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ORIGINAL PAPER

Assessing water quality of Deepor Beel, Assam, NE India, using water quality index: a case of Ramsar wetland

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Abstract

In this study, the water quality index (WQI) of the Deepor Beel, one of the most important Ramsar site of Assam, was assessed. Sixteen parameters were analyzed, namely, pH, temperature, turbidity (T), electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), and nitrate (NO_3^{-}) were analyzed. Based on these 16 parameters, the WQI of 10 sampling locations in the wetland was estimated. The WQI ranges between 93.69 and 158.26, indicating all the sampling sites fall under poor category of water quality, except one sample which falls under good category water. Moreover, low DO, high range of COD and BOD along with the presence of NO_3^{-} and PO_4^{3-} indicates both organic and inorganic pollution in the study area. Overall, multivariate statistical analysis identified anthropogenic effect as a controlling mechanism for lake water environment along with processes like silicate weathering and ion exchange. Anthropogenic activities such as the usage of fertilizer, waste dumping, and surface runoff are key factors for degradation of lake water environment. As this wetland has immense biological, environmental, and social importance, the detoriation of the water quality will have adverse effect in the wetland ecosystem. This degradation of the water quality by anthropogenic factors might subsequently increase in the near future, which might cause serious problems to the aquatic species or disrupt the natural food chain of the wetland afterward affecting the people surrounding Deepor Beel as they are dependent on this wetland for their survival.

Keywords Physicochemical parameters · Water quality index · Pollution · Ramsar site

Introduction

Wetlands are highly productive ecosystems that preserve biodiversity, help produce food, and provide ecological services like flood control, carbon sequestration, water filtration, toxin reduction, sediment and nutrient transfer, and flood mitigation (Chapman 1996; Ghermandi et al. 2008). It also creates opportunities for teaching and research (Fleming-Singer and Horne 2006; Ghermandi et al. 2010). Many plant and animal species, many of which are endangered, have natural habitats in wetlands. They act as a buffer zone between aquatic and terrestrial ecosystem and sustains a large variety of wildlife (Hammer and Bastian 1989; Zhang et al. 2012). They support a huge variety of wildlife which depend upon wetlands for their survival. Because of their similarity to human kidneys, wetland ecosystems are often referred to as "the kidneys of nature." Wetlands act as natural kidneys, filtering out pollutants and purifying water in the environment. As water moves through their intricate system of plants, soils, and microbes, they filter out harmful substances, excess nutrients, and sediments. Each wetland has its own local, regional, and global importance in terms of their ecological and socioeconomic values and hence has a unique role in the ecosystem and in the society. To ensure the preservation and effective management of these ecosystems, it is essential to evaluate the water quality of wetlands. In order to sustain the health and wellbeing of the wetland ecosystem, it is essential to identify potential sources of pollution and take the necessary corrective action. Moreover,

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wetlands are frequently used for recreational pursuits like swimming and fishing as well as a supply of drinking water. Regular water quality assessment helps to ensure that these uses remain safe for human consumption and use. Ultimately, assessing the water quality of wetlands is crucial for the long-term sustainability and conservation of these important ecosystems (Aswathy et al. 2021).

The Deepor Beel is the largest and the most biodiversity rich wetland in NE India which has been declared as a Ramsar site in the year 2002. It accommodates a huge number of avian species from different parts of the globe (Islam and Rahmani 2004). It is the habitat for 232 species of birds, 24 species of mammals, 32 species of reptiles, and 11 species of amphibians (Saikia 2005; Saikia and Saikia 2011). It supports various species of fish belonging to more than 20 families (Saikia 2005). These fish provide livelihood and protein supplements to the poor communities who live around this wetland (Islam et al. 2014). Almost 500 families are directly dependent on the aquatic resource and edible plant species of the wetland for their survival (Gogoi 2013; Saikia et al. 2014). However, it has been reported that there was a 26% decrease in the fish species of Deepor Wetland and the overall aquatic species has also shown a declining trend (Saikia 2013). The cutting of timber in Rani and Garbhanga Reserve forests located around the southern fringe of the wetland has greatly affected the Asiatic Elephant population in terms of food availability and habitat fragmentation. It has also led to an increase in man-animal conflicts. The total area of the beel has declined by 59.19% (Deka et al. 2011). However, due to the increase in developmental activities in the urban areas, there is a decrease in areal extent of wetlands since they are converted to agricultural land and built up area. Both global and regional wetlands are showing a declining trend (Darraha et al. 2019), and this phenomenon is also reflected in the status of Indian wetlands (Kumar et al. 2017). Today, many authors have detected heavy metals in the water of Deepor Beel (Kapil and Bhattacharya 2013; Roy and Kalita 2011). Moreover, it was estimated that the concentrations of all the heavy metals in the leachate were higher than the permissible limits laid down by Indian National Effluent Standards (Karak et al. 2013). Any threat whether natural or anthropogenic can conceivably affect the water quality of the wetland ecosystem. This may consequently have adverse effect on the socio-economic aspect of the entire area. Hence, information regarding pysico-chemical parameters of the surface water has become very essential, for proper environmental management of these wetland ecosystems.

Water quality index (WQI) is a widely recognized tool for determining the pollution status of a water resource, both ground and surface water. The main purpose of WQI is to synthesize a complex set of physical and chemical water quality parameters into a single number or minimize a huge volume of data into a single number. The use of a WQI was initially proposed by Horton (1965) and Brown et al., (1970), and subsequently, other ideas were suggested as improvements to the original method (Lermontov et al 2009; Ocampo-Duque et al. 2006; Liou et al. 2004). Although there are many shortcomings in this technique (Ali et al. 2014; de Rosemond et al. 2009; Kannel et al. 2007), but still it is considered as one of the most effective tools which can be easily understood by the common people as well as policy makers for decision-making purpose. It has been widely used by researchers all over the globe to interpret water quality data (Walsh and Wheeler 2012, Hou et al. 2016; Lai et al. 2013; Gitau et al. 2016; Ewaid and Abed 2017, Sutadiana et al. 2018, Mahmud et al. 2020, Hasan et al. 2020). However, only a handful of studies on the WQI have been reported from the northeastern part of India till date (Bora and Goswami 2016; Kangabam et al. 2017; Lkr et al. 2020).

Guwahati city has not adequately addressed its solid waste management problem for long. Every day about 500 metric tonnes of waste is generated from the city which is dumped at Boragaon near Deepor Beel in a very unscientific manner (Sayed et al. 2015). Under such circumstances, regular water quality monitoring is essential to determine its current status and to improve the environmental conditions related to this biodiversity hotspot. The organic and inorganic pollutants which results from anthropogenic inference have rendered the water bodies unsuitable for both primary and secondary uses (Tomasa et al. 2017). These activities increase the exploitation of the water bodies (Simeonov et al. 2003; Agbaire and Obi 2009; Effendi 2016). Guwahati is experiencing very rapid urbanization, illegal constructions, uncontrolled population growth, new developing factories in the fringe area of the wetland, encroachment of the wetland from all the sides, and change in the land use pattern. Under such circumstances, the water quality of the wetland becomes immensely important for sustainability of the aquatic flora and fauna. Hence, the WQI estimated considering sixteen water quality parameters will assist the administrative bodies to plan necessary measures for the conservation of this wetland.

Study area

The Deepor Beel wetland is located to the southwest part of the city of Guwahati, Assam, India (91°35′–91°43′ E and 26°05′–26°11′ N). The total area of the wetland and its depth changes depending on whether the season is dry or monsoon. Initially, Deepor Beel had an area of about 40 km^2, but due to large-scale developmental activities and pressure from the expanding city, today it has reduced to around 7 km^2 (Kapil and Bhattacharya 2013). The wetland along with its Rani Garbhanga Reserve Forest supports a large number of threatened and endangered species. Due to urban development and construction of the National Highway, the wetland got cut off from the River Brahmaputra which was its major feeding canal. The water flows into the wetland through inlets: Mora Bharalu and the Basishtha-Bahini rivers which carry rainwater along with sewage from Guwahati city. The outlet is Khanajan in the north, which joins the waters of the Beel to the Brahmaputra River in the north-western side of the water body. The study area map is given in Fig. 1.

Methodology

The sampling was conducted during the months from March to April to May 2022. Ten sampling sites (SS) were selected by random sampling method, and their coordinates were obtained using a Handheld Garmin GPS receiver.

Sample collection and laboratory analyses

Sampling was done in the month of March–April–May 2022. A boat was utilized while collecting the sample, and the samples were collected at 30 cm below the surface water level at each sampling station. Sample collection, stabilization, and transportation as well as the assessment of the water quality parameters of the wetland were done according to the standard methods of APHA guidelines (APHA/AWWA/WEF 2012). Prerinsed and dried polythene sampling bottles of 500 mL capacity was used to collect the sample. While collection, the bottles were rinsed thrice with the sample, and then, sample was taken. pH, temperature, EC, and DO were measured at the sampling site itself. Then, the sample was transported to the department laboratory and stored in refrigerator for further analysis. The 16 measured parameters for water quality assessment were pH, electrical conductivity (EC), turbidity, total alkalinity (TA), turbidity, total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), total dissolved solids (TDS), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), chloride (Cl^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), and sulphate (SO_4^{2-}). The used analytical procedures are listed down in Table 1.

Water quality index calculations

The WQI was calculated for the 10 sampling locations of the wetland. The sixteen parameters which were selected were namely: temperature, pH, EC, turbidity, DO, BOD, COD, TDS, TH, TA, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-}. The WQI was calculated based on these 16 parameters which are assigned a weight (w_i) between 1 and 5 based on their importance to water quality evaluation.

Secondly, each weight was divided by the sum of all weights in order to get the relative weight (W_i) (Boyacioglu 2007; Hamlat and Guidoum 2018).

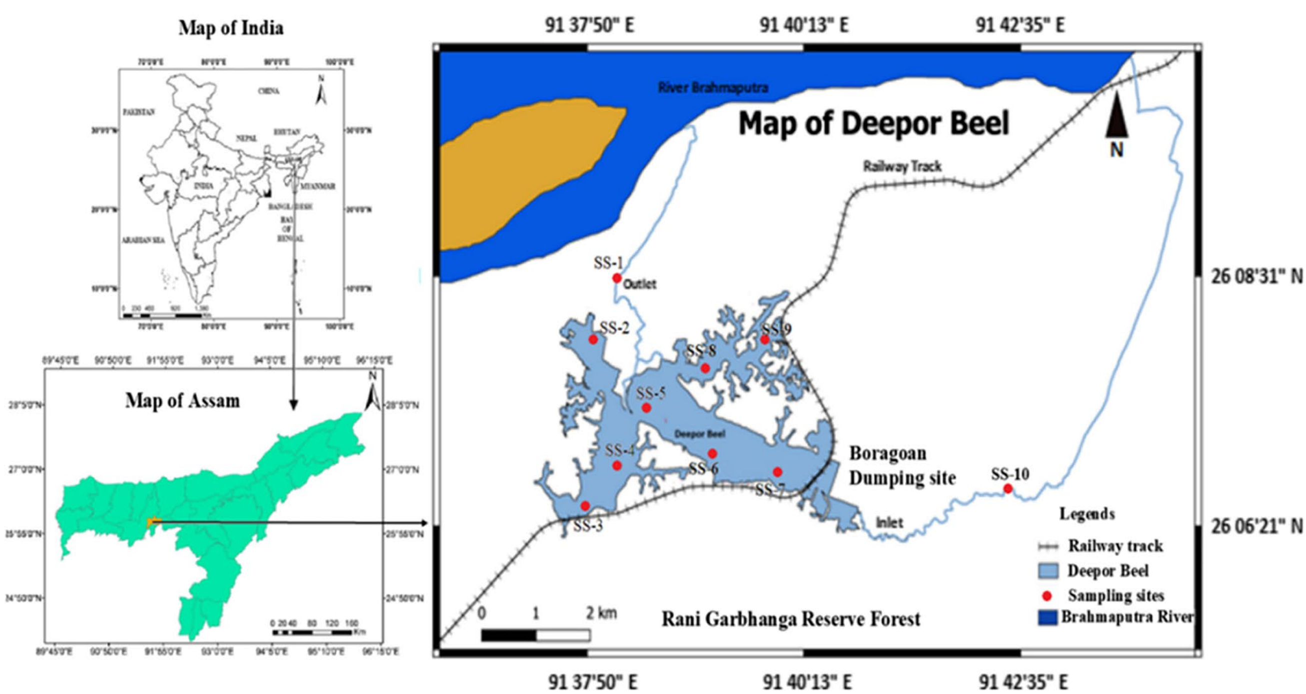

Fig. 1 Location map of the study area

Table 1 Adopted methodologies for water quality parameter analysis

Parameter	Abbreviation	Measurement unit	Analytical method
pH	pH	pH units	Digital multi parameter (Systronics Water Analyser 371)
Electrical conductivity	EC	mS/cm	
Turbidity	-	NTU	
Total dissolved solids	TDS	mg/L	
Temperature	-	°C	
Dissolved oxygen	DO	mg/L	
Total alkalinity	TA	mg/L as $CaCO_3$	APHA titrimetric method
Total hardness	TH	mg/L as $CaCO_3$	APHA titrimetric method
Calcium	Ca^{2+}	mg/L	Flame photometer
Magnesium	Mg^{2+}	mg/L	
5-Day biochemical oxygen demand	BOD_5	mg/L	5-day BOD test
Chemical oxygen demand	COD	mg/L	Closed reflux, titrimetric method
Chloride	Cl^-	mg/L	Ion chromatography (IC)
Nitrate	NO_3^-	mg/L	
Phosphate	PO_4^{3-}	mg/L	
Sulphate	SO_4^{2-}	mg/L	

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$$

where W_i is the relative weight, w_i is the weight of each parameter, and n is the number of parameters.

Thirdly, a quality rating scale (q_i) for each parameter was assigned using the equation

$$q_i = \left(C_i/S_i\right) \times 100$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in milligrams per liter, and S_i is the drinking water standard for each chemical parameter (mg/L) according to the guidelines of the WHO (2011).

In the fourth step, the SI_i is first determined for each chemical parameter, which was then used to determine the WQI:

$$SI_i = W_i \times q_i$$

The water quality index was calculated by adding together each sub-index values of each water samples as follows

$$\text{WQI} = \sum SI_i$$

where SI_i is the sub index of the ith parameter.

On the basis of WQI, water quality was categorized from excellent water quality to water unsuitable for all purposes as shown in Table 2.

Table 2 Water quality categories (Sahu and Sikdar 2008)

Range	Class	Type of water
< 50	1	Excellent
50–100	2	Good
100–200	3	Poor
200–300	4	Very poor
> 300	5	Unsuitable for all purpose

Multivariate statistical analyses

The statistical tool SPSS20 was used to run Pearson's correlation matrix, principal component analysis (PCA), and hierarchical cluster analysis (HCA) on normalized data; the specifics of these analyses are described in the "Results and Discussions" section. In order to normalize the data, the individual values for each physico-chemical parameter were subtracted from the mean, and the resulting number was then divided by the standard deviation. To find a linear link between the various physicochemical characteristics of the lake water, Pearson's correlation matrix was used. PCA is a form of multivariate analysis,

A huge number of variables were initially broken down into a small number of factors with the aid of linear combinations. Each principal component's (PC) relevance is determined by the variance's percentage; normally, the first two or three PCs account for the majority of the variation in the data (Critto et al. 2003). In our investigation, the orthogonal form of rotation known as the Varimax rotation was applied to produce the unrelated PCs (Tabachnick et al. 2013). Another popular multivariate statistical technique in earth and environmental sciences is HCA analysis, which groups or clusters parameters depending on their similarity in

Table 3 Statistical summary of physico-chemical parameters along with WHO standards and suitability for aquatic life (all units are in mg L^{-1}, except temperature(°C), EC (μS cm^{-1}), pH, turbidity (NTU)

Parameter	WHO standards (2017)	Aquatic life	Range (min–max)	Mean ± SD
Temperature	-	20–30	24–27	25.5 ± 1.204
pH	6.5–8.5	5–9	6.3–7.5	6.7 ± 0.4
EC	2000	-	120–750	395 ± 176
Turbidity	5	< 10	9–19	13.3 ± 2.8
DO	5	5–8	0.8–8.1	4.85 ± 2.34
BOD	5	< 10	8.5–18.6	13.06 ± 3.85
COD	5	< 50	20–64	39.1 ± 13.13
TDS	1000	-	75–382	217.8 ± 101.86
Total hardness (TH)	300	75–150	84–256.72	124.42 ± 52.88
Total alkalinity (TA)	500	25–100	100–190	141 ± 29.6
Ca^{2+}	100	25–100	9.62–51.3	30.21 ± 11.67
Mg^{2+}	50	-	0.49–49.7	11.89 ± 15.04
Cl^-	250	< 300	13–36	24.3 ± 8.3
NO_3^-	50	< 45	2.58–13.99	7.796 ± 3.6
PO_4^{3-}	1	-	0.03–0.14	0.09 ± 0.03
SO_4^{2-}	250	< 100	1.18–52.91	18.573 ± 14.77

Suitability of water for Aquatic life is compiled from Chapman 1992; Bhatnagar and Devi 2013, World Health Organization 2017

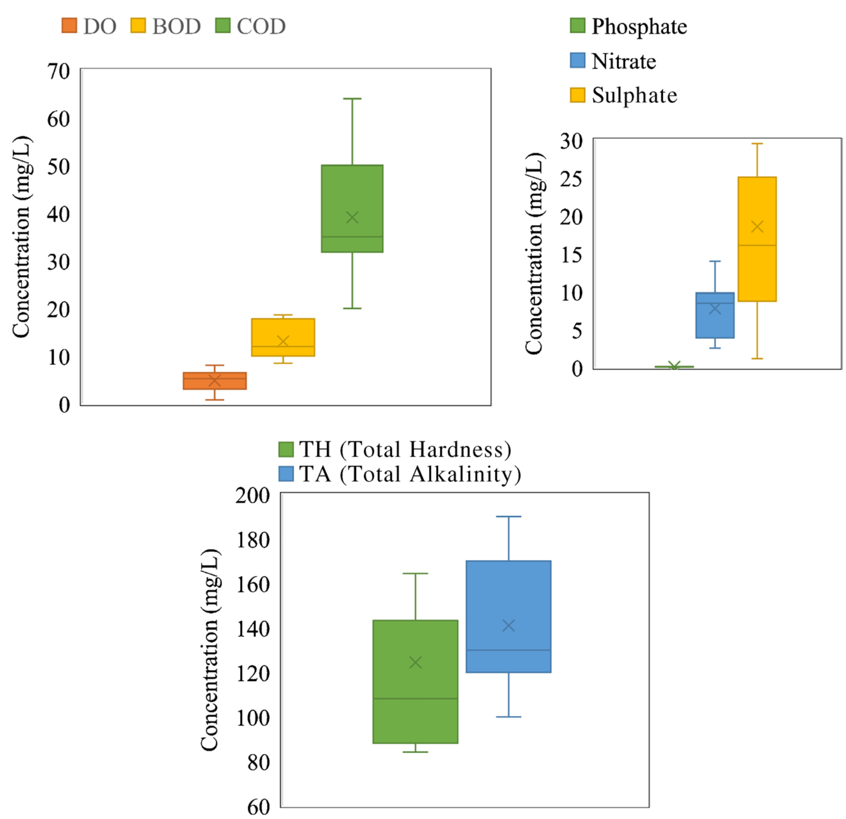

Fig. 2 Variation of water quality parameters

Table 4 Relative weight the physico-chemical parameters

Parameters	WHO standards (S_i)	Relative weight (w_i)	Unit weight (W_i)
Temperature	30	2	0.044
pH	6.5–8.5	2	0.044
EC	300	1	0.022
Turbidity	5	2	0.044
DO	5	5	0.111
BOD	5	5	0.111
COD	10	5	0.111
TDS	500	1	0.022
TH	300	2	0.044
TA	200	3	0.067
Ca^{2+}	75	2	0.044
Mg^{2+}	30	2	0.044
Cl^-	250	2	0.044
NO_3^-	45	4	0.089
PO_4^{3-}	5	4	0.089
SO_4^{2-}	200	3	0.067
$\sum W_i = 1$			

subsequent steps (Chen et al. 2007). Greater similarity results from smaller distances between two parameters in a cluster, but the contrary is true for bigger distances (Chen et al. 2007).

Results and discussions

Water quality parameters

The physical and chemical parameters of the water samples of Deepor Beel along with their statistical analysis are given in Table 3. Also, find Fig. 2. for box plots showing the variation of parameters in Deepor Beel.

The water temperature is critical for other parameters of any aquatic system. The temperature of Deepor Beel wetland varies between 24 and 27 °C, with a mean temperature of 25.5 °C which is considered normal for a lake; however, a higher temperature may affect the survival of aquatic organisms. The pH of the Deepor Beel wetland ranges between 6.3 and 7.5, with a mean of 7.2, indicating that the water is marginally alkaline. According to Whitemore et al. (2006), eutrophic lakes are known for having an alkaline pH. Freshwater ecosystems have been deemed productive when their pH ranges from 6.0 to 8.5. (Garg et al. 2010). Several writers also obtained similar pH values (Deb et al. 2019; Deb and Kalamdhad 2016). The study samples' electric conductivity (EC) ranges from 120 to 750 µS cm^{-1}, with a mean of 395 µS cm^{-1}. High conductivity in a water body suggests the presence of dissolved particles from a variety of anthropogenic and natural sources, including runoff from the Boragoan waste disposal site and the nearby agricultural fields. The water samples have a

Table 5 Calculation of WQI of SS-1, SS-2, and SS-3

Parameters	SS-1			SS-2			SS-3		
	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i
Temperature	24	80	3.55	26	86.66	3.85	27	90	4
pH	7.5	107.14	4.76	6.8	97.14	4.32	7.3	104.29	4.63
EC	275	91.67	2.04	751	250.33	5.56	276	92.00	2.04
Turbidity	14	280.00	12.44	13	260.00	11.56	15	300.00	13.33
DO	6.2	124.00	13.78	6.3	126.00	14.00	5.1	102.00	11.33
BOD	13.5	270.00	30.00	9	180.00	20.00	11.2	224.00	24.89
COD	34	340.00	37.78	32	320.00	35.56	38	380.00	42.22
TDS	132	26.40	0.59	382	76.40	1.70	144	28.80	0.64
TH	84.1	28.03	1.25	256.72	85.57	3.80	118.18	39.39	1.75
TA	140	70.00	4.67	120	60.00	4.00	120	60.00	4.00
Ca^{2+}	32.1	42.75	1.90	20.84	27.79	1.23	33.67	44.89	2.00
Mg^{2+}	0.98	3.27	0.15	49.7	165.67	7.36	8.28	27.60	1.23
Cl^-	27	10.80	0.48	13	5.20	0.23	14	5.60	0.25
NO_3^-	11.9	26.47	2.35	13.99	31.09	2.76	8.64	19.20	1.71
PO_4^{3-}	0.13	2.60	0.23	0.05	1.00	0.09	0.07	1.40	0.12
SO_4^{2-}	5.74	2.87	0.19	52.91	26.46	1.76	1.18	0.59	0.04
	$W_iq_i = 116.15$			$W_iq_i = 118.29$			$W_iq_i = 114.18$		
	WQI = 116.15			WQI = 118.29			WQI = 114.18		

Table 6 Calculation of WQI of SS-4, SS-5, and SS-6

Parameters	SS-4			SS-5			SS-6		
	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i
Temperature	27	90	4	26	86.66	3.85	27	90	4
pH	7.2	102.86	4.57	7.14	102	4.53	6.6	94.29	4.19
EC	395	131.67	2.93	353	117.67	2.61	285	95	2.11
Turbidity	10	200	8.89	9	180	8	14	280	12.44
DO	4.6	92	10.22	7	140	15.56	1.4	28	3.11
BOD	10.4	208	23.11	8.5	170	18.89	17.6	352	39.11
COD	32	320	35.56	36	360	40	56	560	62.22
TDS	261	52.2	1.16	197	39.4	0.88	240	48	1.07
TH	164.4	54.79	2.44	102.15	34.05	1.51	92.15	30.72	1.37
TA	100	50	3.33	120	60	4	190	95	6.33
Ca^{2+}	27.25	36.33	1.61	29.66	39.55	1.76	25.65	34.2	1.52
Mg^{2+}	23.39	77.97	3.47	6.82	22.73	1.01	6.82	22.73	1.01
Cl^-	24	9.6	0.43	34	13.6	0.6	36	14.4	0.64
NO_3^-	3.93	8.73	0.78	3.83	8.51	0.76	8.64	19.2	1.71
PO_4^{3-}	0.08	1.6	0.14	0.09	1.8	0.16	0.11	2.2	0.2
SO_4^{2-}	29.54	14.77	0.98	14.88	7.44	0.5	9.74	4.87	0.32
	W_iq_i = 103.614			W_iq_i = 104.618			W_iq_i = 141.353		
	WQI = 103.614			WQI = 104.618			WQI = 141.353		

mean turbidity of 13.3 NTU and a range of 9 to 19 NTU. In our study, a high level of turbidity was discovered in nearly all of the samples. Runoff from the adjacent Rani Hills and the industrial communities close to the wetland may be the cause of this high turbidity.

DO, BOD, and COD are the most important parameter for assessing water quality in surface water as it affects aquatic life and distribution (Rabee et al. 2011; Naubi et al. 2016). The dissolved oxygen (DO) range of 0.8 to 8.1 mg L^{-1} is important for the survival of aquatic organisms. Aquatic

Table 7 Calculation of WQI of SS-7, SS-8, and SS-9

Parameters	SS-7			SS-8			SS-9		
	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i	C_i	q_i	W_iq_i
Temperature	25	83.33	3.7	25	83.33	3.7	24	80	3.55
pH	6.3	90.00	4.00	7.4	105.71	4.70	6.8	97.14	4.32
EC	476	158.67	3.53	494	164.67	3.66	528	176.00	3.91
Turbidity	19	380.00	16.89	13	260.00	11.56	15	300.00	13.33
DO	0.8	16.00	1.78	3.6	72.00	8.00	5.4	108.00	12.00
BOD	18.6	372.00	41.33	18.4	368.00	40.89	12.8	256.00	28.44
COD	64	640.00	71.11	48	480.00	53.33	31	310.00	34.44
TDS	299	59.80	1.33	333	66.60	1.48	115	23.00	0.51
TH	114.1	38.03	1.69	136.1	45.38	2.02	88.12	29.37	1.31
TA	170	85.00	5.67	160	80.00	5.33	170	85.00	5.67
Ca^{2+}	44.89	59.85	2.66	51.3	68.40	3.04	27.25	36.33	1.61
Mg^{2+}	0.49	1.63	0.07	1.95	6.50	0.29	4.87	16.23	0.72
Cl^-	32	12.80	0.57	27	10.80	0.48	17	6.80	0.30
NO_3^-	6.97	15.49	1.38	9.11	20.24	1.80	8.36	18.58	1.65
PO_4^{3-}	0.13	2.60	0.23	0.14	2.80	0.25	0.03	0.60	0.05
SO_4^{2-}	23.61	11.81	0.79	17.31	8.66	0.58	9.94	4.97	0.33
	W_iq_i = 156.72			W_iq_i = 141.1			W_iq_i = 112.16		
	WQI = 156.72			WQI = 141.1			WQI = 112.16		

Table 8 Calculation of WQI of SS-10

Parameters	SS-10		
	C_i	q_i	W_iq_i
Temperature	24	80	3.55
pH	6.6	94.29	4.19
EC	117	39	0.87
Turbidity	11	220	9.78
DO	8.1	162	18
BOD	10.6	212	23.56
COD	20	200	22.22
TDS	75	15	0.33
TH	88.23	29.41	1.31
TA	120	60	4
Ca^{2+}	9.62	12.83	0.57
Mg^{2+}	15.59	51.97	2.31
Cl^-	19	7.6	0.34
NO_3^-	2.58	5.73	0.51
PO_4^{3-}	0.07	1.4	0.12
SO_4^{2-}	20.88	10.44	0.7
	W_iq_i = 92.35		
	WQI = 92.35		

Table 9 Summary of WQI values of Deepor Beel along with its water quality status (WQS)

Sampling site	WQI value	Class	Water quality status
SS-1	116.15	3	Poor water
SS-2	118.29	3	Poor water
SS-3	114.18	3	Poor water
SS-4	103.614	3	Poor water
SS-5	104.618	3	Poor water
SS-6	141.353	3	Poor water
SS-7	156.723	3	Poor water
SS-8	141.104	3	Poor water
SS-9	112.164	3	Poor water
SS-10	92.356	2	Good water

organisms may become stressed or even perish with a decreased DO level. Dissolved oxygen less than 5 mg L^{-1} can affect the functioning of the aquatic ecosystem, and a value less than 2 mg L^{-1} can be led to the death of all fish (Chapman 1992). Occurrences of hypoxia events are noticed with such low DO level in aquatic systems (Osborne et al. 2022). The primary cause of hypoxia can be mostly linked to human activities, specifically the discharge of waste materials into the lake. This discharge leads to an excessive accumulation of organic matter and nutrients, a reduction in the availability of freshwater, inadequate mixing or dilution of freshwater, and the release of effluents from surrounding urban areas, among other factors (Saga et al. 2023; Vea et al. 2022). The fact that some sampling sites (SS 6 and SS 7) are close to a dump site may be the reason why the minimum DO in this study of less than 2 mg L^{-1}.

The BOD was high in all the samples which signify organic loading in the wetland. The COD of the water samples varies between 20 and 64 mg L^{-1}, with a mean value of 39.1 mg L^{-1}. A high concentration of COD value indicates a high concentration of organic material inputs from adjacent industrial settlements (Deb et al. 2019). TDS shows considerable variations in different geological regions owing to differences in the weather conditions and solubilities of minerals. The TDS in the study samples varied between 75 and 382 mg L^{-1}, with a mean of 217.18 mg L^{-1} indicating the amount of inorganic and organic matter in the water. A higher TDS level can impact the taste and quality of water and affect aquatic life. The presence of Ca^{2+} and Mg^{2+} present in water causes total hardness (TH). Both Ca^{2+} and Mg^{2+} are controlled by the geological structure of the catchment area, plant cover, and the weather condition of the region (Potasznik and Szymczyk 2015). The TH of the sampling sites varied between 84 and 256 mg L^{-1}, with a mean of 124.42 mg L^{-1}. Ca^{2+} concentration in Deepor Beel varies between 9.62 and 51.3 mg L^{-1}, with a mean value of 30.22 mg L^{-1}. Mg^{2+} in the sampling point ranges between 0.49 and 23.39 mg L^{-1}, with a mean value of 24.3 mg L^{-1}. The TH, Ca^{2+}, and Mg^{2+} are mainly contributed by the surface runoff from the hills near Deepor Beel wetland. It is also influenced by organic compounds supplied by wastewater (Kolanek and Kowalski 2002). Total alkalinity (TA) in the surface water is primarily a function of carbonate, and hydroxide content and also includes the contributions from borates, phosphates, silicates, and other bases (Dutta et al. 2016; Uduma 2014). In Deepor Beel, the total alkalinity ranges between 120 and 190 mg L^{-1}, with a mean of 141 mg L^{-1}. Alkalinity results from the degradation of the organic matter which enters the water body.

Cl^- is associated with sewage and is often used as the measure of the extent of domestic sewage, wastewater discharge, and food waste entering the water body (Chapman 1996). The Cl^- in Deepor Beel wetland varies between 13 and 36 mg L^{-1}, with a mean of 24.3 mg L^{-1}. Cl^- is generally found in sewage effluents and might be a future pollutant for this sensitive wetland. Phosphate (PO_4^{3-}) is released into the water bodies by fertilizers, wastewater, and detergents. PO_4^{3-} in Deepor Beel wetland varied between 0.03 and 0.14 mg L^{-1}, with a mean of 0.09 mg L^{-1}. A similar range of PO_4^{3-} in Deepor Beel wetland was also obtained by other authors (Deb et al. 2019). This large PO_4^{3-} content in the wetland is contributed by the agricultural fields and the neighboring residential areas. It plays an important role in stimulating eutrophication. NO_3^- in the study area varies between 2.58 and 14 mg L^{-1}, with a mean of 7.79 mg L^{-1}. Both NO_3^{2-} and PO_4^{3-} are associated with nutrient load

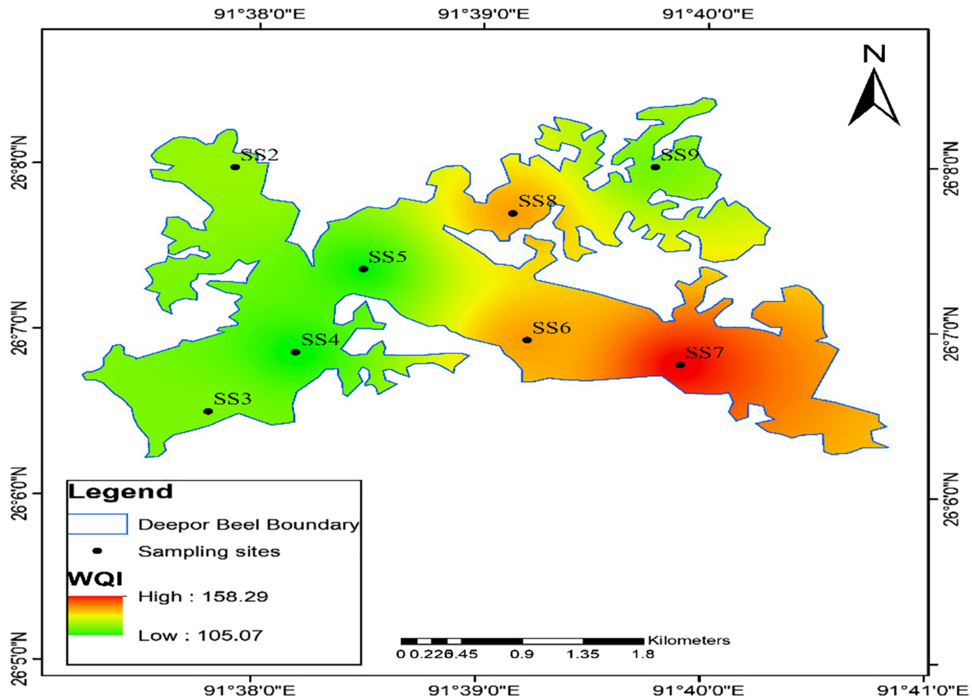

Fig. 3 IDW map showing the WQI values of Deepor Beel

(Sutadiana et al. 2018; Xu et al. 2012) and might cause eutrophication in the wetland. SO_4^{2-} in Deepor Beel Wetland varies between 2.46 and 8.62 mg L^{-1} with a mean value of 4.67 mg L^{-1}. SO_4^{2-} can be naturally occurring or the result of municipal or industrial discharges.

Water quality index

Sixteen water quality parameters were assigned weight (w_i) between 1 and 5, based on their importance in water quality assessment. The maximum weight of 5 was assigned to DO, BOD, and COD, followed by PO_4^{3-} and NO_3^- as they play an important role in determining the surface water quality. EC and TDS were given the least weightage of 1. The water quality parameters along with their WHO standards (2011) and relative weight are given in Table 4.

The results of physical and chemical parameters obtained from the water samples and their respective WQI values are shown in Tables 5, 6, 7, and 8. The samples were marked as SS.

The WQI of Deepor Beel ranges from 92.35 to 156.72, indication poor water quality status (Table 9). The minimum WQI was obtained in SS-10 and the maximum

Table 10 Correlation matrix for the lake water parameters of Deepor Beel

	pH	EC	DO	BOD	COD	TDS	Turbidity	TH	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	PO_4^{3-}	NO_3^-	SO_4^{2-}
pH	1.00														
EC	−0.35	1.00													
DO	0.62	0.12	1.00												
BOD	−0.33	−0.14	**−0.85**	1.00											
COD	−0.58	−0.15	**−0.91**	**0.84**	1.00										
TDS	−0.30	**0.65**	−0.31	0.19	0.34	1.00									
Turbidity	−0.54	0.08	**−0.61**	**0.63**	**0.59**	−0.03	1.00								
TH	−0.07	**0.76**	0.22	−0.40	−0.27	**0.75**	−0.21	1.00							
Ca^{2+}	0.12	−0.10	−0.44	**0.68**	0.57	0.20	0.38	−0.28	1.00						
Mg^{2+}	−0.10	**0.67**	0.35	−0.58	−0.44	0.55	−0.32	0.93	−0.60	1.00					
HCO_3^-	−0.53	−0.05	**−0.68**	**0.82**	**0.68**	−0.04	0.61	−0.50	0.31	−0.53	1.00				
Cl^-	−0.21	−0.47	−0.48	0.49	**0.62**	0.05	−0.08	−0.52	0.30	−0.54	0.42	1.00			
PO_4^{3-}	0.13	−0.40	−0.49	**0.68**	**0.65**	0.22	0.18	−0.33	**0.70**	−0.54	0.31	**0.71**	1.00		
NO_3^-	0.04	0.40	0.14	0.08	−0.12	0.19	0.36	0.37	−0.14	0.36	0.17	−0.46	−0.06	1.00	
SO_4^{2-}	−0.31	**0.83**	0.09	−0.28	−0.12	**0.81**	−0.17	0.91	−0.26	**0.86**	−0.33	−0.27	−0.24	0.24	1.00

The bold values specifies strong correlation in SS-7. The result depicts that the sampling locations (SS-1, DS-2, SS-3, SS-4, SS-5, SS-6, SS-7, SS-8, and SS-9) falls under the class of poor water category ($100 < WQI < 200$), and only one sample SS-10 falls under the good category water ($50 < WQI < 100$). The maximum WQI value was observed in SS-7, followed by SS-6, and SS-8. SS-6 and SS-7 were also the sampling points which were in close proximity to the Boragaon Municipal Dumping site. The sampling location SS-10 happens to be the inlet channel of the wetland. This also gives an indication that the water which enters the wetland is a better quality of water, but slowly shows an increasing pollution trend. The high values of WQI in the study area were contributed by runoff from dumping site, agricultural fields and factories established in its fringe area of the wetland. The IDW map of the studied area is shown in Fig. 3.

Multivariate statistical analyses to identify governing processes

The previous sections mainly dealt with the bivariate analysis of the different parameters and WQI; however, such techniques will be more useful when we study the relationship between different parameters and their effects. Therefore, the use of multivariate statistical techniques was applied to delineate valuable information on the degree of any inter or intrarelationship among the group of variables.

Correlation analysis

The relationship between the different variables in this study was observed using correlation analysis, a bivariate statistical method. The SPSS 20 software was then used to generate the correlation matrix (Table 10). A good correlation between TDS and EC represents evaporative processes. A good correlation of EC with TH and Mg^{2+} indicates Mg^{2+} to be the main contributor to the hardness of the lake water. Also, EC shares a positive correlation with SO_4^{2-} indicating anthropogenic influence. A good correlation between EC-SO_4^{2-} and Cl^--HCO_3^- is mainly related to the weathering of silicate-containing minerals and gypsum (Deka et al. 2015). A high negative correlation between DO with COD, BOD, and turbidity indicate a harmful lake water environment for aquatic life. Aquatic life is already under more stress due to the lake's significant drop in oxygenation potential. It is further proved by a good correlation between COD, BOD, and turbidity. BOD and COD also share a positive correlation with PO_4^{3-} indicating the onset of an algal bloom. A good correlation between Cl^--PO_4^{3-} indicates attributes of silicate minerals.

Principal component analysis

In our study, we used principal components analysis (PCA) using R mode and varimax rotation; four components were obtained (Table 11). The first principal component (PC1) had a variance of 35.0% and was represented by BOD, COD, turbidity, Ca^{2+}, HCO_3^-, Cl^-, and PO_4^{3-}. High loading of BOD, COD, and turbidity clearly represents the degradation of the lake water environment which is further emphasized by the high negative loading of DO. High positive loading of PO_4^{3-} might be due to the dissolution of minerals like apatite [$Ca_5(PO_4)_3(F,Cl,OH)$] or manmade influences, such as the use of fertilizer(Das et al. 2016). High loading of Ca^{2+}, HCO_3^-, and Cl^- shows the effect of weathering. **PC2** is constituted by EC, TDS, TH, Mg^{2+}, NO^{3-}, and SO_4^{2-} with a variance of 27.57%. Very high loading of EC, TDS, TH, and Mg^{2+} indicates hard water. High loading of NO_3^- and SO_4^{2-} potentially shows the anthropogenic impact of fertilizer application. **PC3** with a variance of 14.73% shows only high loading of pH only indicates pH-induced ion exchange. **PC4** shows high loading of NO_3^- with a variance of 12.23%, indicating anthropogenic influence. Overall, PCA clearly shows the dominance of anthropogenic influence controlling the lake water environment.

Table 11 PCA loadings of the various parameters of Deepor Beel

Parameter	Component			
	PC 1	PC 2	PC 3	PC 4
pH	−0.18	−0.22	0.85	0.41
EC	−0.09	0.89	0.01	0.18
DO	−0.84	−0.36	0.14	0.14
BOD	0.93	0.14	−0.07	0.03
COD	0.89	0.34	−0.02	−0.16
TDS	0.18	0.90	0.28	−0.26
Turbidity	0.64	0.29	−0.43	0.44
TH	−0.47	0.86	0.16	−0.06
Ca^{2+}	0.72	0.25	0.48	0.20
Mg^{2+}	−0.74	0.61	−0.09	−0.14
HCO_3^-	0.81	0.09	−0.39	0.14
Cl^-	0.68	−0.18	0.21	−0.56
PO_4^{3-}	0.74	−0.02	0.50	−0.21
NO_3^-	0.09	0.60	0.08	0.65
SO_4^{2-}	−0.46	0.77	−0.06	−0.36
Eigen values	**5.24**	**4.13**	**2.21**	**1.83**
% of variance	**35.00**	**27.57**	**14.73**	**12.23**
Cumulative %	**35.00**	**62.56**	**77.29**	**89.53**

The bold specifies the Eigen value, % of variance and cumulative % in the Principle component analysis

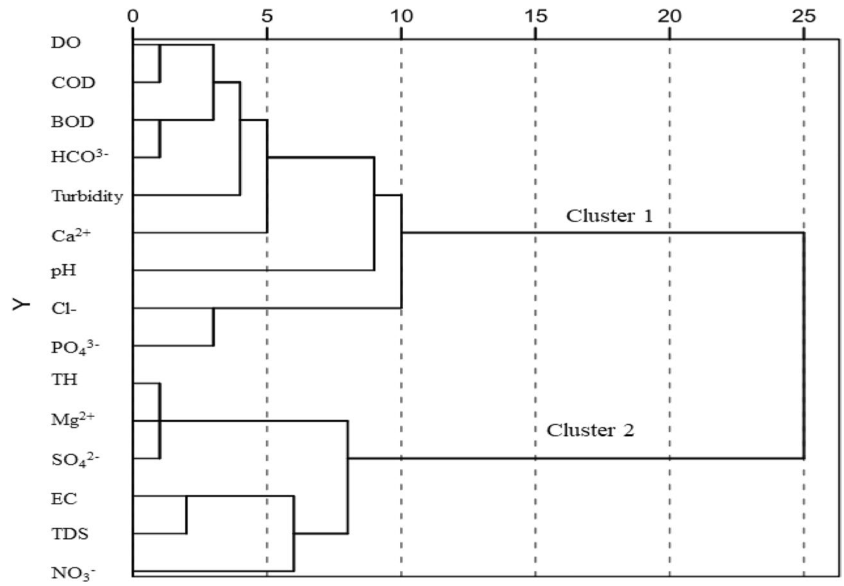

Fig. 4 Dendrogram showing the clusters of different water quality parameters

Hierarchical cluster analysis

In this work, hierarchical cluster analysis (HCA) was utilized to identify similarities and differences among the various water quality metrics. Ward's approach was applied to the HCA, using squared Euclidean distance. In our study, two main clusters were formed (Fig. 4). The first cluster was formed by HCO_3^-, Na^+, DO, COD, BOD, HCO_3^-, Ca^{2+}, pH, Cl^-, and PO_4^{3-}. The second cluster was formed by TH, Mg^{2+}, SO_4^{2-}, EC, TDS, and NO_3^-. The first cluster mainly represents the degrading lake water environment, and the second cluster mainly represents the anthropogenic influence on the lake water environment.

Conclusion

WQI proposed using sixteen water quality parameters has given a very clear picture of the water quality of the wetland. In this study, WQI value indicates poor category water in almost all the sampling sites. The study showed low DO in certain location, along with high BOD and COD. The high COD indicates inorganic pollution from anthropogenic sources. NO_3^- and PO_4^{3-} were also contributing to the pollution load of the wetland.

Along with other processes like silicate weathering and ion exchange, multivariate statistical analysis also identified anthropogenic effect as a governing mechanism for lake water environment. The degradation of the lake aquatic ecosystem is largely due to anthropogenic activities such the use of fertilizer, waste disposal, and surface runoff. The runoff from the nearby hills during the rainy season also contributes major ions in the water body. Moreover, the pressure of urbanization is forcing the conversion of this wetland from a biologically important ecosystem to a newly developing zone of the city.

The dumping site in the vicinity of the wetland is also causing a serious threat to the wetland ecosystem. Encroachments in the fringe area and municipal dumping site should be evicted as per extant norms by district administration. The study provided an index-based data which can help the local people and the policy makers to formulate strategies for conservation and management of the wetland. This is very crucial in order to sustain the flora, fauna, and human community of the surrounding area. The unplanned urbanization that is taking place close to Deepor Beel is the major concern. This uncontrolled growth and the lack of a wastewater treatment plant in Guwahati city signify the relevant hazard of anthropogenic intrusion to Deepor Beel. The ongoing dumping site in the west and the annual Brahmaputra flood will make the situation more precarious because human activity has entered the boundaries of limited flood basins. The inherent topography of the area will cause this problem to worsen, since more unsuitable construction in the city's mountainous portion would inevitably lead to an expansion of urbanization in the area around lake.

Declarations

Conflict of interest The authors declare no competing interests.

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