monsoon}. A strong physico-chemical relationship was observed between BOD, COD, T. alkalinity, T. hardness, chlorides, magnesium, ammonia, nitrate and orthophosphate in both seasons, which are responsible for water mineralization. Ammonia was strongly correlated with COD, T. hardness, chlorides, and magnesium indicating that these variables are derived from similar sources and also moving together.

Water quality index

The water quality index is a critical tool for determining the overall water quality of any body of water. A total of 13 water physico-chemical parameters were included in the development of the water quality index in both seasons. The results of these water sample parameters were compared to the Bureau of Indian Science's (2012) water quality index, and the water quality index was produced for all five locations (Fig. 3).

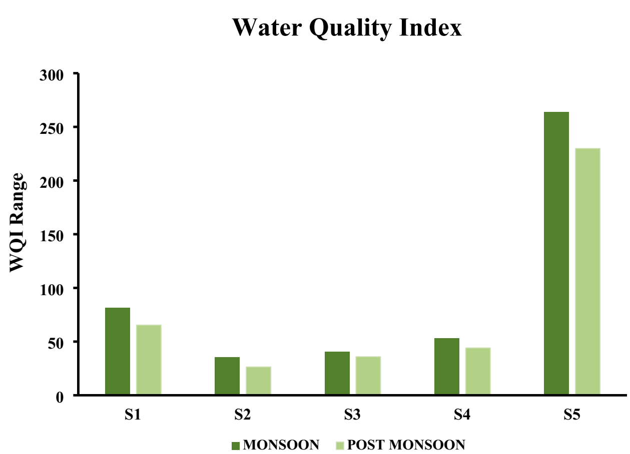

Fig. 3 Trend of water quality index of surface water bodies at different sites in different season

Sampling sites 1 to 5 had WQI values in monsoon season as 81.485, 35.349, 40.694, 53.185, and 264.111, respectively and in post-monsoon season was 65.380, 26.615, 35.935, 44.104, and 229.922, respectively. Table 9 represents the water quality status of the selected sites on the basis of Water Quality Index values in monsoon and post-monsoon season.

WQI values of S2 and S3 are good, indicating that there may be minimal addition of effluents from various sources. Sampling site S4 has a higher WQI value, indicating that water quality is poor, whereas S1 had much higher WQI value, indicating that water quality is very poor, possibly due to the addition of waste water. Due to the addition of wastewater from villages with feces and agricultural runoff to this water body, S5 with a value of 264.111 fell under the category unfit for consumption. According to the aforementioned data for sampling sites 3 to 5, there was an upward trend in WQI values, indicating an increase in pollution levels at these locations.

Conclusion

Fresh water is a limited resource, accounting for approximately 0.3% of total global water resources. Water accessibility is influenced by both natural and anthropogenic factors. Drinking water quality is determined by the hazardous components contained in it. Each metric was compared to the Bureau of Indian Standards specified desirable limits to assess the quality of surface water (BIS). These findings revealed considerable differences in water quality parameters throughout the studied sites in monsoon and post-monsoon season. The pH of water samples from around the region reveals an alkaline tendency. Some locations average alkalinity has surpassed the recommended level. Almost half of the samples exhibited levels of pH, DO, BOD, COD, total hardness, magnesium, ammonia, and orthophosphate that were higher than allowed. As a consequence of the findings of this study, it can be inferred that the majority of surface water bodies were highly contaminated, while the remainder were moderately polluted. Out of the five water bodies examined, two were determined to have fair water quality, S4 had bad water quality, S1 had exceptionally poor water quality, and S5

Table 9 Water quality status of the selected sites on the basis of water quality index values in monsoon and post-monsoon season

Sampling sites	Monsoon		Post monsoon	
	Values	Status	Values	Status
S1 (Baan Ganga)	81.485	Very poor water	65.380	Poor water
S2 (Braham Sarovar)	35.349	Good water	26.615	Good water
S3 (Sannihit Sarovar)	40.694	Good water	35.935	Good water
S4 (Jyoti Sarovar)	53.185	Poor water	44.104	Good water
S5 (Sunhedi Pond)	264.111	Unsuitable for drinking	229.922	Unsuitable for drinking

was found to be inappropriate for human consumption. The presence of coliform, fecal coliform, and a high MPN index value suggests that the water at these locations is inappropriate for drinking, outdoor bathing, and other human activities. Animal trash and residential garbage should not be dumped near water sources, according to experts. In agriculture, fertilizers and pesticides should be used in moderation and only standard-quality pesticides should be utilized. Surface water should be assessed and monitored on a regular basis. The government and the local residents may work together to maintain and safeguard these water sources via collective and collaborative efforts. Regular monitoring, public awareness initiatives, and better pond management may all aid in the protection of these aquatic water bodies. This study will enable the advancement of traditional water treatment procedures, as well as the development of safe, innovative, environmentally friendly, efficient, and cost-effective solutions based on residues, natural and sophisticated materials, and enhanced detection methods. Water treatment methods can employ nanotechnology-based treatments, which have attracted a lot of attention recently due to their high surface to volume ratios and magnetic characteristics. In addition to that, indigenous bacteria may be employed to cleanse water owing to their diverse enzyme generating activity, which can destroy a wide range of organic and inorganic contaminants. Therefore, application of safe and eco-friendly approaches is investable. In this regard, naturally occurring autochthonous bacteria along with metal nanoparticles, such as Ag and Zn, have synergistic effect on water contaminants and can enhance the water quality index as well.

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Author contributions AB contributed to the study conception and design, supervised the research and checked the manuscript. NT performed the experiments, analyzed the samples, compiled the data and did the statistical analysis of data. Both authors participated in the writing of manuscript and approved the final manuscript.

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Data availability statement The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors have no financial or non-financial competing interests.

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