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ORIGINAL ARTICLE

Development of a water quality index (WQI) for the Loktak Lake in India

Rajiv Das Kangabam[1,2] · Sarojini Devi Bhoominathan[1] · Suganthi Kanagaraj[1] · Munisamy Govindaraju[1]

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Abstract The present work was carried out to assess a water quality index (WQI) of the Loktak Lake, an important wetland which has been under pressure due to the increasing anthropogenic activities. Physicochemical parameters like temperature (Tem), potential hydrogen (pH), electrical conductivity (EC), turbidity (T), dissolved oxygen (DO), total hardness (TH), calcium (Ca), chloride (Cl), fluoride (F), sulphate (SO_4^{2-}), magnesium (Mg), phosphate (PO_4^{3-}), sodium (Na), potassium (K), nitrite (NO_2), nitrate (NO_3), total dissolved solids (TDS), total carbon (TC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were analyzed using standard procedures. The values obtained were compared with the guidelines for drinking purpose suggested by the World Health Organization and Bureau of Indian Standard. The result shows the higher concentration of nitrite in all the location which is beyond the permissible limit. Eleven parameters were selected to derive the WQI for the estimation of water potential for five sampling sites. A relative weight was assigned to each parameter range from 1.46 to 4.09 based on its importance. The WQI values range from 64 to 77 indicating that the Loktak Lake water is not fit for drinking, including both human and animals, even though the people living inside the Lake are using it for drinking purposes. The implementation of WQI is necessary for proper management of the Loktak Lake and it will be a very helpful tool for the public and decision makers to evaluate the water quality of the Loktak Lake for sustainable management.

Keywords Physicochemical parameters · Water quality index · Pearson's correlation matrix · Floating island · Loktak Lake

✉ Rajiv Das Kangabam
rajiv.kangabam@gmail.com

[1] Department of Environmental Biotechnology, School of Environmental Sciences, Bharathidasan University, Tiruchirappalli, Tamil Nadu 620024, India

[2] Present Address: Department of Agricultural Biotechnology, Assam Agricultural University, Jorhat, Assam 785013, India

Introduction

Water quality is an important contributor touching on all aspects of ecosystems and human well-being and a significant tool in determining the human poverty, wealth, and education levels (UN Water 2010). The ecosystem services of water from rivers and lakes are directly or indirectly contribute to both human welfare and aquatic ecosystem (Costanza et al. 1997; Kar 2007, 2013). The increase in pollution of water sources like lakes and rivers is a major concern for the global scenario as most of the water bodies around the world are the source for water supply including human consumption and domestic purposes (Kazi et al. 2009; Dey and Kar 1987). The health of the aquatic ecosystem is determined by the water quality parameter which includes the physical, chemical, and biological characteristics (Kar 1990; Sargaonkar and Deshpande 2003; Venkatesharaju et al. 2010). Therefore, a particular problem with water quality monitoring is a complex issue associated with analyzing a large number of associate measures of variables (Boyacioglu 2007) and the high variability among the variables is due to increase in anthropogenic activities including natural influences (Simeonov et al. 2002). The anthropogenic discharges constitute a constant polluting source, thereby reducing the water quality. Human activities are the major factor determining the quality of water (Niemi et al. 1990; Kar 2010). Environmental pollution of water resources has become a major global issue, including developing countries which have been suffering from the impact of pollution due to poor socio economic growth associated with the exploitation of natural resources. As a result of it, water is considered as the highest risk to the world for future due to increase in demand as well as increase in pollution (Kar 2013; Global Risks 2015).

Many methods have been proposed and adopted for analysis of water quality. One of the most effective approaches for studying water quality is using of suitable indices (APHA 2005; Dwivedi and Pathak 2007). Indices are measure of changes in a representative group of individual data points of various physicochemical and biological parameters in a given sample. The advantage of indices is that it has the potential to inform the general public and decision makers about the status of the ecosystem (Nasirian 2007; Simoes et al. 2008). The benefit of this approach is the provision to evaluate the success and failure of any management plan for improving the water quality (Rickwood and Carr 2009).

A number of studies have reported the importance of water quality indices (WQI) which serve as an indicator for assessment of water quality as proposed for the first time by Horton (1965). Later, numerous researchers have carried out studies on water quality assessment using WQIs around the world in various water bodies (Pesce and Wunderlin 2000; Bordalo et al. 2001; Abdul et al. 2010; Akbal et al. 2011; Altansukh and Davaa 2011; Hector et al. 2012; Abdulwahid 2013; Mohamed et al. 2014; Chrysoula et al. 2014; Mehmet and Huseyin 2014; Will et al. 2015; Gerald et al. 2015; Hefni and Romanto 2015; Lobato et al. 2015; Mehrnoosh et al. 2015). Similarly, a number of studies have been carried out in India (Dwivedi and Pathak 2007; Joshi et al. 2009; Samantray et al. 2009; Chauhan and Singh 2010; Alam and Pathak 2010; Parmar and Parma 2010; Chaturvedi and Bassin 2010; Kalavathy et al. 2011; Kankal et al. 2012; Srinivas et al. 2013; Prerna et al. 2014; Salim and Ashok 2014; Jindal et al. 2014; Mrunmayee et al. 2015; Krishna et al. 2014, 2015; Kosha and Geeta 2015). However, there was no literature which reveals scientific study carried out with respect to WQI in North–East India, a mega biodiversity region. Nevertheless, a substantive amount of works has been done on the water quality parameters of lentic bodies of North–East (NE) India (Dey and Kar 1989a, b, 2012; Puinyabati et al. 2013; Kar et al. 2013; Kar 2014; Dutta and Kar 2014; Puinyabati et al. 2014; Das et al. 2015a, b; Das and Kar 2015; Singh et al. 2015; Das et al. 2015a, b) The rationale of the present study was to identify the water quality status of the Loktak Lake using the physicochemical parameters as the people living inside the lake used it for drinking. This study will also help in assessment and periodic monitoring of water quality for proper management strategies to minimize the water pollution level (Shuchun et al. 2010) in spite of increasing anthropogenic activity and urbanization within the sensitive area.

Methodology

Study area

Loktak Lake is a unique natural ecosystem with numerous national and international significances designated under the Ramsar Convention (Fig. 1). It is the largest fresh water lake in North–East India covering an area of 246.72 km^2 (National Wetland Atlas 2009) and located between 93°46′E–93°55°E and 24°25′N–24°42′N. About 12 towns and 52 settlements are located in and around the Loktak Lake with a population of 2,20,017 persons, i.e., 9% of the total population of the state of Manipur (Census Report 2011). The lake is famous for its floating island locally knows as *Phumdis* (floating heterogeneous masses of vegetation, soil, and organic matters in various stages of decomposition and has been thickened into a solid form). Loktak is one of the 48 wetland sites in the world under the Montreux Record, a record of Ramsar sites where changes in ecological character have occurred is occurring or is likely to occur (Ramsar). The Lake is an oval shape and depth varies from 0.5 to 4.6 m with an average depth of 2.7 m. The lake is divided into three zones: the northern zones, the central zone, and southern zone. The main open water area is the central zone, which was relatively free from floating island, and the southern part is Keibul Lamjao National Park (KLNP), the world's only floating national park, and last natural habitat of Manipur brow antlered deer *Rucervus eldii eldii* (Gray et al. 2015) locally known by *Sangai* has its habitat. The lake has a rich biodiversity, including 233 macrophytes, 425 species of animals, including 249 vertebrates and 176 invertebrates (Trishal and Manihar 2004).

Sample collection and analysis

In this study, all sampling sites were selected to cover a wide range of variables and key sites which represent the water quality of the lake. Water samples from five sites located in the open water area of central and southern areas were collected at a depth of 0.5 m seasonally (monsoon, post-monsoon, winter, and pre-monsoon) during July 2013–May 2014 from Loktak Lake. The sample collection sites are shown in Table 1. Water samples in triplicates were collected at each site by random sampling. The water samples were preserved in prerinsed 2-l polyethylene

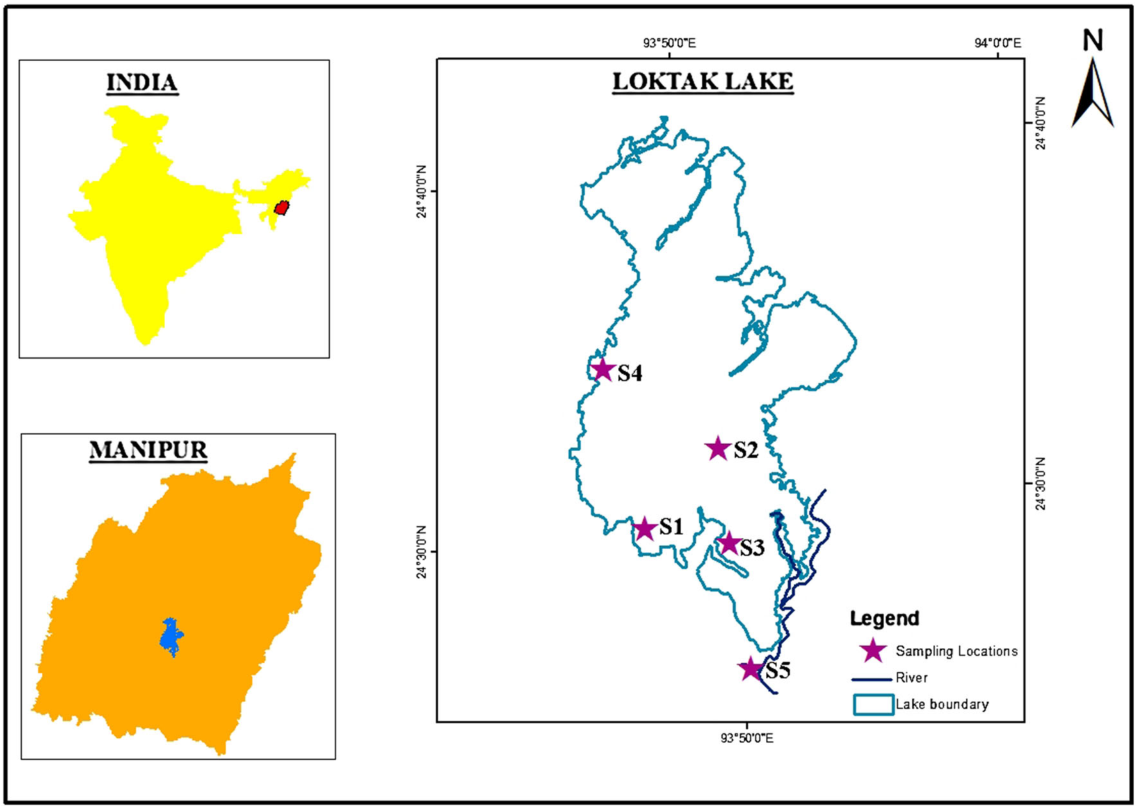

Fig. 1 Location map of the study area

Table 1 GPS reading for sampling sites

Sample site	Latitude	Longitude	Altitude (m)	Description of site
Sendra site 1	24°50′74″N	93°78′47″E	771	Major tourist spot of Loktak Lake
Thanga site 2	24°53′86″N	93°83′40″E	768	Area between Thanga Karang (island) and Thanga
KLNP site 3	24°47′71″N	93°81′38″E	759	Keibul Lamjao National Park
Ningthoukhong site 4	24°34′34″N	93°46′43″E	768	Aquaculture and water runoff for hydroelectric project
Ithai site 5	24°25′42″N	93°50′19″E	761	Runoff from Loktak Lake

terephthalate (PET) bottles at 4 °C in darkness. Each container was clearly marked with the name and date of sampling. All analysis was done following the standard method of APHA (2005) and guide manual: water and wastewater analysis (CPCB). Various physicochemical parameters such as pH, EC, T, TH, and TDS were measured in situ using water analyzer kit. The methodologies adopted for determination of water quality parameters of the collected samples (Table 2).

Water quality index (WQI)

The WQI was prepared using the measured values of the physicochemical parameters. Eleven parameters were selected based on their importance in water quality. They were pH, DO, T, EC, TH, Na, BOD, NO_2, NO_3, TDS, and COD. The values used for each parameter are the mean value of the sites under investigation. The standard for drinking water used in this study was the recommended by the Guidelines for drinking water World Health Organization (2011) and BIS (Indian Standard Specification for Drinking Water 2012).

The following steps were involved in the calculation of the WQI:

1. Initially, each of the 11 parameters has been assigned a weight (AW) ranging from 1.46 to 4.09 depending on the collective expert opinions taken from the previous studies (Table 3). The mean weight values of the selelcted parameter along with the reference are listed (Table 4). A relative weight of 4.09 was considered the most significant and 1.46 was less significant.

Table 2 Water quality parameters and their associated units and analytical method used

Variables	Unit	Analytical methods
Temperature	°C	Digital thermometer
pH	pH unit	pH meter
Electrical conductivity	µs/m	Electrometric
Turbidity	NTU	Nepheloturbidity method
Total dissolved solids	mg/l	Electrometric
Dissolved oxygen	mg/l	Winkler method
Total hardness	mg/l	Titrimetric
Calcium	mg/l	Titrimetric
Magnesium	mg/l	Titrimetric
Potassium	mg/l	Flame photometer
Sodium	mg/l	Flame photometer
Chloride	mg/l	Titrimetric
Sulphate	mg/l	Spectrophotometric
Fluoride	mg/l	Spectrophotometric
Phosphate	mg/l	Spectrophotometric
Nitrite	mg/l	Spectrophotometric
Nitrate	mg/l	Spectrophotometric
TOC	mg/l	Wet oxidation method
Chemical oxygen demand	mg/l	Winkler's azide method
Biological oxygen demand	mg/l	Dichromate method

The relative weight (RW) was calculated using the following equation:

$$\mathrm{RW} = \frac{\mathrm{AWI}}{\sum_{i=1}^{n} \mathrm{AW1}}, \tag{1}$$

where RW = relative weight, AW = assigned weight of each parameter, and n = number of parameters.

2. A quality rating scale (Q_i) for each parameter is computed by dividing its concentration in each water sample by its respective standard according to the guidelines of World Health Organization guidelines. If WHO standard is not available, then the Indian Standard BIS (2012) is used and the result is multiplied by 100 using Eq. 2.

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100, \tag{2}$$

while the quality rating for pH and DO was calculated on the basis of

$$Q_{i\mathrm{pH,DO}} = \left[\frac{C_i - V_i}{S_i - V_i}\right] \times 100, \tag{3}$$

where, Q_i = the quality rating, a C_i = value of the water quality parameters obtained from the analysis, S_i = value of the water quality parameter obtained from WHO and BIS parameters, V_i = ideal value for pH = 7.0, and DO = 14.6.

3. Next, the sub-indices (SI) have been calculated to compute the WQI:

$$\mathrm{SI}_i = W_\mathrm{r} \times Q_i \tag{4}$$

$$\mathrm{WQI} = \sum \mathrm{SI}_i. \tag{5}$$

The computed WQI values were classified according to the proposed categorization of Yadav et al. (2010); Ramakrishnaiah et al. (2009), and Mohanty (2004). The Pearson's correlation coefficient was computed to study the possible cause of pollution in the Loktak Lake and was computed with WQI and water quality parameters (Hameed et al. 2010).

Results and discussion

The analysis of result of physical and chemical parameters of lake water provides a considerable insight of water quality of the Loktak Lake. This study identifies the parameters which are responsible for decreasing the water quality. The obtained physicochemical parameters' average values were compared with the World Health Organization standards and Bureau of Indian Standard for each sampling site in Loktak Lake (Table 5; Figs. 2, 3, 4). The highest temperature values were recorded during pre-monsoon with 28.2 °C in Sendra and a minimum of 16.4 °C recorded in the Keibul Lamjao National Park during winter. There is a seasonal variation of the temperature recorded with minimum temperature in Keibul Lamjao is all the seasons.

The pH of the Loktak Lake ranges from 6.15 to 7.66, indicating that water of Loktak is almost neutral to sub-alkaline. The highest values were observed in Sendra 7.66 in pre-monsoon and minimum 6.15 in Keibul Lamjao in winter. The low pH indicates acidity nature, which is due to the deposition of acid forming substance and Phumdis acts as a sink for nutrients and plays an important role in phytosanitation. The high organic content will tend to decrease the pH due to its carbonate chemistry. The pH from the study shows that the values are within the guidelines of the WHO and BIS. The result obtained is similar to the previous data reported from KLNP by Sharma et al. (2013). The DO values were found in the range of 3.19–9.18 mg/l. The lowest DO was observed in Thanga during the monsoon and the highest was recorded in Ithai during winter. The low DO suggest the poor quality of water indicating the slow rate of photosynthesis by phytoplankton present in the Loktak Lake. This made the water unsuitable for drinking purpose. The concentration of

Table 3 Relative weight of the physiochemical parameters

Parameters	Reference: Dwivedi and Pathak (2007)	Pesce and Wunderlin (2000)	Pathak and Banerjee (1992)	Boyacioglu (2007)	Kannel et al. (2007)	Abrahao et al. (2007)	Chougule et al. (2009)	Karakaya and Evrendilek (2009)	Prema et al. (2014)	Ramakrishnaiah et al. (2009)	Hector et al. (2012)	Pesce and Wunderlin (2000)	Ravikumar et al. (2013)	Mean values
pH	1	4	4	4	1	1	1	4	1	4	4	1	3	2.54
DO	4	5	4	4	4	4	4	4	4	–	4	4	–	4.09
Turbidity	2	–	2	2	–	–	4	–	2	–	3	2	–	2.43
EC	4	5	2	–	–	1	4	4	2	–	4	–	3	3.22
Hardness	1	–	1	1	–	1	1	2	1	2	–	1	3	1.46
Sodium	–	1	–	–	–	–	1	–	–		–	–	3	1.67
BOD	3	–	3	3	2	3	3	4	3	–	–	3	–	3.00
Nitrate	2	–	–	–	3	2	2	–	2	–	–	2	5	2.57
Nitrite	2	–	–	–	–	2	2	–	2	–	–	2	–	2.00
TDS	–	4	2	2	–	2	–	–	–	4	1	2	5	2.75
COD	–	–	–	–	–	3	2	–	–	–	–	3	–	2.00

Table 4 Relative weight of the each parameter

Parameters	Water quality standard	Assigned weight (AW)	Relative weight (RW)
pH (pH unit)	6.5–8.5(8)	2.54	.091174
DO (mg/l)	5	4.09	.145878
Turbidity (NTU)	5	2.43	.087527
EC (μS/cm)	250	3.22	.116703
Hardness (mg/l)	100	1.46	.051057
Sodium (mg/l)	200	1.67	.058351
BOD (mg/l)	5	3.00	.072939
Nitrate (mg/l)	50	2.57	.109409
Nitrite (mg/l)	3	2.00	.093727
TDS (mg/l)	1000	2.75	.100291
COD (mg/l)	10	2.00	.072939

DO was recorded highest in all the location during winter as cold water can hold more dissolved oxygen than pre-monsoon. The DO values also depend on many factors like temperature, microbial population, pressure, and time of sampling.

Turbidity was found to vary between season and location of the sampling sites. Turbidity ranges from 0.23 to 2.84 NTU. The lowest were recorded in Ningthoukhong during winter and highest in Ithai during monsoon suggesting greater addition of particulate matters from the major rivers like Nambul and Nambol River to the Lake. The variation in the turbidity values in Ithai is due to the variation in the turbidity level in Loktak Lake. High deposition of sediments brought down by the rivers makes the lake turbid and deterioration of water quality. The presence of BOD in the water sample is from polluted rivers, including Nambul and Nambol River, and also from the domestic waste from the local areas of human settlement in and around the lake. The COD values range from 8 mg/l during monsoon in KLNP to 280 mg/l in Ningthoukhong during winter. The free carbon dioxide was present throughout the year in the Loktak Lake.

The EC values of the study site range from 136 to 298 μs/m. The lowest values were observed in Sendra during post-monsoon and highest in Thanga during monsoon. The higher value of EC is attributed to the high degree of anthropogenic activities like waste disposal, household waste, and chemicals runoff from agricultural and apiculture activities. The seasonal variation shows the increased in EC along the downstream. All the sites recorded higher EC as compare to the guidelines limit of WHO and BIS. The high concentration of EC implies the high level of pollution of the Loktak Lake. TDS values of the study area range from 46.52 to 168.9 mg/l. The high value of TDS was observed in Ithai during monsoon and lowest values KLNP during monsoon. The TDS

Table 5 Measured average values of each parameter

Parameters	WHO	BIS	Site 1	Site 2	Site 3	Site 4	Site 5
Temp ± SD	25–30	25.30	22.87 ± 3.5	23.02 ± 2.57	19.55 ± 4.27	23.65 ± 3.89	23.02 ± 2.95
pH ± SD	7.0–8.5	6.5–8.5	7.34 ± .21	6.90 ± .33	6.43 ± .38	7.06 ± .34	6.99 ± .13
EC ± SD	180–1000	–	161.25 ± 33.18	224.50 ± 60.52	176 ± 16.99	171.00 ± 33.91	263.50 ± 93.23
Turb ± SD	–	5	.05 ± .31	.52 ± .45	.36 ± .14	.51 ± .18	1.89 ± 1.13
TDS ± SD	1000	500	88.23 ± 21.63	105.30 ± 27.18	69.78 ± 20.67	72.27 ± 21.03	179.08 ± 50.42
DO ± SD	–	5	6.13 ± 3.65	4.01 ± 1.52	4.26 ± 1.32	4.11 ± .76	4.76 ± 1.28
TH ± SD	–	300	73.75 ± 30.92	80 ± 33.66	16.50 ± 9.03	30 ± 8.16	157.50 ± 68.49
BOD ± SD	6	–	1.84 ± .95	2.61 ± 1.15	2.26 ± 1.37	2.19 ± .80	1.74 ± .72
COD ± SD	10	–	32.5 ± 6.56	31.19 ± 9.29	21.62 ± 6.22	40.5 ± 6.83	29.25 ± 7.27
TOC ± SD	–	–	183.37 ± 79.41	53.20 ± 19.35	129.15 ± 34.90	72.21 ± 22.95	176.58 ± 32.97
Ca ± SD	75	75	24.50 ± 9.57	37.00 ± 12.70	19 ± 9.96	37 ± 3.83	70 ± 28
Mg ± SD	30	30	6.25 ± 3.45	17.41 ± 9.17	6.61 ± 4.31	6.84 ± 3.90	4.92 ± 1.41
K ± SD	12	–	3.82 ± 1.14	4.75 ± 2.06	4.80 ± 2.67	4.47 ± 1.83	12.07 ± 3.60
Na ± SD	–	–	6.30 ± 2.17	8.95 ± 2.54	8.77 ± 4.59	9.05 ± 4.90	11.50 ± 3.29
Cl^- ± SD	–	250	4.37 ± 1.10	28.12 ± 6.88	35.00 ± 7.07	22 ± 10.29	27.50 ± 10.40
S^- ± SD	250	200	.10 ± .10	.07 ± .01	.06 ± .02	.05 ± .00	.62 ± .31
F^- ± SD	1	1.5	.20 ± .015	.21 ± .03	.21 ± .03	.20 ± .02	.22 ± .02
PO_4^{3-} ± SD	≤.2	–	.003 ± .00	.004 ± .00	.005 ± .00	.01 ± .00	.06 ± .03
NO_2 ± SD	≤.1	–	1.43 ± 1.19	1.78 ± .43	1.03 ± .82	1.58 ± .56	1.53 ± .43
NO_3 ± SD	50	45	14.23 ± 4.06	7.02 ± 3.17	26.50 ± 2.99	5.67 ± 1.92	30 ± 9.93

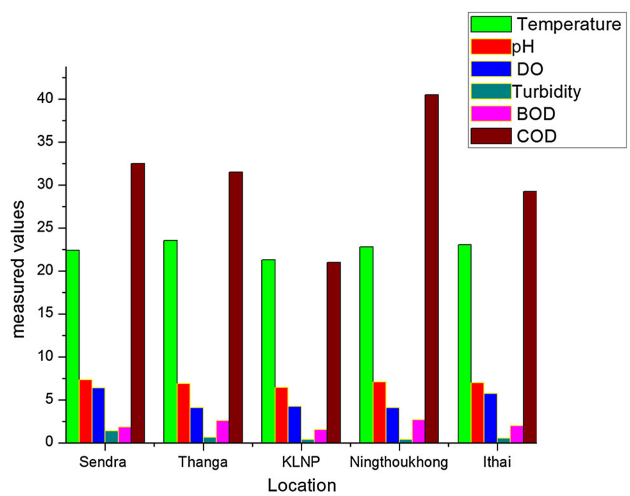

Fig. 2 Trend of temperature, pH and DO, turbidity, and BOD and COD in designated sites

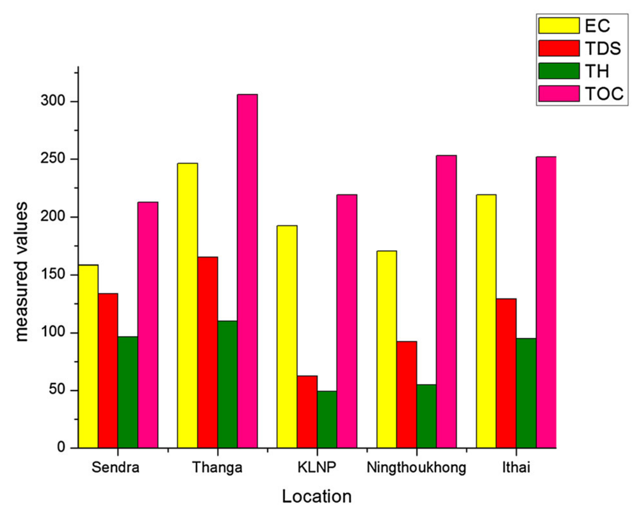

Fig. 3 Trend of EC, total hardness and TDS in designated sites

proportionality enhanced the electrical conductivity in the water. The TDS of Loktak Lake originates from natural sources, sewage, urban, and agricultural runoff. The high TDS of Ithai was similar to the early reported study (Annual report 2011–2012). However, the TDS of Loktak is lower than the Yamuna and Ganga River (Prerna et al. 2014). Total hardness values range from 38 to 130 mg/l with KLNP recorded minimum in monsoon and maximum at Ithai and Thanga at monsoon. The total hardness value of Loktak Lake ranges from 38 mg/l in KLNP in pre-monsoon to 130 mg/l in Ithai during monsoon. On all the location, total hardness values are within the permissible limit of 300 mg/l (BIS 2012). BOD in the Loktak ranges from .99 to 4.19 mg/l. The lowest value was recorded in Sendra during post-monsoon and maximum during pre-monsoon in KLNP. The total organic carbon shows high variation among the study site with the highest reported in Sendra with 258.56 mg/l during monsoon and a minimum

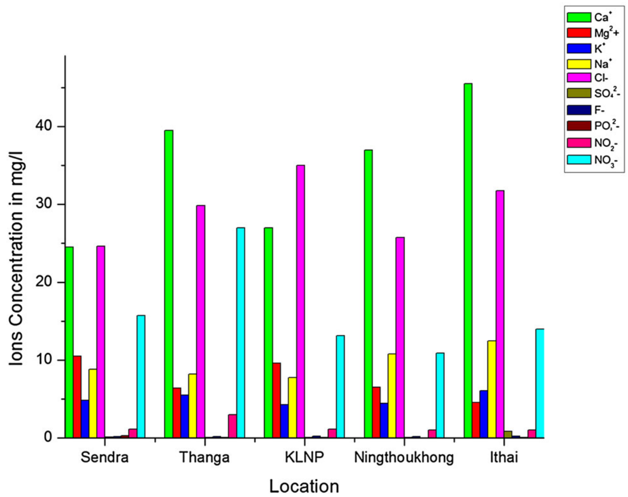

Fig. 4 Concentration of ion at designated sites

of 28.96 mg/l in Thanga during post-monsoon. This variation in the TOC is due to the seasonal changes in stream flow, soil wetness, and temperature (Kohler et al. 2008).

Determination of major ions

The major ions like Na^+, K^+, Ca^+, Mg_2^+, P^+, Cl^-, F^-, SO_4^{2-}, PO_4^{3-}, NO_2^-, and NO_3^- were measured, and the values are given in Table 5; Fig. 4. It was observed that the concentration of Na^+, Ca^+, and Mg_2^+ remained dominant in the water during the post-monsoon. Maximum concentration of Na^+ was at Ithai 14.5 mg/l during winter and minimum of 3.9 mg/l in Thanga during monsoon. K^+ values range from 3.2 mg/l in Ningthoukhong during post-monsoon to 9.2 mg/l in Ithai during monsoon. Similarly, concentration of Ca^+ ranges from 20 to 58 mg/l. The minimum concentration was observed in Sendra in Monsoon. The concentration of Ca^+ showed an increasing trend towards the downstream due to agriculture runoff, precipitation, and weathering of soil. Concentration of Mg_2^+ was recorded highest at Sendra 14.84 mg/l during post-monsoon and lowest at Ithai 3.24 mg/l during monsoon. The high rate of Mg_2^+ in Sendra is due to the presence of magnesium containing rocks and minerals in the surrounding hills. P^+ is found highest at Ithai 9.2 mg/l during the monsoon and the minimum at Ningthoukhong 3.2 mg/l during post-monsoon. The high concentration of P^+ is due to the weathering of rocks which released P^+. The concentration of the measured cations was found to be within the permissible limits.

The elemental anions Cl^-, F^-, SO_4^{2-}, PO_4^{3-}, NO_2^-, and NO_3^- were measured. The concentration of Cl^- shows the highest in KLNP 40 mg/l during post-monsoon and lowest at Ningthoukhong 14 mg/l during monsoon. Chloride concentration was found maximum during rainy season.

Table 7 Water quality Scale

Water Quality	WQI Yadav et al. (2010)	WQI Ramakrishnaiah et al. (2009)	WQI Mohanty (2004)
Excellent	0–25	<50	<50
Good	26–50	50–100	50–100
Poor	51–75	100–200	100–200
Very Poor	76–100	200–300	200–300
Unsuitable	Above 100	>300	>300

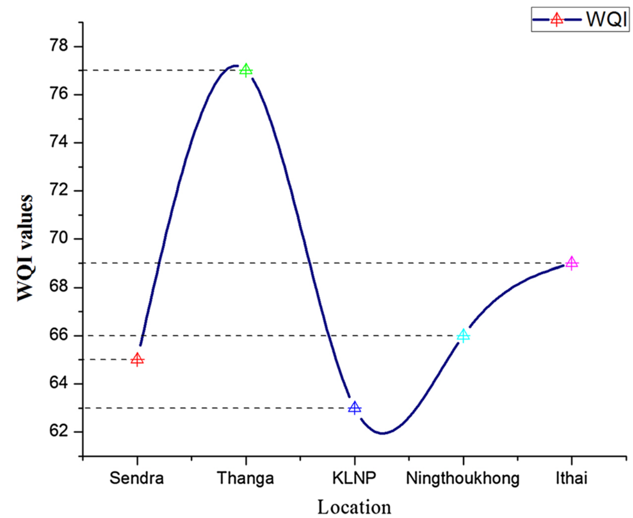

Fig. 5 Water quality index graph for designated sites

Table 6 Water quality indices and water quality at five sampling locations

Locations	WQI values	Water quality based on scale suggested by		
		Yadav et al. (2010)	Ramakrishnaiah et al. (2009)	Mohanty (2004)
Sendra	66	Poor	Good	Good
Thanga	77	Very poor	Good	Good
Keibul Lamjao National Park	64	Poor	Good	Good
Ningthoukhong	67	Poor	Good	Good
Ithai	69	Poor	Good	Good

Table 8 Correlation matrix of physiochemical parameters and WQI

	Temp	pH	EC	Turb	TDS	DO	TH	Ca	Mg	K	Na	Cl	S	F	Po	NO_2	NO_3	TC	BOD	COD	WQI
Temp	1																				
pH	.829	1																			
EC	.242	−.078	1																		
Turb	.312	.190	.828	1																	
TDS	.335	.189	.916[a]	.964[b]	1																
DO	.141	.657	−.271	.111	.091	1															
TH	.457	.384	.844	.908[a]	.971[b]	.264	1														
Ca	.509	.224	.876	.941[a]	.926[a]	−.115	.868	1													
Mg	.168	−.106	.194	−.351	−.115	−.437	−.057	−.139	1												
K	.156	−.015	.861	.979[b]	.940[a]	−.040	.840	.919[a]	−.333	1											
Na	.080	−.339	.831	.750	.713	−.565	.538	.826	−.081	.844	1										
Cl	−.506	−.891[a]	.435	.111	.126	−.852	−.090	.179	.214	.306	.688	1									
S	.224	.139	.810	.995[b]	.955[a]	.143	.893[a]	.905[a]	−.394	.982[b]	.733	.127	1								
F	−.036	−.270	.889[a]	.890[a]	.874	−.237	.733	.840	−.212	.963[b]	.909[a]	.539	.903[a]	1							
Po	.259	.089	.788	.980[b]	.904[a]	−.011	.809	.937[a]	−.429	.982[b]	.827	.218	.974[b]	.910[a]	1						
NO_2	.883[a]	.575	.416	.207	.337	−.140	.441	.465	.590	.102	.160	−.221	.118	.012	.132	1					
NO_3	−.559	−.419	.408	.592	.521	.157	.397	.333	−.568	.678	.460	.359	.667	.725	.608	−.625	1				
TC	−.161	.266	.066	.497	.412	.797	.453	.193	−.728	.433	−.068	−.407	.558	.301	.434	−.447	.707	1			
BOD	−.925[a]	−.740	−.328	−.537	−.475	−.113	−.532	−.689	.153	−.406	−.314	.387	−.460	−.203	−.534	−.703	.294	−.012	1		
COD	−.169	−.472	−.109	−.634	−.485	−.706	−.515	−.420	.842	−.540	−.094	.472	−.661	−.343	−.614	.226	−.544	−.896[a]	.409	1	
WQI	.469	.103	.598	.142	.361	−.384	.409	.365	.866	.128	.278	.195	.082	.180	.052	.824	−.400	−.548	−.242	.538	1

[a] Correlation is significant at the 0.05 level (two-tailed)

[b] Correlation is significant at the 0.01 level (two-tailed)

This finding is similar to the previous report by Rai and Raleng (2012). F-concentration recorded a range of .18–26 mg/l. The concentration of F^{-} is low in all the locations in all the seasons. Concentration of SO_4^{2-} ranges from 0.016 mg/l in Sendra during monsoon and highest of 1.17 mg/l in Ithai during pre-monsoon. PO_4^{3-} concentration shows the least among all the anions. The values range from .002 to .08 mg/l. The lowest was recorded in Ningthoukhong in pre-monsoon and highest in Ithai during Monsoon. The concentration of NO_2^{-} is higher than the permissible limit of $\leq$.1 according to WHO. All the locations recorded beyond the permissible limit in all the four seasons with maximum value of 4.12 mg/l in Thanga during winter and lowest of .11 mg/l in Sendra during monsoon. NO_3^{-} value shows a seasonal variation with the highest value of 35 mg/l recorded from Thanga during winter and minimum value of 6.3 mg/l in Ningthoukhong during pre-monsoon. The highest concentration of NO_3^{-} is mainly from agricultural activity including application of inorganic nitrogen fertilizers and manures in the aquaculture and agricultural farm in and around the location (WHO 2004). The spatial variations of the major ions are essential as it reflects the influence of various anthropogenic and lithology's activities in the lake and river system (Chen et al. 2002).

Water quality index (WQI)

The values of the WQI of Loktak are given in Tables 6 and 7, and Fig. 5. It can be seen that the Loktak Lake has WQI ranges from 64 to 77 which reflects the poor status of the water quality. The result shows the different water quality at different locations. The WQI was classified accordingly following Yadav et al. (2010). These values indicate that the water quality was found unsuitable. Considering this observation, we reclassified the WQI values on the scale suggested by Ramakrishnaiah et al. (2009) and Mohanty (2004). From this classification, the water quality of the Loktak Lake falls under the poor. Thanga recorded that the highest and KLNP show lowest WQI values. Sendra, Ningthoukhong, and Ithai recorded a WQI of 66, 67 and 69. The high value of WQI in Thanga is due to domestic discharge from the Thanga Karang, an island located in the Loktak Lake. The low value in KLNP is due to the presence of Phumdis which acts as a sink for nutrients and plays an important role in phytosanitation. From this result, KLNP has better water quality follow by Sendra and Ningthoukhong. The WQI values gradually increased towards the downstream where it was recorded 70 in Ithai indicating the decreasing water quality. In all the sites, COD is well above the standard limit. The water is not fit for drinking purpose and pollution control should be enhanced and improved in areas where pollution is more. The present finding is similar to the earlier report by Rai and Raleng (2012).

The poor quality of the Loktak Lake is due to increase in concentration of physicochemical parameters bought by the two important rivers like Nambul and Nambol River which discharge the polluted water directly into the lake. The increase in agricultural and pisciculture activities in and around the Lake also increased the pollution due to use of fertilizers and chemicals including pesticides. These increases in pollution are a major concern for the local people living in and around the lake as they depend on the lake water for drinking and household activities.

Statistical analysis

The Pearson correlation matrix was carried out to study the correlation between the parameters (Table 8). It is seen that temperature is significantly positively correlate with turbidity, chlorine, and nitrate, and negatively correlated with BOD. Similarly, pH is significantly correlated with nitrite, EC with TDS and potassium, and negatively correlated with nitrate. Turbidity with nitrate and negatively correlated with BOD, TDS, and chloride. TDS is significantly correlated with potassium and negatively with nitrate. Total hardness is correlated with DO, magnesium is with phosphate, potassium with EC and TDS, chlorine is correlated with temperature and turbidity, and negatively with BOD, phosphate was significantly correlated with magnesium and nitrate, and finally, WQI is positively correlated with total carbon. Our study has found a significant correlation between the parameters and the highest correlation is with turbidity followed by TDS with significant correlation of 7 and 5 parameters, respectively. The correlation reflects both spatial and temporal variations.

Conclusion

The study of WQI reveals that the water quality of Loktak water is polluted and not fit for drinking purpose, even though the local people are drinking. The high WQI values were due to the high value of sub-indices of DO, EC, nitrite, and COD. The result revealed that the local people need to treat the water before usage. The study recommends the urgent need for continuous monitoring of the lake water and identifying the pollution sources to protect the largest fresh water lake from further contamination.

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