



Assessment of water quality trends in Loktak Lake, Manipur, India

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Abstract

Loktak Lake is the largest natural freshwater lake of Northeastern India, characteristic by floating islands, known as *Phumdis*. The lake supports rich biodiversity including some globally threatened species, hence declared as a Ramsar Site. The lake facilitates hydropower, irrigation and provides a livelihood to the local villagers in the form of fishing and agriculture. Loktak Lake is deteriorating in recent years due to rapid urbanization, increased settlement and other anthropogenic activities. A study was, therefore, undertaken to assess the water quality and its trends for this important lake. The water quality of Loktak Lake was assessed in monthly intervals for a period of 3 years, using multiple water quality indices. Temporal distribution functions of the individual water quality parameters and indices were developed to assess the water quality trend of the lake. Overall water quality of this lake was found to be good throughout the year with slight deterioration during winter. However, the water of this lake was a little turbid and contained significant organic load.

Keywords Water quality assessment · Water quality index · Water quality trend · Loktak Lake · Manipur · India

Introduction

Loktak Lake is the largest natural lake of North-eastern India situated on the west of Imphal, the capital of Manipur, a northeastern state of India (NWA 2013). Loktak is a huge lake (24,672 ha), with 12 km of buffer area, which is mainly agriculture land, along with some forest area (NWA 2013). The lake is oval-shaped, having a length of 13 km and width of 26 km, with depth varies between 0.5 and 4.58 m (average depth 2.7 m) (Laishram and Dey 2014). Loktak Lake is located within a central valley, surrounded by mountainous ranges with steep slopes (Singh et al. 2010).

Loktak Lake is rich in biodiversity and supports a variety of wetland flora and fauna including some globally threatened species. Being so important in ecological perspective, the lake was declared as Ramsar Site in 1990 (NWA 2013). The lake is famous for floating islands of different sizes and thicknesses covered with vegetation, locally known as

phumdis. They are basically heterogeneous mass of soil, vegetation and organic matter at various stages of decomposition (LDA 2002). They float on lake water with about $\frac{1}{5}$ th of thickness above and $\frac{4}{5}$ th under the water surface (Takhelmayum and Gupta 2011). The *phumdis* play an important role in the ecological processes of the lake. Being biological sink of the key nutrients, *phumdis* are vital in resisting eutrophication and algal bloom (LDA 2002). Thus, *phumdis* control the quality of water and nutrient dynamics of the lake (LDA 2002). Keibul Lamjao National Park (KLNP), the largest contiguous mass of *phumdis*, is the only natural habitat of the highly endangered ungulate species, Sangai deer (*Rucervus eldii eldii*), the state animal of Manipur (Devi and Sharma 2002). Loktak Lake is also the only habitat in India for a rare wild rice species Manchurian Wild Rice (*Zizania latifolia*) (NWA 2013).

Loktak Lake is extremely important for the ecological and economic security of the region. The local population of nearly 1 lakh in 55 rural and urban hamlets is largely dependent on the lake for its sustenance mainly by fishing and cultivation (Kosygin and Dhamendra 2009). The lake is the only source of water for drinking and other domestic purposes for surrounding settlement (Laishram and Dey 2014). People of Manipur as a whole are culturally, socially and economically linked with the Loktak which gives the lake the status of the *Lifeline of Manipur*

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(LDA 2002). The Loktak Hydropower Project dam was constructed in 1983, downstream of the Manipur River, as a part of the National Loktak Multipurpose Hydro-Electric project, to facilitate the generation of power as well as irrigation (Singh and Khundrakpam 2011). This project is an important source of power for the entire North Eastern India.

Urbanization, increased settlement and change in traditional practices are causing stress on the ecosystem of this lake. Municipal wastes are being deposited into the lake through Imphal River. Fertilizers and pesticides from the surrounding agricultural land are also polluting the lake. Bathing, washing of clothes and utensils are also contributing to the pollution (Laishram and Dey 2014). The poisons, used for fishing in this lake, are also important sources of pollution (Suresh 2000). The lake has a high microbial load with high faecal coliform count (LDA 2002). In the last few decades, the phumdis are spreading rapidly over the lake, but their thickness is reducing (LDA 2002). This phenomenon has a massive impact on the ecological balance of the lake. Construction of dams caused increased water level, holding of water, slow circulation and minimized seasonal variation which may have adverse effects on phumdis (LDA 2002).

Thus, this ecologically crucial and economically extremely important lake is degrading in recent years. In this context, a study was undertaken to assess the quality of water in the lake and its trend. The water quality parameters were estimated for a period of 3 years in monthly intervals to understand the trend of the water quality. The study gives an insight into how water quality of Loktak Lake is changing. This information may help to plan a better management system for the lake.

The overall quality of the water of Loktak Lake was assessed with multiple water quality indices (WQI) with different methodologies to avoid the possible biasness of individual indices. Canadian Council for Ministers of Environment Water Quality Index (CCME WQI) (CCME 2001) was used to assess the overall quality of the lake on long term basis, while National Sanitation Foundation Water Quality Index (NSF WQI) (Brown et al. 1970) and Grey Relational Analysis Water Quality Index (GRA WQI) (Roy and Majumder 2017) were used to assess the quality at temporal points. In Multi-Criteria Decision-Making (MCDM) method based GRA WQI, important attributes like *Hazard Potential*, *Utilization Potential*, *Cost of Mitigation* and *Popularity among Researchers* were taken as MCDM criteria (Roy and Majumder 2017). So, a holistic and more realistic reflection of the actual water quality scenario can be expected from this WQI. Thus, using all these WQI ensures an unbiased assessment of the overall quality of the lake from different aspects.

Study area

The Loktak Lake is located in the Moirang Block of Bishnupur district in the central part of the State of Manipur, India. The lake forms a geographical area of 247 km² and situated at a distance of about 53 km from Imphal—the state capital of Manipur. The lake is situated in between 24°21'37"N to 24°43'02"N and 93°44'44"E to 93°00'47"E (NWA 2013). Locations of Manipur and Loktak Lake in India and the sampling points in Loktak Lake are shown in Fig. 1.

Methodology

Loktak Lake was sampled to estimate 12 water quality parameters (WQP) in every month for a period of 3 years (2014–2016) from 10 sampling points (Fig. 1). The sampling points were made fixed throughout the study period by the aid of GPS Device (Garmin Nuvi 2565LM). Sampling was done between 15th and 20th day of every month to maintain the regular intervals. All samplings were completed between 08:00 AM and 11:00 AM to minimize possible daily fluctuations.

Temperature (*T*), pH, electrical conductivity (EC), dissolved oxygen (DO), Total dissolved solids (TDS), total nitrate (N) and turbidity (Turb) were estimated in the field using sensor-based Multiparameter Water Quality Analyzer (YSI 6600). Water samples were collected in sampling bottles (1 L) and brought to the laboratory in ice boxes to estimate biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total hardness (TH) and total phosphate (P) using standard methods (APHA 1999). The permissible limits of different WQP were taken as prescribed in Indian Standard 10500: 2012 (IS 10500: 2012) (BIS 2012) and World Health Organization (WHO) guidelines (WHO 2017) (Moharana et al. 2014).

Values of all the WQP were compared with desirable limits to assess the water quality in terms of each of the WQP. Statistical analyses of the temporal distribution of individual WQP were made to observe their distribution pattern. The values of different WQP were plotted against the month to assess the trend of individual WQP. Yearly trends were assessed by comparing the year wise monthly patterns of individual WQP.

As some WQP are correlated to other WQP, the correlation coefficient of each of the WQP with all other WQP were calculated. Those correlation coefficients are useful in determining the correlation among different WQP. The coefficients were calculated using all the WQP data in the entire study period.

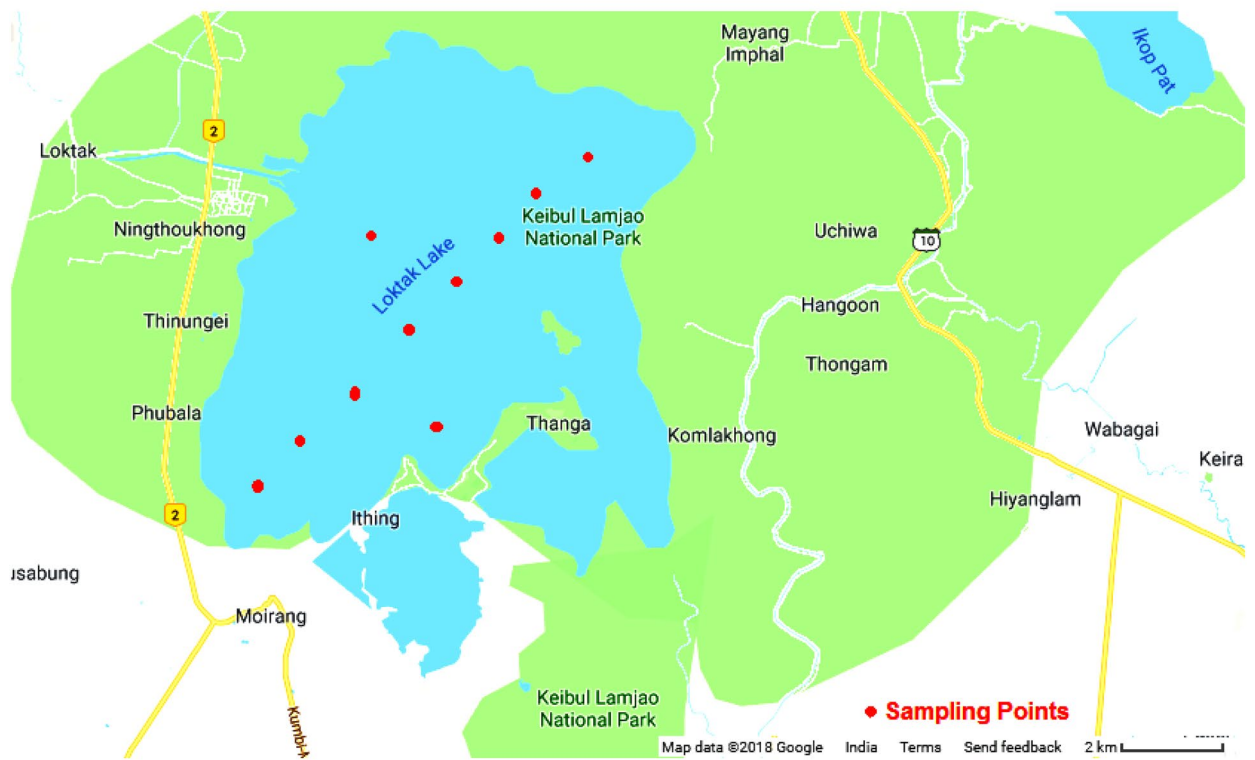
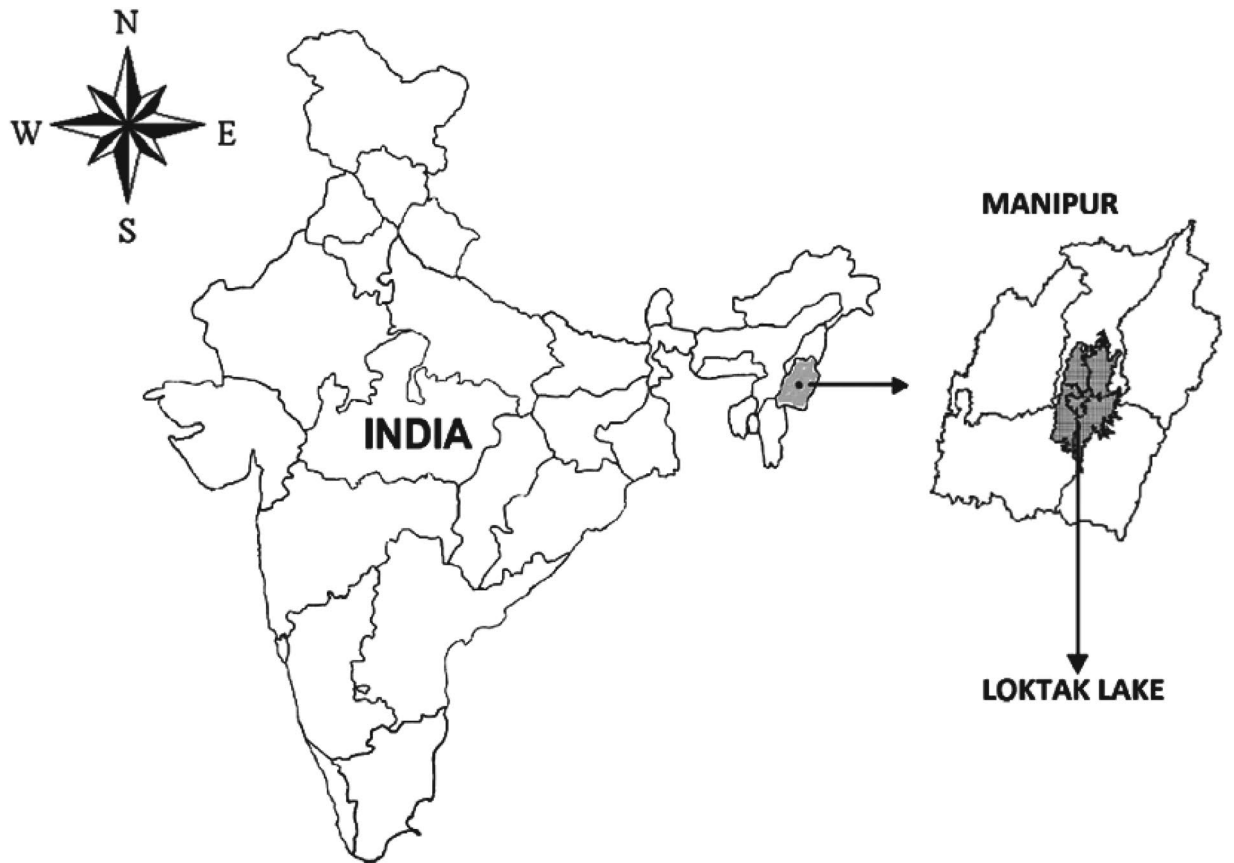


Fig. 1 Locations of Manipur and Loktak Lake in India and sampling points in Loktak Lake

The overall quality of water of the lake was determined by CCME WQI, NSF WQI and GRA WQI. Year wise monthly plots exhibit the seasonal pattern in overall water quality and its yearly trend. Different WQI were plotted together against month for the entire study period to compare those WQI.

The distribution functions of each WQI were determined, using 6th order polynomial regression, to find out the mathematical pattern of their distribution. However, regression models are based on the outcome of the complex interactions of different factors, not on the interactions themselves. A model based on such interactions would have been more reliable and insightful, but much more complex and require much more information to develop. A regression model, on the other hand, is comparatively simple and applicable for practical purposes.

Results and discussion

Most of the WQP values were found within the desirable limits and hence the water quality of the lake can be considered as good. The trend of individual WQP is discussed below. The minimum and maximum values of all the WQP, along with their mean, are given in Table 1.

The statistical analyses of the distribution of the values of the selected WQP throughout the study period were done to understand their distribution pattern. The mean, standard deviation (SD), coefficient of variance (CV), skewness, kurtosis and 85th percentile of the WQP were calculated and their values are given in Table 2.

The correlation coefficients among different WQP calculated to understand their interdependence (Table 3). High correlations (Correlation Coefficient > 0.7) are marked in bold.

Temperature

The range of temperature of the water of the lake is from 18 to 29 °C (Table 1), with a mean of 24.29 °C (Table 2), which were within the desirable limits as per World Health Organization (WHO) guidelines (15–35 °C). Temperature of 85% of the samples were below 27.87 °C during the study period (Table 2).

As expected, the temperature is higher during summer (25–29 °C) and lower during winter (18–24 °C) (Fig. 2) due to variation in sunlight intensity and atmospheric temperature. High negative correlation between temperature and DO (−0.80) and temperature and hardness (−0.74) were found (Table 3). Significant positive correlation between

Table 1 Range and mean of different water quality parameters

Parameters	2014			2015			2016		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Temp	17.64	28.22	24.30	18.14	28.78	24.12	17.89	28.64	24.46
pH	6.30	8.20	7.33	6.20	8.10	7.23	6.30	8.20	7.22
EC	138.00	192.00	159.33	142.00	196.00	161.33	146.00	188.00	161.58
DO	5.12	8.38	6.86	5.92	8.68	7.22	5.86	8.28	7.01
BOD	3.18	7.46	5.04	3.96	6.58	4.90	3.86	5.98	5.02
COD	13.86	32.68	19.72	15.17	25.82	19.23	15.78	21.51	19.51
TSS	17.49	55.03	43.72	40.18	79.26	54.97	32.52	81.32	55.71
TDS	42.68	78.36	61.40	38.09	78.34	59.36	32.75	76.24	59.29
Hardness	24.53	58.34	42.99	28.39	56.34	43.10	26.18	58.74	44.22
Nitrate	0.16	0.53	0.36	0.18	0.58	0.36	0.14	0.57	0.36
Phosphate	0.24	0.82	0.54	0.26	0.78	0.54	0.28	0.77	0.55
Turbidity	4.30	13.60	7.58	4.70	12.70	7.61	4.90	11.60	7.46

Table 2 Descriptive statistics of the distribution of different water quality parameters

Month	T	pH	EC	DO	BOD	COD	TSS	TDS	TH	N	P	Turb
Mean	24.29	7.26	160.75	7.03	4.99	19.49	51.46	60.02	43.44	0.36	0.54	7.55
SD	3.64	0.59	14.64	0.93	0.82	3.31	13.73	12.19	9.15	0.12	0.15	2.59
CV	0.15	0.08	0.09	0.13	0.16	0.17	0.27	0.20	0.21	0.33	0.28	0.34
Skewness	−0.54	0.04	0.86	−0.15	0.60	1.82	0.16	−0.25	−0.23	−0.02	−0.25	0.74
Kurtosis	−1.12	−1.01	0.09	−0.78	1.40	6.33	0.40	−0.79	−0.68	−0.84	−0.64	−0.52
85th Percentile	27.87	7.98	177.00	7.92	5.74	21.46	67.12	73.94	53.91	0.48	0.69	10.18

Table 3 Correlation coefficients among different WQP

	Temp	pH	EC	DO	BOD	COD	TSS	TDS	Hardness	Nitrate	Phosphate	Turbidity
Temp	1.00											
pH	0.34	1.00										
EC	-0.01	-0.57	1.00									
DO	-0.80	-0.25	-0.19	1.00								
BOD	0.00	0.43	-0.06	-0.13	1.00							
COD	-0.13	0.28	-0.10	0.02	0.87	1.00						
TSS	-0.13	-0.34	0.30	0.12	-0.18	-0.12	1.00					
TDS	-0.33	-0.41	0.71	-0.07	0.24	0.15	0.09	1.00				
Hardness	-0.74	-0.38	0.44	0.46	0.16	0.22	0.27	0.61	1.00			
Nitrate	0.14	-0.11	0.47	-0.46	0.31	0.16	0.02	0.65	0.35	1.00		
Phosphate	-0.31	-0.42	-0.34	0.54	-0.40	-0.24	0.01	-0.30	-0.19	-0.62	1.00	
Turbidity	0.66	0.10	0.45	-0.82	0.16	-0.03	-0.04	0.31	-0.13	0.74	-0.70	1.00

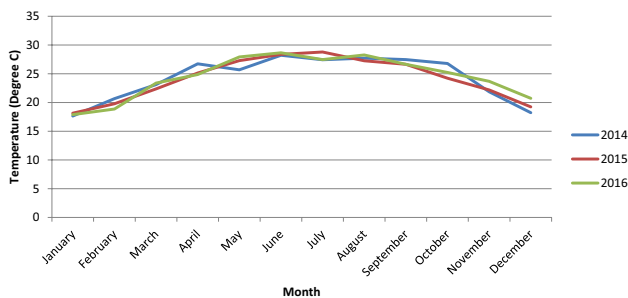


Fig. 2 Temperature of Loktak Lake throughout the year during the study period

temperature and turbidity (0.66) was also found (Table 3). As the particles in water absorb heat, temperature increase is induced by turbidity. Lower values of standard deviation (3.64), coefficient of variance (0.15), skewness (-0.54) and kurtosis (-1.12) indicate there was a little variance of temperature among the samples (Table 2). No significant change was found in temperature across the years (Fig. 2).

pH

The pH of Loktak Lake varied between 6.2 and 8.2 (Table 1), with a mean of 7.26 (Table 2), during the study period. pH values of some samples were found below the desirable limits as per IS 10500: 2012 (6.5–8.5). pH of 85% of the samples was below 7.98 during the study period (Table 2).

The pH of lake water is almost uniform throughout the seasons, with very little variations. Lake becomes slightly acidic (6.2–6.8) in winter and slightly alkaline (7.1–8.2) in spring and post-monsoon. During winter, high DO and lower temperature enhances respiration in organisms and decomposition, which, in turn, causes more CO₂ generation. Also, due to low temperature, more CO₂ can remain dissolved in

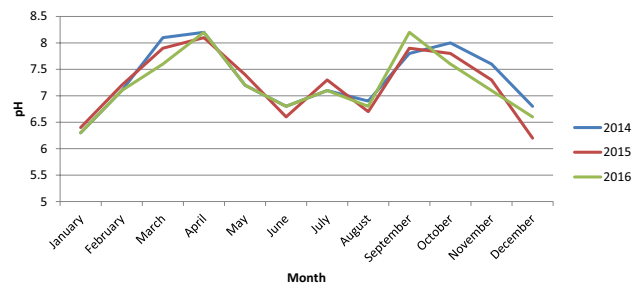


Fig. 3 pH of Loktak Lake throughout the year during the study period

water. The increased CO₂ forms carbonic acid with water, so the water becomes slightly acidic. In spring and post-monsoon, release and retention of CO₂ are hindered due to increased temperature and turbidity, and thus pH rises. In summer pH drops again as ionisation of water is enhanced in higher temperature.

Low negative correlation between pH and EC (-0.80) was observed (Table 3) probably due to the fact that high mobility H⁺ and OH⁻ ions have significant contribution in EC. Lower values of standard deviation (0.59), coefficient of variance (0.08), skewness (0.04) and kurtosis (-1.01) indicate there was a little variance of pH among the samples (Table 2). The pH values were found to be decreasing gradually in summer and post-monsoon every year during the study period (Fig. 3).

Electrical conductivity

The EC of the samples was found to vary from 138 to 196 μS/cm (Table 1), with a mean of 160.75 μS/cm (Table 2), during the study period. EC of all the samples was within the desirable values as per WHO (Less than 300 μS/cm). EC of 85% of the samples was below 177 μS/cm during the study period (Table 2).

EC was found higher during summer than any other period in a year. High EC in summer may be due to increased concentration of ions for a decrease in water volume, caused by enhanced evaporation.

High positive correlation between EC and TDS (0.71) was found (Table 3) as more dissolved salts in water results increased TDS and increased ions. Lower values of coefficient of variance (0.09), skewness (0.86) and kurtosis (0.09) indicate there was a little variance of EC among the samples (Table 2). No significant change in EC was found across the years during the study period (Fig. 4).

Dissolved oxygen

DO of Loktak Lake ranged from 6.92 to 12.62 ppm (Table 1), with a mean of 7.03 ppm (Table 2), during the study period. The DO values were above the desired minimum limit (6 ppm) as per WHO except in summer. DO of 85% of the samples were below 7.92 ppm during the study period (Table 2).

As expected, DO is lower in summer and higher in winter due to temperature variation as the solubility of gases in water decreases with increase in temperature. So, high negative correlation between DO and temperature (-0.80) was found (Table 3). Turbidity in water causes reduced photosynthesis by blocking sunlight. Turbidity also induces temperature increase due to heat absorption by the suspended particles. Thus, there is a high negative correlation between DO and turbidity (-0.82) (Table 3). Lower values of standard deviation (0.93), coefficient of variance (0.13), skewness (-0.15) and kurtosis (-0.78) indicate there was a little variance of DO among the samples (Table 2). No significant change in DO was found across the years during the study period (Fig. 5).

Biochemical oxygen demand

BOD of Loktak Lake varied from 3.18 to 7.46 ppm (Table 1), with a mean of 4.99 ppm (Table 2), during the study period.

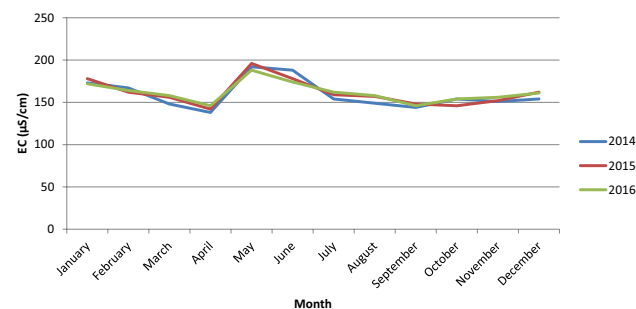


Fig. 4 EC of Loktak Lake throughout the year during the study period

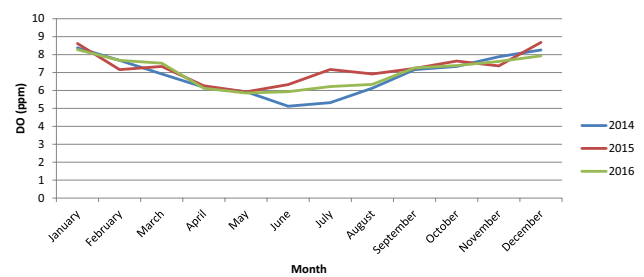


Fig. 5 DO of Loktak Lake throughout the year during the study period

BOD of some samples was above the permissible limits as per WHO (5 ppm). The high BOD of this lake seems to be due to the dense phumdis. BOD of 85% of the samples was below 5.74 ppm during the study period (Table 2).

BOD reached to peak during spring and low during monsoon in the study period. The plankton population of Loktak Lake is maximum during winter. In spring sudden rise in temperature causes decrease in DO. The low oxygen results in the mortality of plankton and increases organic load of the lake. Increased evaporation due to higher temperature makes the organic load concentrated. In monsoon increased water level dilutes the organic load, and thus BOD decreases.

Being a natural environment, the BOD contributes to most of the COD. Thus, a high positive correlation (0.87) between BOD and COD was observed (Table 3). Lower values of standard deviation (0.82), coefficient of variance (0.16), skewness (0.60) and kurtosis (1.40) indicate there was a little variance of BOD among the samples (Table 2). No gradient of BOD was observed across the years during the study period (Fig. 6).

Chemical oxygen demand

COD of Loktak Lake ranged from 13.86 to 32.68 ppm (Table 1), with a mean of 19.49 ppm (Table 2), during the study period. All the values were much beyond the

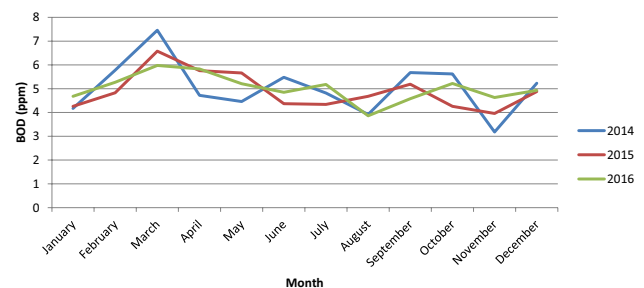


Fig. 6 BOD of Loktak Lake throughout the year during the study period

permissible limit as per WHO (10 ppm). COD of 85% of the samples were below 21.46 ppm during the study period (Table 2).

As COD consists mostly of BOD, it also follows the similar temporal pattern as of BOD. COD increased during spring and decreased during monsoon such as BOD. Lower values of standard deviation (3.31), coefficient of variance (0.17), skewness (1.82) and kurtosis (6.33) indicate there was a little variance of COD among the samples (Table 2). COD also decreased every year in spring during the study period (Fig. 7).

Total suspended solids

TSS of Loktak Lake varied from 17.49 to 81.32 ppm (Table 1), with a mean of 51.46 ppm (Table 2), during the study period. All the values were below the permissible limits (100 ppm). TSS of 85% of the samples were below 67.12 ppm during the study period (Table 2).

No recognisable seasonal pattern of TSS was found for Loktak Lake in the study period (Fig. 8). However, lower values of coefficient of variance (0.27), skewness (0.16) and kurtosis (0.40) indicate there was a little variance of TSS among the samples (Table 2). TSS of the lake decreased in every year during spring and summer in the study period.

Total dissolved solids

TDS of the lake ranged between 32.75 and 78.36 ppm (Table 1), with a mean of 60.02 ppm (Table 2), during the study period. The TDS values were well within the permissible limits as per IS 10500: 2012 (2000 ppm). TDS of 85% of the samples were below 73.94 ppm during the study period (Table 2).

TDS increased in summer and winter and decreased in spring and post-monsoon. In winter and summer, water level drops due to increased evaporation and decreased inflow. In decreased water volume the solutes get concentrated, so TDS increases. In spring density of water decreases due to sudden increase in temperature, this makes the solutes, as

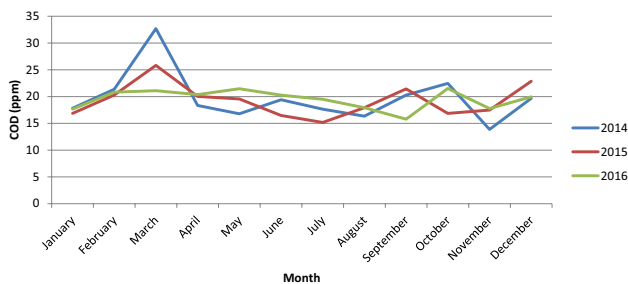


Fig. 7 COD of Loktak Lake throughout the year during the study period

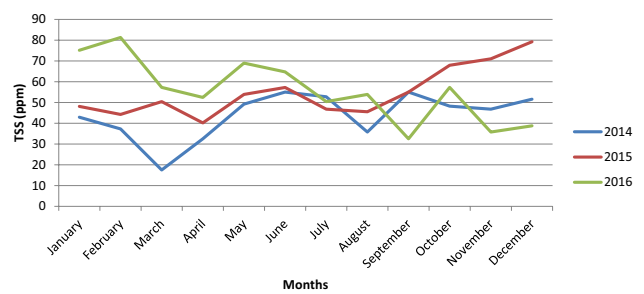


Fig. 8 TSS of Loktak Lake throughout the year during the study period

well as TDS, to get diluted. During post-monsoon water volume increases much due to heavy precipitation in monsoon. Thus, TDS increases in post monsoon.

TDS has a high positive correlation (0.71) with EC and low positive correlation (0.65) with nitrate (Table 3). Lower values of coefficient of variance (0.20), skewness (-0.25) and kurtosis (-0.79) indicate there was a little variance of TDS among the samples (Table 2). No significant trend was found in TDS across the years during the study period (Fig. 9).

Total hardness

TH of Loktak Lake varied from 24.53 to 58.74 ppm (Table 1), with a mean of 43.44 ppm (Table 2), during the study period. TH of all the samples were within the permissible limit as per IS 10500: 2012 (600 ppm). TH of 85% of the samples were below 53.91 ppm during the study period (Table 2).

TH tended to increase in winter and decrease in monsoon. In winter, due to the increased density of water, hardness increases. In monsoon increased runoff with high sediments, consisting of different minerals and ions increases the hardness of the lake.

High negative correlation (-0.74) between Hardness and Temperature and low positive correlation (0.61) between

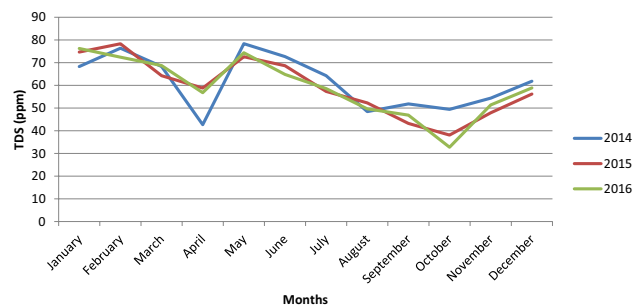


Fig. 9 TDS of Loktak Lake throughout the year during the study period

Hardness and TDS were observed (Table 3). As the temperature is negatively correlated to water density and water density is positively correlated to the concentration of hardness, so temperature and hardness are negatively correlated. More TDS means the possibility of more dissolved calcium and magnesium ions in water. Thus TDS and Hardness are positively correlated. Lower values of coefficient of variance (0.21), skewness (-0.23) and kurtosis (-0.68) indicate there was a little variance of hardness among the samples (Table 2). No significant trend of hardness was found across the years (Fig. 10).

Total nitrate

The nitrate of Loktak Lake ranged from 0.14 to 0.58 ppm (Table 1), with a mean of 0.36 ppm (Table 2), which were well within the permissible limit as per IS 10500: 2012 (45 ppm). Nitrate of 85% of the samples was below 0.48 ppm during the study period (Table 2).

Nitrate increased in summer and decreased in post monsoon. Biological activities reduce in summer due to low DO and increased temperature, which, in turn, decrease the nitrate utilization. Also increased Temperature and decreased pH induce the release of more nitrates from the phumdis in summer (Gupta 2012). Thus Nitrate increases in summer.

High positive correlation (0.74) between nitrate and turbidity and low positive correlation (0.65) between nitrate and TDS were found (Table 3). However, low negative correlation (-0.62) was observed between nitrate and phosphate (Table 3). Higher level of nitrate in water induces algal growth, which, in turn, increases turbidity. As nitrate salts contribute to TDS, there is a positive correlation between them. As nitrate induces algal growth, higher nitrate means higher photosynthesis. Now, as phosphorus is crucial in Krebs's Cycle, availability of phosphorus is essential for photosynthesis. Thus, phosphates are consumed during photosynthesis. This can be an explanation of the negative correlation between nitrate and phosphate, though there

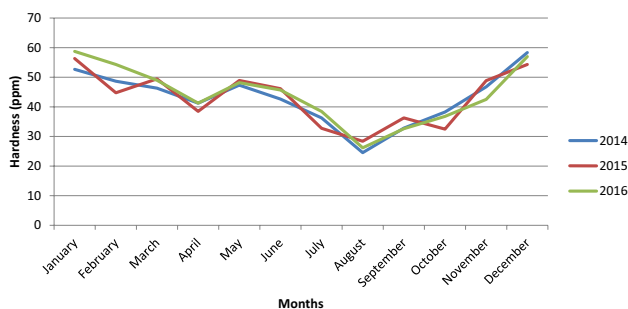


Fig. 10 Hardness of Loktak Lake throughout the year during the study period

are several other factors in this very complex environment. Lower values of standard deviation (0.12), coefficient of variance (0.33), skewness (-0.02) and kurtosis (-0.84) indicate there was a little variance of Nitrate among the samples (Table 2). Nitrate had a tendency to decrease in winter every year during the study period (Fig. 11).

Total phosphate

Phosphate of the lake varied from 0.24 to 0.82 ppm (Table 1), with a mean of 0.54 ppm (Table 2), during the study period. The values were much beyond the permissible limit (0.03 ppm). Phosphate of 85% of the samples were below 0.69 ppm during the study period (Table 2).

Phosphate of Loktak Lake increased during monsoon and decreased during summer in the study period.

High negative correlation (-0.70) between phosphate and turbidity and low negative correlation (-0.62) between phosphate and nitrate were observed (Table 3). As nitrate and turbidity are positively correlated, but nitrate and phosphate are negatively correlated, turbidity and phosphate are negatively correlated. Lower values of standard deviation (0.15), coefficient of variance (0.28), skewness (-0.25) and kurtosis (-0.64) indicate there was little variance of Phosphate among the samples (Table 2). It also tended to increase

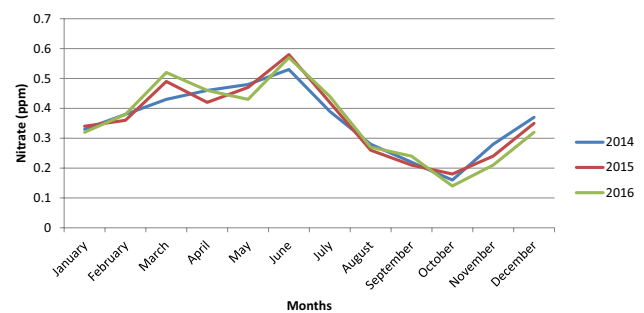


Fig. 11 Nitrate of Loktak Lake throughout the year during the study period

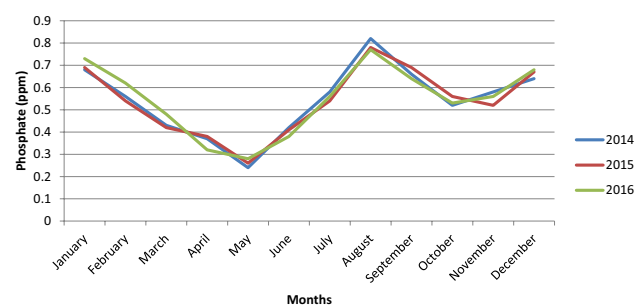


Fig. 12 Phosphate of Loktak Lake throughout the year during the study period

during summer and decrease during monsoon across the years (Fig. 12).

Turbidity

Turbidity of Loktak Lake ranged from 4.3 to 13.6 NTU (Table 1), with a mean of 7.55 NTU (Table 2), during the study period. Most those values were beyond the permissible limit as per IS 10500: 2012 (5 NTU). Turbidity of 85% of the samples was below 10.18 NTU during the study period (Table 2).

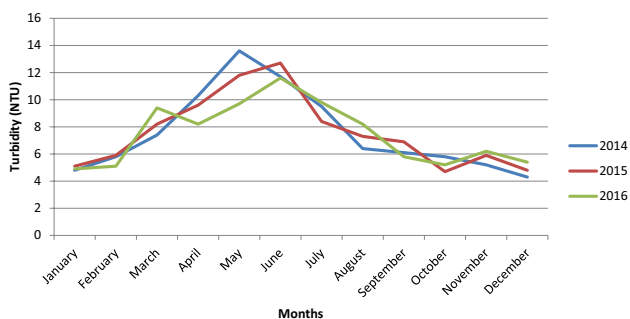


Fig. 13 Turbidity of Loktak Lake throughout the year during the study period

Turbidity of the lake increased during summer and decreased during winter. Lower values of standard deviation (2.59), coefficient of variance (0.34), skewness (0.74) and kurtosis (-0.52) indicate there was a little variance of turbidity among the samples (Table 2). Turbidity decreased across the years during summer in the study period (Fig. 13).

From this study, it was observed that BOD, COD and turbidity of the lake were mostly and Phosphate was always beyond the desirable limits throughout the year. pH went below the desirable limit during winter. Rest of the WQP were within the desirable limits throughout the study period. Similar facts were found in some other studies (Sharma et al. 2013; Rai and Raleng 2011).

Temperature, EC, nitrate, and turbidity increased and DO decreased during summer throughout the study period. pH increased in spring and post-monsoon, BOD and COD increased in spring, TDS increased in spring and summer, phosphate increased in post monsoon and hardness increased in winter. Similar trends were observed in some other studies also (Laishram and Dey 2014; Kangabam et al. 2017).

The distribution functions of each of the WQP are given in Table 4. The distribution functions were obtained by 6th order polynomial regression of the temporal distributions of individual WQP for each year during the study period. These functions are the mathematical expressions of the trend of each of the WQP.

Table 4 Distribution functions of different water quality parameters

Parameters	2014	2015	2016
Temperature	$-0.021x^5 + 0.325x^4 - 2.363x^3 + 8.151x^2 - 9.489x + 21.09$	$-5 \times 10^{-5}x^6 + 0.001x^5 + 0.002x^4 - 0.243x^3 + 1.838x^2 - 2.279x + 18.82$	$-0.009x^5 + 0.18x^4 - 1.627x^3 + 7.089x^2 - 10.89x + 23.09$
pH	$-0.011x^5 + 0.179x^4 - 1.249x^3 + 3.964x^2 - 4.569x + 7.964$	$-0.011x^5 + 0.165x^4 - 1.161x^3 + 3.710x^2 - 4.37x + 8.063$	$-0.015x^5 + 0.224x^4 - 1.563x^3 + 5.123x^2 - 6.675x + 9.226$
EC	$-0.009x^6 + 0.341x^5 - 4.698x^4 + 29.82x^3 - 86.2x^2 + 94.53x + 141.4$	$-0.005x^6 + 0.183x^5 - 2.394x^4 + 13.46x^3 - 28.06x^2 - 0.212x + 196.2$	$-0.005x^6 + 0.215x^5 - 2.958x^4 + 18.57x^3 - 52.29x^2 + 53.56x + 155.8$
DO	$-0.007x^5 + 0.114x^4 - 0.763x^3 + 2.509x^2 - 4.472x + 11.02$	$-0.005x^5 + 0.072x^4 - 0.464x^3 + 1.651x^2 - 3.711x + 11.01$	$6 \times 10^{-5}x^6 - 0.001x^5 + 0.014x^4 + 0.002x^3 - 0.416x^2 + 0.693x + 7.953$
BOD	$-0.013x^5 + 0.159x^4 - 0.788x^3 + 1.006x^2 + 2.480x + 1.287$	$-0.022x^5 + 0.332x^4 - 2.296x^3 + 7.505x^2 - 9.950x + 8.651$	$-0.005x^5 + 0.078x^4 - 0.556x^3 + 1.719x^2 - 1.613x + 5.046$
COD	$0.001x^6 - 0.068x^5 + 0.900x^4 - 5.176x^3 + 11.55x^2 - 2.810x + 12.88$	$0.002x^6 - 0.072x^5 + 0.998x^4 - 6.365x^3 + 18.21x^2 - 18.45x + 22.36$	$0.012x^5 - 0.174x^4 + 1.290x^3 - 5.343x^2 + 11.94x + 10.05$
TSS	$-0.003x^6 + 0.116x^5 - 1.555x^4 + 9.003x^3 - 19.14x^2 - 0.356x + 56.59$	$-0.001x^6 + 0.036x^5 - 0.376x^4 + 1.375x^3 + 0.546x^2 - 10.18x + 56.87$	$-0.005x^6 + 0.212x^5 - 3.166x^4 + 22.70x^3 - 79.79x^2 + 120.0x + 16.69$
TDS	$-0.008x^6 + 0.319x^5 - 4.818x^4 + 34.99x^3 - 125.4x^2 + 201.0x - 37.23$	$-0.005x^6 + 0.218x^5 - 3.258x^4 + 23.28x^3 - 81.42x^2 + 124.4x + 12.08$	$-0.004x^6 + 0.162x^5 - 2.381x^4 + 16.47x^3 - 54.93x^2 + 77.29x + 39.58$
Hardness	$-0.001x^6 + 0.056x^5 - 0.691x^4 + 3.663x^3 - 7.853x^2 + 1.469x + 56.35$	$-0.001x^6 + 0.037x^5 - 0.354x^4 + 0.677x^3 + 5.829x^2 - 27.87x + 77.84$	$-0.002x^6 + 0.081x^5 - 1.124x^4 + 7.225x^3 - 21.74x^2 + 23.40x + 51.25$
Nitrate	$-3 \times 10^{-5}x^6 + 0.001x^5 - 0.016x^4 + 0.105x^3 - 0.336x^2 + 0.538x + 0.036$	$-3 \times 10^{-5}x^6 + 0.001x^5 - 0.017x^4 + 0.118x^3 - 0.382x^2 + 0.611x + 0.003$	$-3 \times 10^{-5}x^6 + 0.001x^5 - 0.015x^4 + 0.112x^3 - 0.407x^2 + 0.754x - 0.132$
Phosphate	$-3 \times 10^{-6}x^6 + 0.000x^5 - 0.011x^4 + 0.118x^3 - 0.526x^2 + 0.836x + 0.251$	$3 \times 10^{-5}x^6 - 0.001x^5 + 0.009x^4 - 0.035x^3 + 0.043x^2 - 0.119x + 0.787$	$-4 \times 10^{-6}x^6 + 0.000x^5 - 0.012x^4 + 0.133x^3 - 0.600x^2 + 0.977x + 0.221$
Turbidity	$0.003x^5 + 0.020x^4 - 0.834x^3 + 5.600x^2 - 11.21x + 11.39$	$0.01x^5 - 0.094x^4 + 0.182x^3 + 1.220x^2 - 3.140x + 6.962$	$0.020x^5 - 0.285x^4 + 1.809x^3 - 5.581x^2 + 9.309x - 0.604$

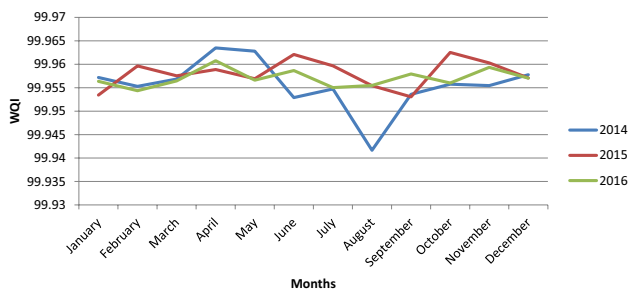


Fig. 14 Year wise CCME WQI of the Loktak Lake

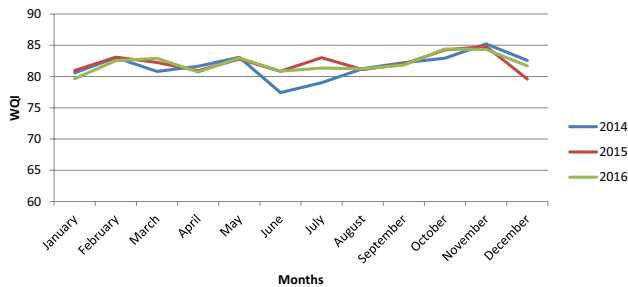


Fig. 15 Year wise NSF WQI of the Loktak Lake

The pH values were found to be decreasing gradually in summer and post-monsoon every year. COD decreased every year during spring. TSS of the lake found to be decreased in every year during spring and summer during the study period. Nitrate had a tendency to decrease in winter every year. Phosphate increased during summer and decreased during monsoon across the years. Turbidity decreased across the years during summer.

As per CCME WQI, the water qualities of the lake were excellent (CCME WQI almost 100 for all samples) throughout the year for the entire study period (Fig. 14). However, there were deteriorations in overall water quality during post monsoon. There was a significant overall deterioration of water quality in the monsoon of 2014 (Fig. 14).

As per NSF WQI, the water qualities of the lake were good (NSF WQI 77–85) throughout the year for the entire study period (Fig. 15). Not much seasonal variation in overall water quality was found, but quality tended to improve during post-monsoon (Fig. 15). No significant yearly variation was also observed, but a significant deterioration was found in summer of 2014 (Fig. 15).

GRA WQI of the samples were almost same as NSF WQI (Fig. 16). However, being based on important criteria like *Hazard Potential*, *Utilization Potential*, *Cost of Mitigation* and *Popularity among Researchers* GRA WQI is more realistic and holistic in nature.

CCME WQI is a long duration quality index, while NSF WQI and GRA WQI are point quality indices. Thus, from CCME WQI, it can be ascertained that the overall quality

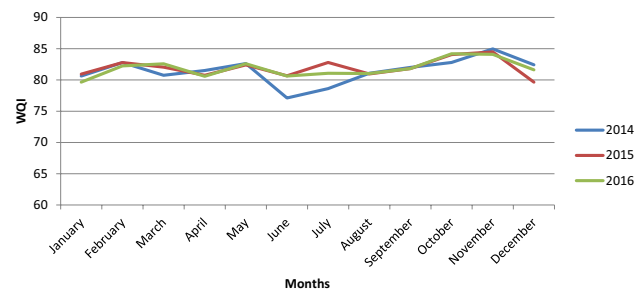


Fig. 16 Year wise GRA WQI of the Loktak Lake

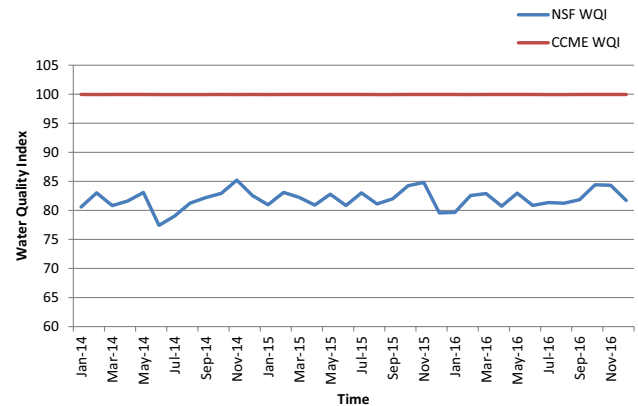


Fig. 17 Comparison between different water quality indices

of Loktak Lake is excellent on long term basis aspect. However, NSF WQI and GRA WQI indicate that short term quality index of the lake was not so good. CCME WQI of this lake was found rather flat which indicates negligible seasonal and yearly variation in the overall quality of this lake. NSF WQI and GRA WQI, on the other hand, exhibit some seasonal fluctuations in the overall water quality (Fig. 17).

The values of individual WQP also indicate that the water of the lake was not always excellent throughout the study period and varied little bit seasonally. As CCME WQI based on the frequency of the failed variables, it may overestimate the quality of the lake. However, as per CCME WQI the long term water quality of the lake can be considered as good. NSF WQI depicted the seasonal variations more prominently and indicated that in some point of time, especially during post monsoon, there were improvements in the overall quality of water. However, no significant yearly trend could be observed.

The distribution functions of each of the WQI are given in Table 5. The distribution functions were obtained by 6th order polynomial regression of the temporal distributions of individual WQI for each year during the study period. These functions are the mathematical expression of the trend of overall quality of water of Loktak Lake.

Table 5 Distribution functions of different water quality indices

WQI	2014	2015	2016
CCME	$2 \times 10^{-6}x^6 - 8 \times 10^{-5}x^5 + 0.001x^4 - 0.011x^3 + 0.046x^2 - 0.082x + 100$	$-3 \times 10^{-6}x^6 + 10^{-4}x^5 - 0.001x^4 + 0.01x^3 - 0.036x^2 + 0.063x + 99.91$	$7 \times 10^{-7}x^6 - 3 \times 10^{-5}x^5 + 0.000x^4 - 0.004x^3 + 0.018x^2 - 0.033x + 99.97$
NSF	$3 \times 10^{-5}x^6 - 0.002x^5 + 0.049x^4 - 0.314x^3 + 0.356x^2 + 1.769x + 78.91$	$-0.001x^6 + 0.039x^5 - 0.579x^4 + 4.170x^3 - 15.35x^2 + 26.48x + 66.20$	$0.020x^5 - 0.307x^4 + 2.321x^3 - 9.394x^2 + 18.77x + 68.27$
GRA	$-0.006x^5 + 0.110x^4 - 0.754x^3 + 1.934x^2 - 0.898x + 80.42$	$-0.001x^6 + 0.036x^5 - 0.531x^4 + 3.829x^3 - 14.08x^2 + 24.22x + 67.47$	$0.017x^5 - 0.251x^4 + 1.904x^3 - 7.808x^2 + 15.89x + 69.92$

This study assessed the water quality and its trend of Loktak Lake, which are important information for the optimum management and planning of this Ramsar Site of international importance. In addition, the more holistic MCDM based WQI were applied to assess the water quality. With the help of the distribution functions developed in this study, the concentration of any selected WQP can be predicted approximately at any point of time. Similarly, the overall quality of the lake can also be predicted from WQI distribution functions. Thus, the water quality of the lake in the near future can be predicted and suitable management can be planned accordingly. The correlation among the WQP were also determined to understand how one WQP has interrelationship with other WQP. The methodology of this study can be followed for other water bodies globally for generating such a useful database for comprehensive planning and management.

Conclusion

The water quality and its trend of Loktak Lake were assessed in this study. 12 important WQP were measured in monthly intervals for a period of 3 years to get a clear idea of the water quality of this lake. Results indicate that the overall quality of Loktak Lake was good throughout the year during the study period. There were little seasonal and yearly variations among the WQP and overall water quality. The water was more turbid and contained more organic load than ideal condition. There was a tendency of deterioration of overall water quality during winter and improvement during post monsoon. No significant yearly trend was found in the overall water quality of this lake. However, a sharp deterioration of the lake was observed in the monsoon of 2014. The correlation among different WQP were determined to assess the interrelationship among them. The distributions functions, developed in this study, can be useful in prediction suitable WQP, as well as the overall quality, of the lake approximately at any point of time. Such prediction models may be useful in future planning and management of this lake.

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