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RESEARCH ARTICLE

Assessment of spatio-temporal variations in lake water body using indexing method

Prachi Vasistha[1] · Rajiv Ganguly[1]

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Abstract

The study assesses the characteristics of two lakes located in close vicinity to each other in identifying the status of the lakes based on Designated Best Use (DBU) criteria for optimum utilization and use. Further, the study reports the characteristic assessment of the lakes for two seasons with sampling carried out in August and October months of 2019 and samples collected at different depths and locations to present the comprehensive existing water quality conditions of the lake. The study utilized about twenty parameters evaluated experimentally for determination of Water Quality Indices. In this context, different water quality indices including National Sanitation Foundation Method (NSFWQI) and BIS 10500 (BISWQI) were utilized in determining the indices. The WQI were determined depth wise and a weighted average method was utilized in presenting the overall WQI of the lakes which represents the true water quality based on depth wise evaluation. Hence, the study represents both spatial and temporal variations in the lake water quality. The overall classification of water quality for both the lakes using the NSFWQI methodology was *good* for both the sampling periods. Similarly, the overall water quality was categorized to be *excellent* for both the sampling periods using the BISWQI. Further, a new approach in determining water quality indexing is presented through introduction of a *Modified Water Quality Index (MWQI)* which utilizes the maximum number of parameters and thereby provides a means to reduce ambiguity and eclipsing problems of WQI. Using this newly developed MWQI, the water quality was categorized to be *excellent* and *good* for samples collected in August and October respectively for both the lakes. However, *conservative* estimation considering spillover effects may lead to classification of *good category* using MWQI. The Heavy Metal Pollution Index (HMI) were classified to be *good* for both the lakes and sampling periods. Spectral characterization of water samples revealed the presence of oxygen (O), tantalum (Ta), sodium (Na) and Zinc (Zn). However, further monitoring studies are being carried out to cover a period of 1 year to observe if there is a change in water quality due or any seasonal variations.

Keywords Designated Best Use (DBU) · Water Quality Assessment (WQA) · Water Quality Index (WQI) · Modified Water Quality Index (MWQI)

Introduction

Water is essential for sustenance and ancient civilizations had often been established near the banks of rivers and lakes (Versari et al. 2002). There are vast number of surface water resources available on the earth surface namely springs, oceans ponds and lakes but not all resources are fit for human use (Bhateria and Jain 2016). In particular, the quality of water available is dependent on the geology of the earth along with different anthropogenic activities surrounding the source (Tamiru 2004; Mahananda et al. 2010; Mehari and Mulu 2013) which affects its quality (Tank and Chippa 2013). The absorption of water into the earth surface causes contamination of water making it unsuitable for human consumption (Hartman et al. 2005). Further, it has been reported that physico-chemical properties of water vary both spatially and temporally (Wang and Yang 2008). Further, for agrarian regions, contamination of water with pesticides and insecticides leads to eutrophication (Voutsa et al. 2001). Water quality is a

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✉ Rajiv Ganguly
rajiv.ganguly@juit.ac.in

[1] Department of Civil Engineering, Jaypee University of Information Technology, District Solan, Waknaghat, Himachal Pradesh 173234, India

major factor which focuses on the human welfare and aquatic ecosystem (Kar 2007, 2013). In principle, the water quality is often assessed in terms of physico-chemical, heavy metals, eutrophication potential and other such associated parameters to ascertain the use of the water body which may be agricultural, industrial, potable or recreational (Sargaonkar and Deshpande 2003; Venkatesharaju et al. 2010).

Comprehensive water quality determination focuses on the measurement of these parameters and their evaluation which requires enormous data set often complex in nature (Boyacioglu 2007). The variability in the parameters can also be seen to be high due to various anthropogenic activities as well as natural factors (Simeonov et al. 2002). In this context, The Designated Best Use (DBU) criteria of Central Pollution Control Board of India (CPCB) gives a set of guidelines for comparing the determined parameters with the predefined value of certain parameters specified by CPCB (CPCB guidelines 2017).

In Indian context, the government has heavily invested in the improvement of water quality of rivers and lakes for utilization of the water for the various uses; but due to do several drawbacks including inadequate information to the general public and absence of rigorous monitoring and testing of such water bodies, the updated information regarding the water quality for such sources are often absent (Dwivedi and Pathak 2007). Further, with multifarious parameters being required to monitor the water quality, it often becomes difficult for the regulatory bodies to classify the actual existing water quality. In this context, the use of Water Quality Index (WQI) is one such method of reporting the existing water quality in a single number which is easy to identify for both regulatory authorities and the general public (Arias et al. 2013). There are a large number of water quality indices available such as BIS (Bureau of Indian Standards), NSFWQI (National Sanitation Foundation Water Quality Index), Oregon Water Quality Index, Canadian Water Quality Index for irrigation purpose, Fuzzy Logic Water Quality Index Zhu and Hu 2010 and a variety of other such indices. The parameters are selected according to the concerned Water Quality Index (WQI) and necessary mathematical calculations are carried out to obtain the suitable single value for the water quality. The choice of the method is dependent upon the parameters concerned and monitored and the possible use of the water source.

However, there exist some potential concerns regarding the determination of WQI. The main problems with water quality indexing are eclipsing and ambiguity which raises concerns about the limitations, opacity and misinterpretations that can take place in these indices which are generally based on aggregation methods (Ott 1978; Horton 1965). The ambiguity can be related to spatial measurements in a water body since spatial measurements are generally not considered in the water quality indexing approaches so far (Nasiri et al. 2007). Rigidity of parameters is one such problem which creates a lack of flexibility in terms of the concerned parameters and their utilization in calculation of the concerned index (Swamee and Tyagi 1999, 2000). Considering the above two major concerns, a Modified Water Quality Index (MWQI) approach can be the best possible solution which not only focuses on decreasing of ambiguity but also focuses on removal of rigidity for the concerned WQI.

Further, existing surface water bodies are often susceptible to heavy metal pollution arising from different anthropogenic sources. Hence, Heavy Metal Index (HMI) is a necessary indexing technique used in determining the effects of increased concentrations of heavy metals on the water surface (Ebrahimpour and Mushrifah 2008). The primary reasons for increased heavy metals concentrations in water bodies are primarily due to natural topography of the area along with increased anthropogenic activities (Karbassi and Bayati 2005). The determination of HMI of the source gives clear indications of level of pollution and effects that may be produced on concerned flora and fauna along with the bio-accumulation in the food chain (Sasmaz et al. 2008). In this context, spectral analysis studies are also often carried out to quantify the major elements present in the study.

The main objectives of the study were as follows: (a) To determine the existing water quality of the lakes and to ascertain their criteria for their utilization as per the existing DBU guidelines mentioned by CPCB. (b) To determine different water quality parameters and WQI at different depths and overall assessment of the lakes using the NSF and BIS 10500 methodology for both the sampling periods using a weighted average technique. (c) Development of a Modified Water Quality Index (MWQI) considering the spatial variation of the pollutants, (d) to determine spectral characterization (EDS) analysis of the water samples and (e) to ascertain the HMI of both the lakes over the two sampling periods.

Materials and methods

Study area

The Twin Lakes of Tikkar Taal are located at an altitude of 30° 42′ N 77°5′ E in Morni Hills of district Panchkula in Haryana state in India. Figure 1 shows the geographical location of the actual lakes.

Lake 1 (Bhim Taal) has a dimension of 560 m long and 460 m wide with maximum depth of 5 to 6 m at the centre of the lake. The depth of the lake has been gradually reducing year on year due to heavy influx of sediments from around the lake. Presently, the DBU status of this lake is unknown but is generally used for recreational activities.

Lake 2 (Draupadi Taal) is the smaller of the two lakes with it being 365 m in length and width. Previously, some pisciculture activities were carried out in this lake but are not in

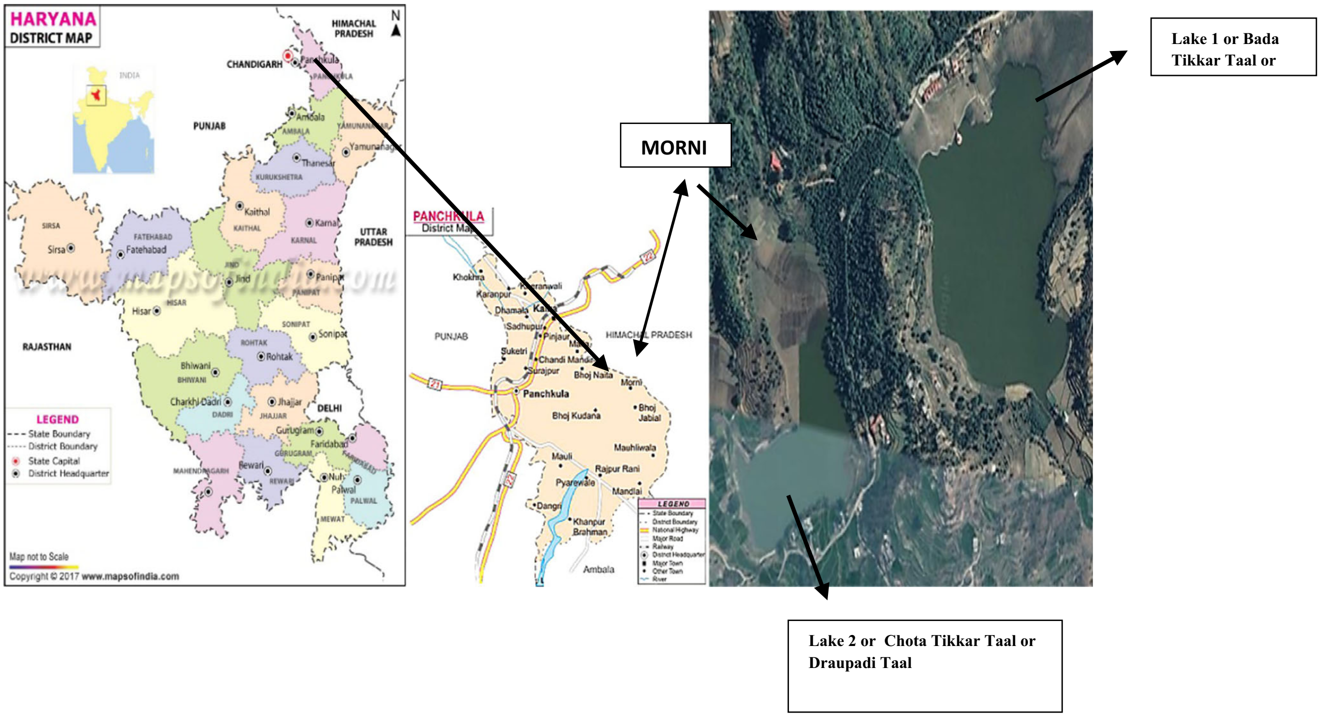

Fig. 1 Location of Twin Lakes of Tikkar Taal, Panchkula (source: www.maps of India.com; Google Maps)

operation presently due to some associated problems. Similar to above, the present DBU status of the lake is unknown.

To summarize, it is possible that the lakes may be considered a fresh source of water, as there is an influx of water from a nearby waterfall which remains active from August to December months of the year. However, detailed assessment of these lakes has not been conducted and reported anywhere and hence the present study has been undertaken for determining the DBU and the existing water quality in the lakes based on initial sampling conditions. Further, the lake and the surrounding area often experience different anthropogenic activities. Hence, in such conditions, it becomes imperative in evaluating the natural lake ecosystem and to develop suitable remedial measures to save the lake ecosystem from degradation.

Methodology

Sampling methodology

Lake 1 was sampled in the month of August and October 2019. Depth-integrated grab sampling technique was carried out. The samples were taken from 4 sampling locations namely S1–S4 from Lake 1 to cover the entire lake. The depth factor was also taken into consideration during the sampling and was divided into three zones based on the total depth. The depth points of sampling were divided into *a, b* and *c* wherein *a* was at 2-m depth from top of the lake, *b* was at 3-m depth from top and *c* was at 4-m depth from top. Hence, the sampling points were divided into S(a), S(b) and S(c) so as to cover the entire depth of the lake. Hence to summarize, the nomenclature pattern followed was S1(a) was sampling location 1 at a depth of 2 m from the surface of the lake. Similarly, S3(b) signifies sampling at location 3 with a depth of 3 m from the surface. Figure 2 shows the Lake 1 and the chosen points for the depth-integrated grab sampling of the lake.

Similar strategy was followed for Lake 2 wherein samples were taken from 3 sampling locations namely D1, D2 and D3 in Lake 2 to cover the lake completely (different nomenclature used w.r.t in Lake 1 to avoid any ambiguity) and at different depths of *a, b* and *c*. However, point *a* was at 1-m depth from top of the lake, *b* was at 2-m depth from top and *c* was at 3-m depth from top. Similar nomenclature was followed as used for Lake 1.

Hence, D1(a) was sampling location 1 at a depth of 1 m from the surface of the lake. Similarly, D3(b) signifies sampling at location 3 with a depth of 2 m from the surface. Figure 3 shows the selected points for the sampling of Lake 2.

As per the guidelines laid out by CPCB (CPCB guidelines 2017) the monitoring campaign for the lakes should be carried out a minimum of 6 times in a year and twice a year for heavy metal analysis considering pre and post moonsoon seasons. The parameters to be considered are specified as per the guidelines and have been selected and discussed in the following section. Hence, for our present study conditions, we present the results of two monitoring campaigns carried out during August and October 2019 for the different physico-chemical and other associated parameters. However, as per guideline, results for heavy metals are only presented for August 2019

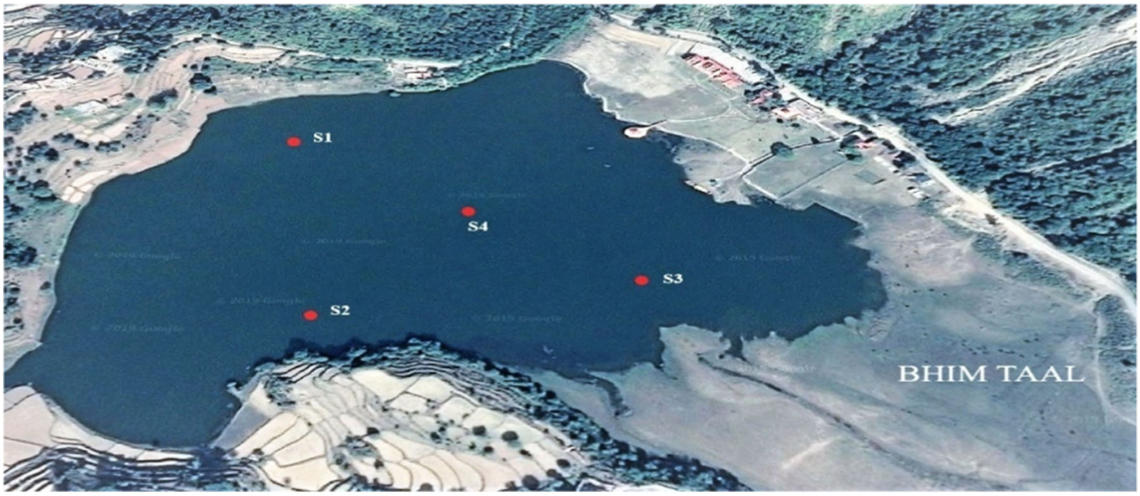

Fig. 2 Sampling points of Lake 1 or Bhim Taal or Bada Tikkar Taal of Morni Hills, Panchkula (Source: Google Earth)

sampling period which represents the post moonsoon sampling time. Monitoring was carried out twice during the first and last week of August and October 2019 and the average was used to represent the overall existing water quality conditions. Since, the CPCB guidelines mention sampling six times a year and there is no definitive suggestion of using continuous monitoring, depth-integrated grab sampling was utilized for the study. All 72 samples (4 sampling points were considered within the lake; 3 depths at each of the sampling locations; 3 samples taken from each depth) were utilized in determining WQI in Lake 1 for each of the sampling months. Similarly, 54 samples (3 sampling points were considered within the lake; 3 depths at each of the sampling locations; 3 samples taken from each depth) were utilized in determining WQI in Lake 2 for each of the sampling months.

Monitored parameters

The Central Pollution Control Board (CPCB) (CPCB guidelines 2017) gives the criteria for water quality characterization of lake based on a list of important parameters as decided by them. The parameters that were considered in this study were from the list of about 33 parameters that were measured after the sampling. The parameters selected are mostly related to the concerned Designated Best Use (DBU) criteria for the water body as given by CPCB and also the Water Quality Index chosen for checking the quality of the water body.

The parameters consist of important physical, chemical and biological parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), dissolved oxygen (percentage saturation), turbidity, total dissolved solids (TDS), total suspended solids (TSS), nitrate, total phosphorous, biological oxygen demand (BOD), chemical oxygen demand (COD), sulphate, calcium, magnesium, chlorides, total alkalinity, bicarbonates and total hardness faecal coliform along with the heavy metal such as zinc, iron, arsenic, cadmium, mercury, lead, nickel and chromium. The unit for all the parameters was milligrams per litre except for pH and EC which was microsecond per centimetre Turbidity was denoted

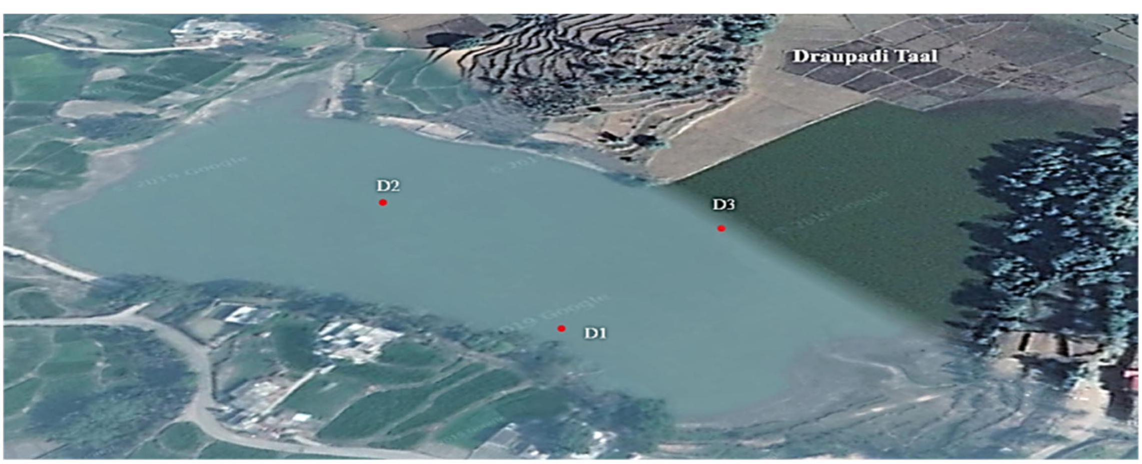

Fig. 3 Sampling points of Lake 2 or Draupadi Taal or Chota Tikkar Taal of Morni Hills, Panchkula (Source: Google Earth)

in nephelometric turbidity unit and temperature in degrees Celsius. The experiments for the determination of these parameters were carried out according to the procedures specified in Standard Procedures for Determination of Water and Wastewater by American Public Health Association (APHA) (APHA 2012). The experimental procedures were carried according to detailed guidelines given in the book and results were recorded after verification with guidelines provided by CPCB.

Designated Best Use

The water quality criteria are different for different water sources. For example, the water of a source might be fit for bathing and recreational activity but may not suitable in terms of human consumption. To identify such conditions and properly categorize these water bodies, the CPCB have used the concept of Designated Best Use (DBU) criteria defined by CPCB which lists the value of certain parameters that need to be met to be categorized under such category. In general, they are classified into different categories, namely potable source with treatment, outdoor bathing source, potable source without treatment, propagation of fishes and other wildlife, irrigation and for other industrial uses. The parameters considered by CPCB for categorizing the surface water body into predefined categories include a combination of physico-chemical and biological parameters. The parameters include pH and electrical conductivity (EC), dissolved oxygen (DO), biological oxygen demand (BOD), free ammonia and sodium absorption ratio (SAR) and total coliform organism test. The range of parameters confirming the fitness in each category is different and all the parameters must be satisfied in each category for the water source to be fit for the particular use.

Spectral characterization

The spectral characterization for the water samples were done to obtain the chemical structure and composition of water of the lake. In this context, energy dispersive X-ray spectroscopy (EDS) instrument was utilized for obtaining the characterization by focussing the electron beam over the surface of the samples. The EDS graphs were obtained due to different energies generated during the bombardment process of electrons and which corresponds to different elements present in the sample. The absorption of different wavelengths was used to obtain the quantitative analysis of the samples by chemical micro analysis technique. The samples for the EDS were prepared on the glass film by thin film deposition technique by depositing water droplets over surface of glass film to analyse it for EDS.

Water quality indexing

Water quality indexing is the method for evaluating the existing water quality of a water body in a simpler form (Swami and Tyagi 2000; Swamee and Tyagi 2007; Ilaboya et al. 2014). The results of the WQI results in a single value which helps the regulatory authorities in identifying the existing water quality and take suitable action for deteriorating water bodies (Tyagi et al. 2013; Rana et al. 2018; Sharma et al. 2020). In principle, the WQI is determined using a different set of water quality testing parameters covering all physico-chemical and biological components. In principle, the parameters are assigned a certain weightage (sub index) as per the importance of the parameter in affecting the existing water quality. Thereafter, the second step involves aggregation of sub index function using suitable aggregation method calculations using mathematical expressions (Tyagi et al. 2013; Swami and Tyagi 2000). The following indices have been used for calculating the WQI of the two lakes of the study area.

National Sanitation Foundation Water Quality Index The National Sanitation Foundation Water Quality Index (NSFWQI) is an internationally recognized index based on the determination of *predefined set* of nine water quality parameters with *pre-decided weightage* already assigned to them. The parameters and weightage considered for determining WQI are DO (0.17), faecal coliform (0.16), pH (0.11), BOD (0.11), total phosphorous (0.10), temperature (0.10), nitrates (0.10), turbidity (0.08) and TS [or TDS/TSS] (0.07) (Noori et al. 2019). The total summation of all the weightage ($\sum W_i$) comes out to be 1. The WQI is then calculated through the following mathematical expression as shown in Eq. (1) below

$$\mathrm{NSFWQI} = \frac{\sum_{i=1}^{n} W\mathrm{i} \times Q\mathrm{i}}{\sum_{i=1}^{n} W\mathrm{i}} \quad (1)$$

where,

W_i assigned weightage of the parameters.
Q_i value of quality rating obtained from quality rating curve.
$\sum_{i=1}^{n} W\mathrm{i}$ summation of assigned weights which should be 1.

The final classification of the water quality obtained through NSFWQI has been summarized in Table 1.

Bureau of Indian Standard Water Quality Index The index is based on the comparison of the sample data values with standards prescribed by Bureau of Indian Standards (BIS). The BIS 2012 (IS: 10500) was used for the comparison of the

Table 1 Rating table for NSFWQI (Brown et al. 1970)

Range	Category
0–25	Very bad
26–50	Bad
51–70	Medium
71–90	Good
91–100	Excellent

parameters obtained with standard values prescribed by the Indian Standards (Rao 1997).

The Bureau of Indian Standard Water Quality Index (BIS WQI) is an Indian national WQI based on parameters defined by Government of India under IS: 10500. The parameters utilized are already *predefined set* under the IS: 10500. The parameters can be chosen according to the intended specific use of the water body (Alobaidy et al. 2010). Many studies have been reported around the country with parameters based on the intended specific use of the considered water body and after suitably referring to experts opinion (Ramakrishnaiah et al. 2009; Singh et al. 2018; Vasanthavigar et al. 2010a, 2010b; Alobaidy et al. 2010) but it should be enlisted in the list of parameters defined by BIS under IS 10500. In the case of our selected water body, the WQI has been determined on the basis of following *10* parameters: pH, EC (μmhos/cm), TDS (mg/L), TA (mg/L), Ca (mg/L), Mg(mg/L), Cl (mg/L), NO_3 (mg/L), SO_4(mg/L) and HCO_3(mg/L).

The weighing factors for BIS WQI are assigned based on the intended use of water body as mentioned above (Alobaidy et al. 2010). The weightage is decided based on the chosen parameter from list of parameters already predefined in IS 10500 as well as after suitably referring to weightage assigned to these parameters as per earlier reported scientific literature (Ramakrishnaiah et al. 2009; Sharma et al. 2014; Singh et al. 2018; Vasanthavigar et al. 2010a, 2010b; Alobaidy et al. 2010).

The first step involves determination parametric values of pH, EC, TDS, TA, Ca, Mg, Cl, NO_3, SO_4 and HCO_3 through standard procedures mentioned in APHA (APHA 2012). The second step involves assigning the weights (w_i) to each of these measured parameters parameter on a scale of 1–5 with 1 being the lowest impact and 5 being the highest one based on their relative importance in affecting the water quality (Sharma et al. 2014; Singh et al. 2018; Vasanthavigar et al. 2010a, 2010b). Step 3 includes relative weightage (W_i) determination based on Eq. (2) below.

$$W_i = w_i / \sum_{i=1}^{n} wi \tag{2}$$

where,

W_i relative weight to be determined.
w_i weight of parameters concerned.
n total number of parameters.

The next step (Step 4) involves the determination of rating scale q_i based on the quality which is generally calculated for each parameter by division of the concentration value obtained for the particular sample by the standards as laid by the BIS 10500 (2012). The following Eq. (3) describes the calculation to obtain the value of q_i.

$$q_i = (c_i/s_i) \times 100 \tag{3}$$

where,

q_i rating scale based on quality.
c_i concentration of associated parameter (mg/L).
s_i standard value as specified in BIS 10500 (2012).

Step 5 involves the calculation of sub index function for each parameter the final aggregation of WQI. The sub index function or *SI* is calculated by the following equation Eq. (4).

$$SI_i = W_i \times q_i \tag{4}$$

where,

SI_i sub index function for *i*th parameter.
W_i relative weight determined for the parameter.
q_i rating scale based on quality.

The final step (Step 5) involves the calculation of final WQI using this method. Equation (5) describes the final calculation of WQI.

$$BISWQI = \sum_{i=1}^{n} SI_i \tag{5}$$

The categorization of water bodies based on WQI is summarized in the Table 2. It is observed from Table 2 that the categorization varies from excellent to unfit wherein WQI values less than 50 are classified as excellent and greater than 300 as not suitable for drinking (Rana et al. 2018).

Table 2 Rating table for BISWQI (Singh et al. 2018)

Range	Category
< 50	Excellent
50–100	Good
100–200	Poor
200–300	Very poor
> 300	Unfit for drinking

Modified Water Quality Index

The Modified Water Quality Index (MWQI) is a proposed indexing method (site specific) to determine the WQI of the two lakes by eliminating some of the rigidness associated with conventional WQI methods. *A quick look at the parameters used for NSF and BIS suggests that only a few parameters are common among both these WQI system.* Further, the parameters considered by the existing WQI techniques are often few. For example, NSFWQI uses only 9 parameters while deciding the overall WQI of the water body. It may also be noted that the weightage of the different parameters affecting the water quality is often reported to be different thereby affecting the actual weightage of the selected parameters.

Hence, in the development of the MWQI, we considered all the parameters considered for NSF and BIS WQI system. Thereafter, we carried out an extensive literature survey to assess the different parameters which affect the water quality (Verma et al. 2019; Singh et al. 2018; Sener et al. 2017; Rishi et al. 2017; Kangabam et al. 2017; Fathi et al. 2016; Singh et al. 2013; Sharma et al. 2014; Arias et al. 2013; Hamid et al. 2013; Ravikumar et al. 2013; Liu et al. 2012; Rubio-Arias et al. 2012; Masood et al. 2012; Kaswanto et al. 2012; Alobaidy et al. 2010; Karakaya and Evrendilek 2010; Chougle et al. 2009; Ramakrishnaiah et al. 2009; Sanchez et al. 2007; Abrahao et al. 2007; Boyacioglu 2007; Dwivedi and Pathak 2007; Kannel et al. 2007; Pesce and Wunderlin 2000). In the process of this detailed literature survey, it was observed that certain other parameters like total hardness (TH), bicarbonates and chemical oxygen demand (COD) were also important parameters that were not considered in determination of WQI and hence we included some of these parameters for framing the Modified WQI for our study. Some other parameters used in earlier reported literature did not suit us since some of these parameters were not detected for samples collected from our study locations. The parameters used for determining Modified WQI had been framed after extensive literature survey ($n = 25$, but not absolute) and encompasses almost all parameters used in NSF and BIS WQI system. As such, the proposed Modified Water Quality Index (MWQI) gives the flexibility in selecting the number of parameters considered for the study.

Further, it is observed that the existing methods of determination of WQI using NSF and BIS have different weightages. For example, while nitrate (NO_3) has a predefined weightage of 0.10 in NSF methodology, its value is 0.13 for our study location as per the BIS standards of methodology for calculating WQI. This shows that the weightage values for same parameters are different and depend on the indexing method used for the analysis.

The framework of the proposed new methodology is described in the following steps.

Step 1: The first step accounts for the weightage of the different parameters selected for the study. The weightage of each of these parameters was determined as the average of weightage of parameters as reported in scientific literature (25) and has been shown in Table S1 of Supplementary material. As per the calculation, the highest weightage was obtained for dissolved oxygen (DO) having a value of 2.85 while the least weightage was observed for Bicarbonates (HCO_3) having a value of 0.36. The relative weights for each of these parameters were determined using Eq. (6) and have been summarized in Table S1 of Supplementary material.

Relative weight (RW) = Assigned Weight (*AW*)/Sum of Assigned Weights (*AW*)

$$RW = AW / \sum_{i=1}^{n} AW \tag{6}$$

where,

AW assigned weights (taken from rating of experts through literature).
RW relative weights.
n number of parameters taken.

Step 2: The second step involves determination of the appraisal (quality assessment) of all the selected parameters with respect to the BIS 105000 2012, as shown in Eq. (7).

$$Q_i = (C_i / S_i) \times 100 \tag{7}$$

where,

Q_i quality assessment scale.
C_i actual concentration of the parameter considered.
S_i standard concentration of parameters as per BIS 10500 2012.

The above Eq. (7) is modified for two parameters namely pH and DO because both affect the water quality significantly. Since the optimum pH for water should be 7 and 100% saturation value for DO is 14.6 mg/l at 23 °C, the quality assessment scale for these parameters is slightly varied as shown in Eq. (8).

$$Q_i = \left(\frac{C_i - V_i}{S_i - V_i} \right) \times 100 \tag{8}$$

where V_i = ideal value of parameters (pH = 7, DO = 14.6 mg/l) Kalra et al. 2012 and other terms have same meaning as described in Eq. (7).

Step 3: This step involves the determination of a sub index factor for all the considered parameters which is determined as the product of the quality assessment factor (Q_i) with the respective relative weight of the parameters. The final WQI value is determined as the summation of the different sub-index values for the different parameters considered. These are now represented in Eqs. (9) and (10) respectively.

$$SI_i = RW \times Q_i \quad (9)$$

where SI_i = sub index function for Ith parameter, and

$$MWQI = \sum_{i=1}^{n} SI_i \quad (10)$$

The above methodology is very similar to determination of MWQI for Loktak Lake in India as reported in scientific literature (Kangabam et al. 2017). However, there exist certain different variations utilized for our study conditions. For example, in our case, we have determined the relative weight of the different parameters considering a larger number of scientific literatures (25) than as used by (Kangabam et al. 2017) which used only 13 scientific reported literature values. The consideration of more scientific literature in comparison with the earlier reported study leads to more robustness of the relative weights. Further, we used a number of extra parameters in determining the MWQI which also presents a more potent result than as reported in the earlier study (Kangabam et al. 2017) (Table 3). The final categorization of the water body based on the WQI has been summarized in Table 4 and follows the same classification system as proposed by the BIS 2012 (IS: 10500). Simple comparison of relative weight of nitrate using this modified method was 0.12, whereas it was 0.10 using NSF method and 0.13 using BIS method.

Table 3 Rating table for MWQI (Mohanty 2004; Ramakrishnaiah et al. 2009)

Range	Category
< 50	Excellent
50–100	Good
100–200	Poor
200–300	Very poor
> 300	Unfit for drinking

Table 4 Rating table for HMI (Goher et al. 2014)

Range	Category
0–25	Excellent
26–50	Good
51–75	Poor
75–100	Very poor
> 100	Unfit for drinking

Heavy Metal Index

The presence of heavy metals in water bodies severely affects the water quality and may have health impacts. Hence, heavy metals are one of the important components for determination of water quality of the source of water (Mohan et al. 1996; Prasad and Jaiprakas 1999). The heavy metals accumulate in the water body both through natural sources and anthropogenic activities. The major heavy metals considered for determination of Heavy Metal Index (HMI) are arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), chromium (Cr), lead (Pb), nickel (Ni) and iron (Fe) and the same were used to evaluate Heavy Metal Index (HMI) for our study. The atomic absorption spectrum (AAS) was used for determination of heavy metals in the water samples at different wavelengths after suitable digestion with nitric acid with the concentrations being reported in micrograms per litre.

The determination of HMI involves assigning of unit weights W_i to each of the heavy metals which is done through the following Eq. (11)

$$W_i = K/s_i \quad (11)$$

where.

W_i unit weights or weightage.
K constant of proportionality taken as 1.
S_i standard value of Ith parameter as in BIS 10500 (2012).

The second step involves the calculation of Q_i or the sub Index function generally associated with the quality rating of parameters calculated. Equation (12) describes the method for the calculation of variable Q_i

$$Qi = \sum_{i=1}^{n} \frac{M_i(-)I_i}{S_i - Ii} \times 100 \quad (12)$$

where.

Q_i sub index value.
M_i value of the parameter evaluated.
I_i permissible value taken from IS 10500 (BIS 2012).
S_i highest permissible value of the parameter from IS 10500 (BIS 2012).

(−) the sign confirms the difference is free of any algebraic sign.

The HMI is then calculated finally through Eq. (13) as follows.

$$\mathrm{HMI} = \frac{\sum_{i=1}^{n} W_\mathrm{i} Q\mathrm{i}}{\sum_{i=1}^{n} W_\mathrm{i}} \tag{13}$$

where,

Q_i sub index value of *i*th parameter.
W_i unit weight or weightage of *i*th parameter.
n number of parameters taken.

The value of 100 on scale was taken to be critical value for drinking water for Heavy Metal Index (Parsad and Bose 2001). The scale is also used for determining the effects of heavy metal contamination on the water source and also for deciding the intensity of remediation measures to be taken for suitability as drinking water presented below in Table 4 (Goher et al. 2014).

Results and discussions

The results and appropriate discussions on them have been presented below in the next few paragraphs.

Designated Best Use

The average of the parametric values for determining the DBU of the two study lakes are presented in Table 5. The DBU value is generally determined on the basis of sampling results carried out from surface locations.

The categorization of Lake 1 for appropriate DBU categorization was determined based on the average values of surface parameters obtained for the months of August 2019 and October 2019 as presented in Table 5 It is observed from Table 5 that based on initial 2-month sampling analysis the existing water quality in Lake 1 is suitable for all DBU categories from B to E with the exception of category A.

Similar to the results reported for DBU conditions of Lake 1, it is observed from Table 5 that based on 2-month sampling analysis the existing water quality in Lake 2 is suitable for all DBU categories from B to E with the exception of category A and hence can be concluded that both the lakes can be categorized as B to E for DBU conditions.

Water quality characteristics

The correlation coefficients among the monitoring parameters were determined for both the sampling months for Lake 1 and Lake 2 respectively and the correlation coefficients were found on depth wise for all the 15 selected parameters considered for the determination of WQI. The overall correlation coefficients covering both the months of sampling data have been presented in Tables 6 and 7 for Lake 1 and Tables 8 and 9 for Lake 2. The depth-wise correlation coefficients of the parameters have been presented in Tables S2–S5 of the supplementary material. Table S6 of the supplementary material presents the actual monitored concentrations of different parameters for Lake 1 for sampling carried out in August 2019.

For example, it is observed from Tables 6 and 7 for Lake 1 and Tables 8 and 9 that electrical conductivity (EC) shows high correlation with NO_3, Mg and Cl since the EC is directly related to conductance due to ions so these ions are related to conductance in the samples and a medium correlation with turbidity, BOD and total hardness. Similarly, it was observed that turbidity was highly correlated to TDS, BOD, Cl, HCO_3, TA and TH, due to presence of organic and inorganic impurities which promotes the turbidity in the water sample. Further, it was observed that pH had high correlation with DO and SO_4. This can be attributed directly that DO of water decreases with decrease in pH due to potential shift in redox reactions; whereas in a general context, a reduction of sulphate leads to increased alkalinity which in turn reduces pH. Hence, it was also observed that sulphate were highly related DO concentrations. It was also observed that NO_3 displayed high correlation with Mg and a medium correlation with Cl due to the affinity toward the ions of different charges. In other significant results, Ca ions showed high correlation with HCO_3 and total alkalinity (TA) and a medium correlation with total hardness (TH) as the ion promotes alkalinity and hardness in water. Similarly, the Mg ions were highly related to Cl, the combination of which leads to $MgCl_2$ which in turn affects hardness in water and a medium correlation was observed between Mg and TH. Also, HCO_3 was found to be highly correlated to TA and TH and SO_4 are found to be highly correlated to TA leading to alkalinity in the water. TA and TH were highly correlated to each other which suggest that an increase in the level of alkalinity promotes hardness in water. BOD was found to be highly correlated to COD, Cl and HCO_3 while COD is found to be highly correlated to Ca and HCO_3, while both BOD and COD had a high negative correlation with DO as they are inversely related in concentrations. The high correlation promotes interdependency among parameters which means that the variation in one of the parameters causes variation in the other which leads to change in the overall characteristics of water.

Table 5 Description of Designated Best Use for water (CPCB 2008, Vasistha and Ganguly 2020)

DBU	Class	Average parameter value (Lake 1)	Average parameter value (Lake 2)	Criteria for quality of water	Status
Drinking water source with chlorination but without treatment	A	1. Total coliform 0	1. Total Coliform 0.005	1. Total coliform group count (most probable number/100 ml) ≤ 50	✓
		2. pH 7.3	2. pH 7.31	2. pH between 6.5 and 8.5	✓
		3. DO 5.49	3. DO 5	3. D.O. ≥ 6 mg/l	x
		4. BOD 0.97	4. BOD 0.67	4. BOD < 2 mg/l	✓
Bathing outdoors (organized)	B	1.Total coliform 0	1. Total coliform 0.005	1. Total coliform group count (MPN/100 ml) organism shall be ≤ 500	✓
		2. pH 7.31	2. pH 7.31	2. pH between 6.5 and 8.5	✓
		3. DO 5.49	3. DO 5.03	3. Dissolved oxygen (D.O.) 5 mg/l or more	✓
		4. BOD 0.97	4. BOD 0.67	4. BOD < 3 mg/l	✓
Potable water source with treatment	C	1. Total coliform 0	1. Total coliform 0.005	1. Total coliform group count (MPN/100 ml) organism ≤ 5000	✓
		2. pH 7.31	2. pH 7.31	2. pH between 6.5 and 9	✓
		3. DO 5.49	3. DO 5.03	3. D.O. ≥ 4 mg/l	✓
		4. BOD 0.97	4. BOD0.67	4. Biological oxygen demand (B.OD.) ≤ 3 mg/l	✓
Development of wildlife & fisheries	D	1. pH 7.31	1. pH 7.31	1. pH between 6.5 and 9	✓
		2. DO 5.49	2. DO 5.03	2. D.O. ≥ 4 mg/l	✓
		3. NH_3 (as N) nil	3. NH_3 (as N) nil	3. NH_3 (in form of nitrogen) ≤ 1.2 mg	✓
Irrigation, controlled disposal & industrial cooling	E	1. pH 7.31	1. pH 7.31	1. pH between 6.0 an 8.5	✓
		2. E.C. 264.87 μmhos/cm	2. E.C. 194.95 μmhos/cm	2.Electrical conductivity < 2250 μmhos/cm	✓
		3. SAR NA	3. SAR NA	3. SAR < 26	✓
		4. Boron NIL	4. Boron NIL	4. Boron (B) < 2 mg/l	✓

Spectral characterization of water

The energy dispersive X-ray spectroscopy (EDS) technique was used for obtaining the chemical structure of water. In this context, Figs. 4 and 5 represent the spectral characterization of the water samples obtained from both the study lakes. It was observed for Lake 1 that the water sample contained elements such as carbon (C), oxygen (O), zinc (Zn), sodium (Na) and tantalum (Ta). Such similar elements were determined from water samples of Lake 2 including carbon (C), oxygen (O), sodium (Na) and tantalum (Ta). It can be further concluded from the wavelengths recorded in these graphs that high amounts of oxygen (O) and tantalum (Ta) were present in the water samples of both lakes. Other prominent elements of high concentrations of zinc (Zn) and sodium (Na) were also recorded.

Water Quality Index

National Sanitation Foundation Water Quality Index

This section discusses the results obtained using the NSFWQI for both the lakes for both the sampling durations. The results for the calculated NSFWQI for both the sampling periods for Lakes 1 and 2 have been summarized in Tables 10 and 11 respectively. It also presents the WQI values depth wise for the study. Sample calculations for determining the WQI using the NSF method and reported depth wise have been summarized in Tables S7–S8 of the supplementary material for Lake 1 for August 2019. In principle, the WQI using the NSF method was determined depth wise for all of the sampling locations and a weighted average system was utilized to determine the overall WQI at each of the sampling locations S1–S4 for Lake 1 and D1–D3 for Lake 2.

The NSFWQI for both the sampling months of August and October for both the study lakes clearly shows a variation of water quality with depth as can be observed for the different sampling locations S1–S4 (Table 10) and D1–D3 (Table 11). For example, the WQI for sampling during August month of 2019 at S1(a) showed an index value of 87.21, it was determined to be 71.73 at S1(c). Similarly, WQI for sampling during August month of 2019 at D1(a) showed an index value of 80.42 and 65.51 at D1(c). Similar trends were observed for all of the other sampling locations and for both of the sampling periods at both the lakes. In this context, it may be summarized that the water quality varies depth wise with the trend being observant for both sampling months at all of the sampling locations in both the lakes. The reason for the declining

Table 6 Correlation coefficient among various parameters for August 2019 for Lake 1

	pH	EC	DO	Turbidity	TDS	NO_3	BOD	COD	Ca	Mg	Cl	HCO_3	SO_4	TA	TH
pH	1.00														
EC	− 0.51	1.00													
DO	0.89	− 0.07	1.00												
Turbidity	− 0.98	0.68	− 0.78	1.00											
TDS	− 0.99	0.39	− 0.94	0.94	1.00										
NO_3	− 0.30	0.97	0.16	0.50	0.18	1.00									
BOD	− 0.99	0.65	− 0.80	1.00	0.96	0.46	1.00								
COD	− 0.90	0.07	− 1.00	0.78	0.94	− 0.15	0.81	1.00							
Ca	− 0.94	0.19	− 0.99	0.85	0.98	− 0.04	0.87	0.99	1.00						
Mg	− 0.48	1.00	− 0.03	0.66	0.37	0.98	0.62	0.04	0.16	1.00					
Cl	− 0.89	0.85	− 0.59	0.97	0.82	0.71	0.95	0.59	0.68	0.83	1.00				
HCO_3	− 0.97	0.28	− 0.98	0.90	0.99	0.71	0.91	0.98	1.00	0.25	0.75	1.00			
SO_4	0.95	− 0.20	0.99	−0.86	− 0.98	0.02	− 0.88	− 0.99	− 1.00	0.25	0.75	− 1.00	1.00		
TA	− 0.97	0.28	− 0.98	0.90	0.99	0.06	0.91	0.98	1.00	0.25	0.75	1.00	0.84	1.00	
TH	− 0.95	0.76	− 0.70	0.99	0.90	0.60	0.99	0.70	0.78	0.74	0.99	0.84	− 0.79	0.84	1.00

water quality with depth may be attributed to the decrease in DO concentrations and reduced sunlight conditions with depth which creates anaerobic conditions in the lake resulting in degradation of water quality.

Some other interesting results were also observed on detailed assessment of depth wise stratification. For example, WQI of some of the sampling locations experienced *spillover effect*. For example, for sampling location S1(c) and S2(b) during the August sampling period yielded a WQI value of 71.73 and 70.20 respectively which is at the threshold range (71–90) of the *good category* as per the classification of NSFWQI. A similar observation can be made for Lake 2 for sampling carried out in October 2019 at sampling location D3(a) which yielded a WQI value of 89.48 and is at the threshold range (91–100) of *excellent category* as per the classification of NSFWQI. Another important observation was the representation of the actual change in water quality with increased depth as was observed for the sampling locations S2(c) and S4(c) during the August sampling period yielded a WQI value of 57.63 and 57.91 respectively and being classified as *medium category* as per the classification of NSFWQI. Similar observations were observed for Lake 2 for sampling

Table 7 Correlation coefficient among various parameters for October 2019 for Lake 1

	pH	EC	DO	Turbidity	TDS	NO_3	BOD	COD	Ca	Mg	Cl	HCO_3	SO_4	TA	TH
pH	1.00														
EC	0.99	1.00													
DO	0.97	0.95	1.00												
Turbidity	− 0.96	− 0.94	− 0.99	1.00											
TDS	0.93	0.99	0.91	− 0.99	1.00										
NO_3	0.97	0.95	0.94	− 0.93	0.99	1.00									
BOD	0.98	0.93	0.95	− 0.94	0.99	0.99	1.00								
COD	0.97	0.92	0.92	− 0.95	0.99	0.99	0.99	1.00							
Ca	− 0.94	− 0.92	− 0.91	0.99	− 0.95	− 0.96	− 0.95	− 0.95	1.00						
Mg	0.97	0.91	0.99	− 0.92	0.99	0.99	0.99	0.99	− 0.96	1.00					
Cl	− 0.96	− 0.99	− 0.94	0.91	− 0.94	− 0.95	− 0.94	0.99	0.99	− 0.96	1.00				
HCO_3	− 0.93	− 0.93	− 0.91	0.99	− 0.95	− 0.97	− 0.95	− 0.94	0.99	− 0.94	0.99	1.00			
SO_4	0.97	0.99	0.99	−0.93	0.99	0.99	0.98	0.98	− 0.95	0.99	− 0.94	− 0.94	1.00		
TA	− 0.99	− 0.96	− 0.95	0.97	− 0.92	− 0.94	− 0.95	0.98	0.98	− 0.94	0.96	0.99	− 0.95	1.00	
TH	− 0.95	− 0.96	− 0.95	0.99	− 1	− 0.98	− 0.93	− 0.94	0.96	− 0.93	0.99	0.99	− 0.91	0.99	1.00

Table 8 Correlation coefficient among various parameters for August 2019 for Lake 2

	pH	EC	DO	Turbidity	TDS	NO_3	BOD	COD	Ca	Mg	Cl	HCO_3	SO_4	TA	TH
pH	1.00														
EC	0.71	1.00													
DO	0.49	0.96	1.00												
Turbidity	0.98	0.83	0.65	1.00											
TDS	0.30	0.88	0.98	0.48	1.00										
NO_3	− 1.00	− 0.67	− 0.44	− 0.97	− 0.25	1.00									
BOD	− 0.76	− 1.00	− 0.94	− 0.87	− 0.85	0.72	1.00								
COD	0.72	1.00	0.96	0.84	0.87	− 0.69	− 1.00	1.00							
Ca	0.34	− 0.43	− 0.66	0.15	− 0.80	− 0.39	0.36	− 0.40	1.00						
Mg	0.58	0.99	0.99	0.73	0.95	− 0.54	− 0.97	0.98	− 0.57	1.00					
Cl	0.53	− 0.22	− 0.48	0.35	− 0.65	− 0.57	0.15	− 0.20	0.98	− 0.38	1.00				
HCO_3	− 0.64	− 1.00	− 0.98	− 0.77	− 0.93	0.59	0.99	− 0.99	0.51	− 1.00	0.32	1.00			
SO_4	0.68	1.00	0.97	0.81	0.90	− 0.64	− 0.99	1.00	− 0.45	0.99	− 0.26	− 1.00	1.00		
TA	− 0.64	− 1.00	− 0.98	− 0.77	− 0.93	0.59	0.99	− 0.99	0.51	− 1.00	0.32	1.00	− 1.00	1.00	
TH	− 0.99	− 0.82	− 0.63	− 1.00	− 0.46	0.97	0.86	− 0.83	− 0.17	− 0.71	− 0.38	0.76	− 0.80	0.76	1.00

carried out in August 2019 at locations D1(c) and D3(c) with WQI value of 65.51 and 66.84 respectively and being classified as *medium category* as per the classification of NSFWQI.

Further, effects of seasonal variations were also observed in monsoon and post monsoon months of August and October respectively on the existing water quality of the study lakes. In essence, the water quality was evaluated to be *good category* for both the months for both the lakes with the average WQI value being determined to be 74.84 and 85.84 for Lake 1 and 73.15 and 85.49 for Lake 2 respectively for sampling months August and October 2019. However, it was observed that post monsoon sampling carried out in October led to considerable improvement in the existing water quality as decrease in temperature often leads to increase in DO concentrations (Said et al. 2004) in comparison with the other seasons (Reddy et al. 1982; Ghosh and George 1989; Swarnalatha and Narasingrao 1993). The other possible factors affecting the intensity of DO such as biological processes, chemical processes, solids and temperature were well within permissible range in winters (Yang et al. 2007). This was corroborated by the interrelationships between different parameters discussed in earlier section. Further, the existing water quality

Table 9 Correlation coefficient among various parameters for October 2019 for Lake 2

	pH	EC	DO	Turbidity	TDS	NO_3	BOD	COD	Ca	Mg	Cl	HCO_3	SO_4	TA	TH
pH	1.00														
EC	− 0.51	1.00													
DO	0.31	− 0.98	1.00												
Turbidity	− 0.91	0.82	− 0.68	1.00											
TDS	− 0.17	− 0.76	0.89	− 0.26	1.00										
NO_3	− 0.97	0.71	− 0.54	0.98	− 0.09	1.00									
BOD	0.94	− 0.76	0.60	− 0.99	0.16	− 1.00	1.00								
COD	0.87	− 0.01	− 0.21	−0.58	− 0.64	− 0.71	0.65	1.00							
Ca	− 0.59	− 0.39	0.58	0.20	0.89	0.37	− 0.30	− 0.92	1.00						
Mg	− 0.77	0.94	− 0.85	0.97	− 0.50	0.90	− 0.93	− 0.34	− 0.06	1.00					
Cl	− 0.19	− 0.75	0.88	− 0.24	1.00	− 0.07	0.14	− 0.65	0.90	− 0.49	1.00				
HCO_3	− 0.57	1.00	− 0.96	0.86	− 0.72	0.76	− 0.80	− 0.08	− 0.33	0.96	− 0.70	1.00			
SO_4	− 0.64	0.99	− 0.93	0.90	− 0.65	0.82	− 0.86	− 0.17	− 0.24	0.98	− 0.63	1.00	1.00		
TA	− 0.57	1.00	− 0.96	0.86	− 0.72	0.76	− 0.80	− 0.08	− 0.33	0.96	− 0.70	1.00	1.00	1.00	
TH	− 0.79	− 0.13	0.34	0.46	0.74	0.61	− 0.54	− 0.99	0.96	0.21	0.75	− 0.06	0.03	− 0.06	1.00

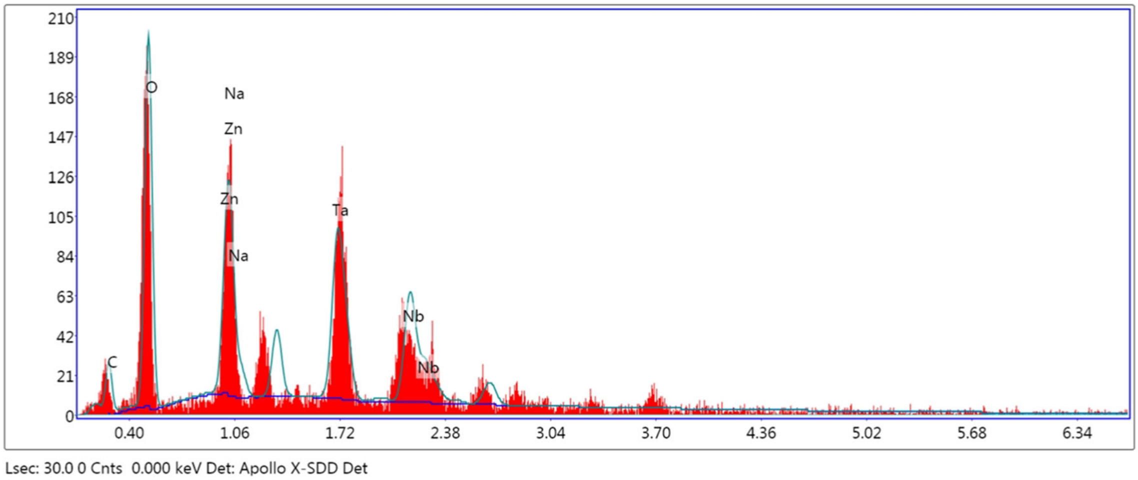

Fig. 4 EDS graph for determination of chemical structure of water of Lake 1

determined to be of good category is also corroborated by the results of the DBU analysis carried out and discussed in earlier section.

Bureau of Indian Standards Water Quality Index

This section discusses the results obtained using the BISWQI for both the lakes and sampling durations. The WQI was determined depth wise for both the study lakes to record any variation of water quality due to change in depth at each of the sampling locations S1–S4 for Lake 1 and D1–D3 for Lake 2. The results for the calculated BISWQI for both the sampling periods for Lake 1 and 2 have been summarized in Tables 12 and 13 respectively which also presents the depth-wise results. Example calculations for determining the WQI using the BIS method have been summarized in Tables S9–S11 of the supplementary material.

It is observed from the tables (Tables 12 and 13) that the overall classification for Lake 1 during August and October month was *excellent* (BISWQI = 36.79 and 46.03 respectively). Similar observations were made for Lake 2, wherein for both the monitoring campaigns, the water quality was determined to be in *excellent category* (BISWQI = 25.08 and 35.69 respectively for August and October). Considering the results obtained from Lake 1 and Lake 2 over the monitoring campaigns carried out in August and October, it may be mentioned that no significant depth-wise variation of Water Quality Index value was noticed. However, there was a decline in water quality in October even though the overall WQI value was less than 50 and was categorized as *excellent*. Some *spillover effects* were observed in Lake 1 for monitoring season of October (for example, S1(a), S1(c), S2(a)) which were close to the threshold value of (50–100) which categorizes the water quality as *good*.

Modified Water Quality Index

This section presents the results obtained using the MWQI for both the lakes and sampling durations. The MWQI for both the sampling periods and the study lakes has been

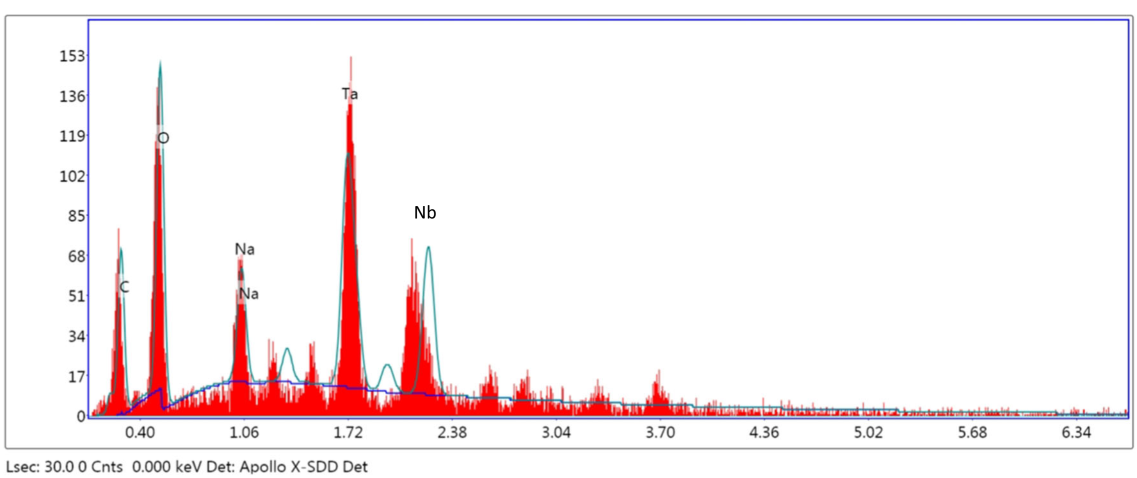

Fig. 5 EDS graph for determination of chemical structure of water of Lake 2

Table 10 Values of NSFWQI for August and October at various points in Lake 1

Points in the Lake	Calculated WQI for the month of August	Calculated WQI for the month of October	Overall WQI at sample locations using weighted average technique (August 2019)	Overall WQI at sample locations using weighted average technique (October 2019)	Category
S1(a) S1(b)	87.21 (G) 84.70 (G)	87.52 (G) 84.00 (G)	S1 = 82.71	S1 = 85.17	Good
S1(c)	71.73(**G**)	81.62 (G)			
S2(a) S2(b)	79.49 (G) 70.20 (**G**)	85.76 (G) 82.22 (G)	S2 = 71.70	S2 = 82.4	Good
S2(c)	57.63 (***M***)	79.74 (G)			
S3(a) S3(b)	78.29 (G) 73.01(G)	92.93 (G) 90.19 (G)	S3 = 75.47	S3 = 87.81	Good
S3(c)	72.28 (G)	75.22 (G)			
S4(a) S4(b)	73.52(G) 72.93(G)	90.69(***G***) 86.94 (G)	S4 = 69.47	S4 = 88.0	Good
S4(c)	57.91(***M***)	83.66(G)			
			74.84	85.84	Good

Table 12 BISWQI value for August and October 2019 at various points in Lake 1

Points in the Lake	Calculated BISWQI for the month of August	Calculated BISWQI for the month of October	Overall BISWQI at sample locations using weighted average technique (August 2019)	Overall BISWQI at sample locations using weighted average technique (October 2019)	Category
S1(a) S1(b)	37.66 (E) 36.35(E)	48.83(***E***) 45.22(E)	S1 = 36.59	S1 = 47.8	Excellent
S1(c)	34.70(E)	48.32(***E***)			
S2(a) S2(b)	36.28(E) 35.79(E)	47.58(***E***) 46.88(E)	S2 = 36.10	S2 = 47.26	Excellent
S2(c)	36.06(E)	47.00(***E***)			
S3(a) S3(b)	37.91(E) 38.03(E)	42.03(E) 40.09(E)	S3 = 37.69	S3 = 43.32	Excellent
S3(c)	36.89(E)	49.13(***E***)			
S4(a) S4(b)	36.38(E) 35.78(E)	45.51(E) 43.44(E)	S4 = 36.76	S4 = 45.73	Excellent
S4(c)	38.48(E)	48.46(***E***)			
			36.79	46.03	Excellent

summarized in Tables 14 and 15 respectively. It also presents the MWQI values depth wise for the study. Sample calculations for determining the WQI using the modified method are shown in Tables S12–S13 of the supplementary material. Similar technique was used for determining the WQI using the modified method wherein depth-wise analysis for all of the sampling locations were carried out and a weighted average system was utilized to

Table 11 NSFWQI value for August and October 2019 at various points in Lake 2

Points in the Lake	Calculated NSFWQI for the month of August	Calculated NSFWQI for the month of October	Overall NSFWQI at sample locations using weighted average technique (August 2019)	Overall NSFWQI at sample locations using weighted average technique (October 2019)	Category
D1(a) D1(b)	80.42 (G) 79.07(G)	87.44(G) 87.00(G)	D1 = 75.00	D1 = 85.01	Good
D1(c)	65.51(**M**)	80.6(G)			
D2(a) D2(b)	79.96(G) 71.17(G)	87.48(G) 87.14(G)	D2 = 73.76	D2 = 85.59	Good
D2(c)	70.17(G)	82.17(G)			
D3(a) D3(b)	74.18(G) 71.08(G)	89.48(***G***) 87.54(G)	D3 = 70.7	D3 = 85.87	Good
D3(c)	66.84(**M**)	80.61(G)			
			73.15	85.49	Good

Table 13 BISWQI value for August and October 2019 at various points in Lake 2

Points in the Lake	Calculated BISWQI for the month of August	Calculated BISWQI for the month of October	Overall BISWQI at sample locations using weighted average technique (August 2019)	Overall BISWQI at sample locations using weighted average technique (October 2019)	Category
D1(a) D1(b)	27.84(E) 27.96(E)	34.28(E) 34.89(E)	D1 = 26.54	D1 = 35.60	Excellent
D1(c)	23.84(E)	37.65(E)			
D2(a) D2(b)	22.95(E) 22.47(E)	33(E) 35.81(E)	D2 = 22.78	D2 = 34.91	Excellent
D2(c)	22.93(E)	35.93(E)			
D3(a) D3(b)	26.86(E) 26.16(E)	35.9 6 (E) 36.92(E)	D3 = 25.92	D3 = 36.56	Excellent
D3(c)	24.73(E)	36.80(E)			
			25.08	35.69	Excellent

Table 14 MWQI value for August and October 2019 at various points in Lake 1

Points in the Lake	Calculated MWQI for the month of August	Calculated MWQI for the month of October	Overall MWQI at sample locations using weighted average technique (August 2019)	Category	Overall MWQI at sample locations using weighted average technique (October 2019)	Category
S1(a)	36.58(E)	60.56(G)	S1 = 40.89	Excellent	S1 = 61.78	Good
S1(b)	38.52(E)	61.39(G)				
S1(c)	51.90(***G***)	64.62(G)				
S2(a)	51.99(***G***)	50.67(***G***)	S2 = 56.22	Good	S2 = 54.55	Good
S2(b)	59.16(G)	51.03(***G***)				
S2(c)	61.75(G)	65.84(G)				
S3(a)	46.04(E)	39.75(E)	S3 = 51.36	Good	S3 = 48.06	Excellent
S3(b)	51.00(***G***)	40.04(E)				
S3(c)	62.37(G)	72.70(G)				
S4(a)	40.28(E)	38.13(E)	S4 = 44.3	Excellent	S4 = 46.66	Excellent
S4(b)	42.46(E)	46.89(E)				
S4(c)	54.18(G)	63.5(G)				
			48.19	Excellent	52.76	Good

determine the modified WQI at each of the sampling locations, S1–S4 for Lake 1 and D1–D3 for Lake 2.

It can be inferred from the above-mentioned tables that the overall MWQI for Lake 1 and 2 for August 2019 (MWQI = 48.19 and 49.63 respectively) was classified in *excellent category* while for October 2019 (MWQI = 52.76 and 57.51 respectively) was in *good category* as per the rating table of MWQI showing seasonal variability. The reason for the degradation of water quality is probably due to the lack of input of freshwater due to end on monsoon season leading to a low or no dilution in the lake leading to increase in concentration of parameters (Fathi et al. 2018). October marks the onset of winters and the variation in the surface and the bottom most layer is significant in the month of October 2019 due to the variations in the physico-chemical parameter concentrations; whereas in the month of August 2019, the variations were modest (Toufeek and Korium 2009; Elshemy and Meon 2016). The correlation among parameters also shows interdependency leading to changes in concentrations. However, some due diligence is required in further interpreting the results. For example, a closer inspection of the values shows that MWQI values (MWQI = 48.19 and 49.63 respectively) obtained for August at both the lakes which classifies the water to be *excellent category* are perilously close to the threshold value of 50 (50–100) which classifies the water quality to be *good category* and hence again experiences the *spillover effect*. Hence, it may be stated *conservatively* that the water quality for both the seasons are in good category.

Further, it may be mentioned that the MWQI obtained for both the sampling durations and for both the lakes showed a clear deterioration in water quality with increased depth. For example, the WQI for sampling during August month of 2019 at S1(a) showed an index value of 36.58 (E), it was determined to be 51.90 (G) at S1(c) for Lake 1. Similarly,

Table 15 Weighted average MWQI values for August and October 2019 at various points in Lake 2

Points in the Lake	Calculated MWQI for the month of August	Calculated MWQI for the month of October	Overall MWQI at sample locations using weighted average technique (August 2019)	Category	Overall MWQI at sample locations using weighted average technique (October 2019)	Category
D1(a)	50.5 (***G***)	53.23(G)	D1 = 51.61	Good	D1 = 57.2	Good
D1(b)	51.87 (G)	48.89(G)				
D1(c)	52.47(G)	69.48(G)				
D2(a)	51.66(G)	55.08(G)	D2 = 53.05	Good	D2 = 57.71	Good
D2(b)	51.66(G)	56.82(G)				
D2(c)	55.83(G)	61.24(G)				
D3(a)	41.08 (E)	56.89(G)	D3 = 44.25	Excellent	D3 = 57.61	Good
D3(b)	41.65 (E)	57.28(G)				
D3(c)	50.03(***G***)	58.66(G)				
			49.64	Excellent	57.51	Good

WQI for sampling during August month of 2019 at D3(a) showed an index value of 41.08(E) and 50.03(G) at D3(c) for Lake 2. The same interpretation may be made even if the overall water quality for all the three depths is in the same category. For example, the WQI for sampling during October month of 2019 at S2(a) showed an index value of 50.67 (G) and was determined to be 65.84 (G) at S2(c) for Lake 1. Although classification of water quality at both the depths is *good*, it may be inferred that WQI has significantly deteriorated from S2(a) to S2(c) sampling locations due to increased MWQI toward the threshold level of 100 (50–100 classified as good category for MWQI). The reason for this possible deterioration of water quality with increasing depth has already been discussed before.

Similar to the NSFWQI analysis, some of the WQI determined using the modified method also experienced the *spill-over effect*. For example, for sampling locations S1(c), S2(a) and S3(b) during the August sampling period yielded MWQI values of 51.90, 51.99 and 51.00 respectively which is at the threshold range (50–100) of the *good category* as per the classification of MWQI. Similar observation was also made during the October sampling period at S2(a) and S2(b) with determined MWQI values 50.67 and 51.03 respectively for Lake 1. Similar observations were made for Lake 2 for sampling carried out in August 2019 at locations at D1(a) and D3(c) with determined MWQI values to be 50.50 and 50.03 respectively. Hence, some diligence may be used while classifying the water quality for such *spillover effect* conditions.

Critical discussion on the results obtained from using different water quality indices

The water quality indexing has been determined using three methods namely National Sanitation Foundation, BIS and the newly proposed modified water quality indexing method. Each of these methods has their own advantages and disadvantages. For example, while using NSFWQI which is based on weighted geometric average (Kachroud et al. 2019), it is able to determine easily the variation in water quality, and it does not represent the definitive use of the water. In general, the NSFWQI presents the overall water quality without any specificity. The interpretation arising out of a Water Quality Index is often complex. For example, differences in interpretation of the existing water quality are primarily due to three reasons and can be summarized as (a) use of the same WQI but with different classification levels, (b) use of different WQI but the parameters remain the same which leads to different classification and finally (c) use of different WQI using different variables varying in both number and parameters selected for the study (Kachroud et al. 2019). Studies have been reported to have disagreements over using different water quality indices (Akkoyunlu and Akiner 2012) and contradiction of results using the same WQI but different scales of assessment (Sharma et al. 2014). In the study presented by Sharma et al. (2014), the values of WQI obtained for River Ganges at different locations around Allahabad were compared using two scales as proposed by Yadav et al. (2010) and Ramakrishnaiah et al. (2009). This is particularly important in the context of the study carried out as the both the BISWQI and the MWQI utilize the scaling system proposed by Ramakrishnaiah et al. (2009). The major difference between the scaling systems is that while the classifications are more compact as proposed by Yadav et al. (2010) in comparison with Mohanty 2004 and Ramakrishnaiah et al. (2009). For example, while *excellent category* is fixed to be between 0 and 25 for the scale suggested by Yadav et al. (2010), any value less than 50 is considered *excellent* on the categorization scale proposed by Ramakrishnaiah et al. (2009). Further, the BISWQI and the MWQI categorize the water based on the scaling system proposed by Ramakrishnaiah et al. (2009).

In the above context, the values obtained MWQI technique and using the scaling factor proposed by Yadav et al. (2010), then the water quality for both the lakes for October sampling duration can be classified as *poor category* (MWQI = 52.76 and 57.51 respectively) and *good category* for August (MWQI = 48.19 and 49.64 respectively). However, considering spillover effects with the above MWQI values being perilously close to the threshold values of (51–75), the water quality may be conservatively classified to be *poor quality.*

From the above discussion, it presents that due diligence is required while interpreting the final results including not only the selection of methodology but also the scale on which the categorization is determined. Further, it may be inferred that no method is perfect or absolute and the selection of the determination of the WQI depends on the purpose, the parameters and specificity (Kachroud et al. 2019). For our study lakes considering the sampling periods of August and October 2019, the WQI calculated using the selected three methods including their scale system suggests that water quality may be classified as *good category* for both the lakes as is observed from MWQI and NSFWQI. However, as per BISWQI, the water quality classification is *excellent category*.

Heavy Metal Index

This section presents the results of HMI for both the lakes and sampling durations. The HMI for both the lakes has been presented in Tables 16 and 17 respectively. The variation of HMI depth wise has also been presented for both the lakes. Although all of the concerned heavy metals were tested, the water samples tested positive only for zinc and iron and consequently the HMI was determined on these two parameters. Example calculations for determining the HMI have been presented in Tables S14–S16 of the supplementary material.

The presence of metal iron (Fe) is high in India (Singh et al. 2013) and is a commonly found mineral on the Indian sub-

Table 16 Values of HMI at various points in Lake 1 for August2018

Points in the Lake	Calculated HMI for the month of August	Overall HMI at sample locations using weighted average technique (August 2019)	Category
S1(a)	36.25	S1 = 33.75	Good
S1(b)	29.53		
S1(c)	32.99		
S2(a)	24.98	S2 = 31.09	Good
S2(b)	37.27		
S2(c)	37.13		
S3(a)	38.45	S3 = 38.57	Good
S3(b)	39.93		
S3(c)	37.45		
S4(a)	40.72	S4 = 35.77	Good
S4(b)	23.35		
S4(c)	38.28		
		34.80	Good

continent (Kumar et al. 2012) especially in rainy season due to the water flowing from nearby shores carrying soil along with it as the earth's crust carrying an abundant amount of metals (Dang et al. 2002; Senapaty and Behera 2012). For our study locations, the presence of iron and zinc in the water can be primarily attributed to natural factors such as geological processes, precipitation and surface runoff and chemical weathering of rocks which are abundantly present around the lake (Manoj et al. 2012). Further, since the lake is surrounded by rocky terrain, it additionally may lead to influx of heavy metals in the lake water. Finally, some anthropogenic sources may also lead to some accumulate concentrations of heavy metals in the lake waters.

It can be inferred from the above-mentioned tables that the overall HMI for Lakes 1 and 2 for August 2019 was 34.80 and 37.82 respectively and were classified in *good category* as per the rating table of HMI. However, it is important to note that only two heavy metal concentrations lead to relatively HMI values which suggests that with increased anthropogenic activities surrounding the lake may lead to increase in HMI value which may affect the classification; however, presently, the heavy metal concentrations are of no immediate concern. Further, unlike the depth-wise variations of WQI observed earlier, no significant depth-wise variations of HMI values were observed for both the lakes. It is possible that depth-wise stratification may not be significant in the case of heavy metal ions since they have a different chemistry in comparison with other physical and chemical parameters.

Conclusions

The following conclusions can be drawn from the present study carried out at the two study lakes:

1. *The Designated Best Use (DBU) for both the lakes* ***satisfies B to E criteria*** *as prescribed by CPCB and hence the water quality can be categorized to be fit for all the intended uses like irrigation, recreational activities, fisheries and wildlife propagation. The water may be used*

Table 17 HMI value for August 2019 at various points in Lake 2

Points in the Lake	Calculated HMI for the month of August	Overall HMI at sample locations using weighted average technique (August 2019)	Category
D1(a)	37.01	D1 = 36.27	Good
D1(b)	36.33		
D1(c)	35.48		
D2(a)	39.03	D2 = 39.06	Good
D2(b)	39.34		
D2(c)	38.83		
D3(a)	37.76	D3 = 38.14	Good
D3(b)	38.86		
D3(c)	37.80		
		37.82	Good

for drinking with treatment but may not be consumed without treatment.

2. There exists *high correlation coefficient* within the parameters monitored for both the lakes and for both the sampling months.
3. *The overall classification of water quality for both the lakes for both the sampling periods using the* ***NSFWQI*** *was determined to be* **good category.** Further, the overall water quality improved when monitored for October month in comparison with sampling carried out during August.
4. *The overall classification of water quality for both the lakes for both the sampling periods was to be of* ***excellent category*** *using the* ***BISWQI****.*
5. *The overall classification of water quality for both the lakes for* ***August sampling period*** *was classified to be of* ***excellent category*** *using the* ***MWQI*** *and was determined to be* **good category** *for the* **October sampling period***. However, if spillover conditions are considered, then* ***conservatively*** *the water quality for both the lakes for* ***August sampling period*** *would be classified as* ***good category****.*
6. *The WQI values obtained using all the three methods showed depth-wise variations in water quality with significant changes being most recorded in WQI obtained using NSFWQI and MWQI. Further, many of the WQI values using the methods showed a tendency of spillover effect.*
7. *Due diligence may be considered when categorizing water quality at those depths which experience spillover effect as they can affect the final outcome of the existing water quality at the different depths.*
8. *The classification of the water quality based on the determined indices is highly dependent on the category scaling system adopted for the study. It was observed that with using the same WQI but different category scaling system the results for water quality were interpreted differently* ***so selection of pertinent scaling system is very important.***
9. *The spectral characterization of the water quality of both lakes showed the presence of oxygen and tantalum along with the presence of carbon, sodium and zinc.*
10. *The* ***HMI*** *for both the lakes was classified as good category as per the rating system of HMI. However, the parameter HMI was determined on basis of only two heavy metals (Fe and Zn) and which also contributed to high values in the good category and which suggests that increased anthropogenic activities may lead to increased accumulation of heavy metals.*

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