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Assessment of water quality trends in Rudrasagar Lake, Tripura, India

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ABSTRACT

Rudrasagar Lake is a one of the vital lakes of Tripura, India and the only Ramsar Site of the state. The lake hosts an ample biodiversity inclusive of few endangered and rare species. This lake provides livelihood to a large number of local people by means of fishing, tourism and collection of aquatic vegetation. The water quality of Rudrasagar Lake is, therefore, important both in ecological and economical aspects. In this study, electrical conductivity, pH, temperature (T), total dissolved solids, dissolved oxygen, turbidity (Turb) and Total nitrate (N) of Rudrasagar were estimated in every month for 3 consecutive years. Assessment of the lake, conducted with multiple indices, revealed the overall quality of water was fair (NSF WQI 67-85) during study period with some deterioration in summer (NSF WQI 67-78). However, the lake was found turbid (17.3–57.2 NTU), lacked dissolved oxygen (3.92–9.16 ppm) and retained considerable organic load biochemical oxygen demand (BOD 1.18–4.92 ppm). A slight yearly deterioration was observed during winter, spring and summer. Functions of distribution for the selected parameters and indices, used in this study, were developed for mathematical expression of water quality trend.

Keywords: Water quality index; Water quality assessment; Water quality trend; Rudrasagar Lake; Tripura; India

1. Introduction

Freshwater consists of only 2.5% of the surface water of the earth and only 1% of the freshwater is accessible [1]. Thus, water is a limited but precious resource. Lakes, both natural and manmade, are important sources of water, which consists about 0.3% of the total surface water [1]. Generally, there is no strong flow of water within a lake, so the pollutants are confined in the lake and deteriorates the quality of water. In recent years, anthropogenic impacts are very significant for the quality of the lakes. Modern agriculture techniques and longer growing seasons cause increased use of fertilizers and pesticides, which eventually contaminate rivers and lakes. Rapid urbanizations and population increase make larger volume of municipal sewage, which also contributes significantly to such pollution. Nutrients from these sources, in the form of nitrogen, phosphorous and potassium, are major factors for algal growth and eutrophication in lake water [2]. Industrial effluents are the most prominent contributors of water body contamination. Plastic contamination is increasing at alarming rate in recent years in all layers of water, whether open, shoreline or benthic areas. Oceanic currents consists higher plastic densities due to accumulations of plastic debris into the oceans [3]. As water scarcity already sets in, the present focus is on the improvement of quality of the water sources [1]. Lakes being vital source of water, monitoring and restoration of lake water quality are of a major concern nowadays.

Rudrasagar Lake is a natural depression, situated 52 km south of Agartala, the state capital of Tripura – a State in North East India [4]. The lake is oval with a length of 2 km and breadth of 750 m, having an area of 147.62 ha and depth of 1.5–8 m [5]. The main source of water of Rudrasagar Lake is Durlavnarayan cherra, Noacherra and Kemtali cherra

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streams (in local language, “cherra” means stream). After depositing silts, clearer water outflows through a connective channel, namely Kachigang, into River Gomati. Thus, the bed of this lake is formed mainly from silt deposition [4].

Rudrasagar Lake provides livelihood to nearly 2,000 families from 15 nearby villages in the form of fishing, tourism and collection of aquatic plants [6,7]. Neer Mahal, once the summer palace of the former kings and presently one of the best tourist attractions of Tripura, is located in north-east edge of the lake. This lake provides habitat to many species, including some threatened and rare [4] ones. Six rare and nine endangered fish species and many species of molluscs, amphibians, reptiles, birds and nineteen aquatic plants are among them [4,7,8]. The most notable among them is the endangered Three-striped roofed turtle (*Batagur dhongoka*) which is in the Red List of IUCN [9]. As Rudrasagar Lake is connected with a major river, it provides a natural breeding ground for fishes, freshwater turtles and tortoises [4]. Being so important ecologically, Rudrasagar achieved Ramsar status in 2005 [4].

Increasing settlement and unplanned urbanization in this area impose stress on this wetland. Siltation from the inlet streams decreases the depth of this lake. Deposition of garbage and excreta from the local settlement are pollution the water of Rudrasagar. Runoff from adjacent cultivation land brings fertilizers and pesticides residues into the lake [10]. Excess amount of fertilizer causes eutrophication, which in turn induce algal bloom and infestation with water hyacinth. Thus, the dissolved oxygen of water decreases which cause mortality of aquatic organisms. The decomposition of the organic load diminishes the oxygen even more. So, the water quality of the lake deteriorates and becomes unhealthy for the aquatic ecosystem.

As Rudrasagar Lake is ecologically and economically extremely important, the quality of the lake is vital for proper maintenance of the life form and livelihood of the local people. There is possible pollution of lake water from various anthropogenic and natural causes, which may be harmful in both ecological and economic aspects. So, it is vital to conceive how the water in the lake is deteriorating with time for the sake of environment and people. A long-term assessment, therefore, was undertaken for Rudrasagar Lake to check whether the water quality of the lake was deteriorating or not (trend of water quality). In the present study, some parameters of the lake were estimated every month during 3 y of study period for assessment of water quality trend. Thus, this study reveals changing pattern of water quality which may be helpful in better management planning.

To minimize the probable bias of a single index, assessment of water quality was performed by multiple water quality indices (WQI). The WQI used in this study were also developed differently and adopted different methods of calculation. Canadian Council for Ministers of Environment WQI (CCME WQI) [11] was used for long duration assessment of water quality. CCME relies on the number of failed (i.e., not meeting the desired value) parameters. The quality is expressed by a scale of 0–100 and classified as excellent (95–100), good (80–94), fair (65–79), marginal (45–64) and poor (0–44). Point assessments were conducted with National Sanitation Foundation WQI (NSF WQI) [12] and weighted sum method WQI (WSM WQI) [13]. In both the methods index is calculated with weights (relative importance) of the parameters and their *Q*-values (scaling of the concentrations of the parameters). The quality is expressed by a scale of 0–100 and classified as excellent (90–100), good (70–89), medium (50–69), bad (25–49) and very bad (0–24). Both CCME WQI and NSF WQI are used universally, widely accepted and comparatively easier to calculate. However, in CCME WQI, more freedom of the user is given as parameters and their desired limits and can be selected by him/her. WSM WQI can be considered as more holistic and realistic WQI as it utilizes multi criteria decision making (MCDM) and relied upon vital criteria, such as Utilization Potential, Hazard Potential, Popularity among Researchers and Cost of Mitigation [13].

1.1. Study area

Rudrasagar Lake is situated at Melaghar Block in the Sonamura Sub-Division under Sipahijala district, at the western fringe of Tripura, India. Rudrasagar is 52 km away from Agartala (state capital of Tripura) and spread over an area of 2.4 km^2. The lake is located between 23°29′10″ N and 23°32′52″ N in north to south and 91°17′23″ E to 91°20′04″ E in west to east [4]. Locations of the lake with the sampling points are depicted in Fig. 1.

2. Methodology

12 sampling points were selected on the surface of Rudrasagar Lake (Fig. 1). Samplings were conducted between 08:00 AM and 11:00 AM from 15th to 20th day of each month during the studied period (2014–2016) for minimizing daily variations and maintaining periodicity as well.

Estimation of electrical conductivity (EC), pH, temperature (T), total dissolved solids (TDS), dissolved oxygen (DO), turbidity (Turb) and total nitrate (N) were performed on site with multiparameter water quality analyzer (Horiba U50 and YSI 6600 Sonde). Chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), total phosphate (P) and total hardness (TH) were performed in laboratory, following Standard Methods [14,15]. For desirable limits of the parameters Indian Standard 10500: 2012 [16], Indian Standard 2296: 1992 [17], Economic Commission for Europe Standard [18] and Water Research [19] were followed [20].

Condition of the lake was ascertained from the estimation of different parameters by comparing with their respective permissible limits. Graphical representation and comparison were made by plotting the water quality parameters (WQP) and WQI values against the respective months of each year. Assessment of the overall water quality of the lake was performed with multiple WQI (e.g., CCME WQI, NSF WQI and WSM WQI) from different aspects (i.e., long duration assessment, point assessment and holistic assessment). Statistical analyses with mean, standard deviation (SD), coefficient of variance (CoV), kurtosis, skewness and 85th percentile were conducted to get insight about the distributions of the WQP. Qualitative yearly trends of WQP and WQI were determined by Mann–Kendall Test [21]. The functions of distribution of the parameters and WQI,

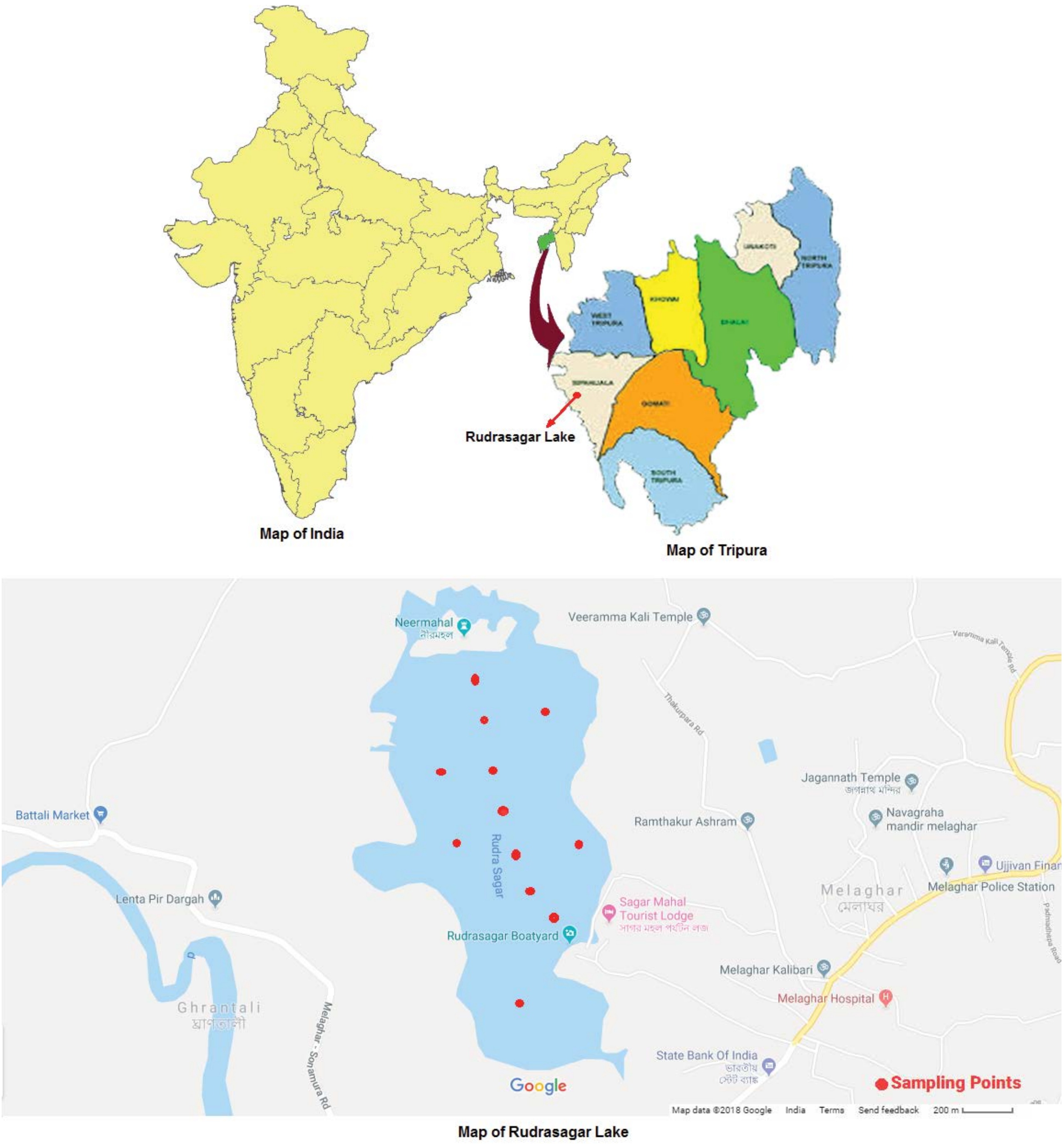

Fig. 1. Locations of the study area and sampling points.

determined by 6th order polynomial regression [22], to express the trend of water quality mathematically.

3. Results and discussion

12 selected parameters were estimated monthly for 3 y. As parameters were mostly within permissible limits, quality of Rudrasagar can be deemed fair during the study period. The maxima, minima mean and standard deviations of the parameters are presented in Table 1.

The distribution of the parameters were assessed by different statistical techniques like mean, coefficient of variance (CoV), standard deviation (SD), 85^{th} percentile, and skewness (Table 2).

Qualitative trend of the WQP and WQI was worked out by Mann–Kendall test and given in Table 3. From this test yearly qualitative trend (whether increasing or decreasing) of the parameters can be determined. All the trends are statistically significant as *P*-values were greater than 0.05 for all cases.

Table 1
Maxima, minima, mean and standard deviation (SD) of the WQP

Parameters	2014				2015				2016			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Temp (°C)	18.26	32.47	25.78	4.82	19.44	31.74	26.28	4.09	18.37	33.26	26.12	4.83
pH	6.80	8.80	7.63	0.61	6.50	8.90	7.51	0.67	6.40	8.60	7.46	0.64
EC (μS/cm)	32.00	128.00	82.33	33.34	29.00	132.00	85.67	35.53	32.00	136.00	91.50	34.02
DO (ppm)	4.12	9.16	6.60	1.65	3.92	8.72	6.21	1.50	4.29	8.63	6.33	1.37
BOD (ppm)	1.18	4.13	2.37	0.82	1.63	4.46	2.63	0.83	1.27	4.92	2.91	0.96
COD (ppm)	17.72	62.38	34.57	15.01	19.56	68.83	38.46	17.40	18.12	72.28	42.92	18.27
TSS (ppm)	32.66	96.36	64.46	22.41	38.72	112.23	70.60	22.09	36.26	93.67	65.38	19.69
TDS (ppm)	23.14	82.95	53.35	20.52	22.84	89.68	57.20	24.34	23.61	84.57	59.12	21.32
Hardness (ppm)	12.62	83.24	46.05	21.72	17.52	86.64	50.26	22.46	19.62	94.27	57.34	26.23
Nitrate (ppm)	1.26	4.13	3.04	0.97	1.18	4.24	2.94	1.02	1.23	4.32	2.89	1.00
Phosphate (ppm)	0.22	0.86	0.47	0.19	0.25	0.83	0.48	0.18	0.27	0.78	0.50	0.15
Turbidity (NTU)	17.30	52.30	33.11	12.00	17.80	54.60	34.43	12.28	19.40	57.20	35.94	12.23

Table 2
Assessment of distribution of the parameters with statistics

Statistics	T	pH	EC	DO	BOD	COD	TSS	TDS	TH	N	P	Turb
Mean	26.06	7.53	86.50	6.38	2.64	38.65	66.82	56.55	51.22	2.95	0.48	34.49
SD	4.47	0.62	33.53	1.48	0.88	16.82	20.99	21.62	23.35	0.97	0.17	11.88
CoV	0.17	0.08	0.39	0.23	0.33	0.44	0.31	0.38	0.46	0.33	0.35	0.34
Skewness	–0.27	0.34	–0.20	0.31	0.75	0.56	0.11	–0.15	0.10	–0.29	0.40	0.15
Kurtosis	–1.08	–0.35	–1.27	–0.82	0.46	–0.97	–0.99	1.30	–1.08	–1.12	–0.46	–1.20
85th percentile	31.02	8.20	124.75	8.53	3.28	60.31	88.74	82.74	75.72	4.05	0.63	48.08

Table 3
Qualitative trend of WQP and WQI of Rudrasagar Lake

Month	T	pH	EC	DO	BOD	COD	TSS	TDS	TH	N	P	Turb	WQI
January	0	0	0	0	0	0	0	0	0	0	0	0	–
February	0	0	+	–	0	+	0	0	+	0	+	0	–
March	0	–	+	0	+	0	0	+	0	0	0	0	0
April	0	0	+	+	+	+	–	0	+	0	+	0	0
May	0	0	0	0	+	+	0	0	+	0	+	+	0
June	0	+	+	0	0	+	0	0	+	–	0	+	0
July	0	0	+	0	0	+	0	+	0	0	0	0	0
August	0	–	+	0	0	+	0	+	+	0	–	0	0
September	0	0	0	0	0	+	0	0	+	0	0	0	0
October	0	–	0	0	+	0	0	0	+	+	0	+	0
November	0	–	+	0	+	+	0	+	0	0	0	+	–
December	0	0	+	0	0	+	0	+	0	0	+	+	0

+ Increasing;
– Decreasing;
0 No trend found.

3.1. Temperature

Temperature of Rudrasagar varied between 18°C and 33°C (Table 1) during study period, having the mean value of 26.06°C (Table 2), The temperature range of this lake was not always within permissible limits according to water research (15°C–25°C). 85% of the samples from this lake had temperature below 31°C (Table 2).

Temperature of Rudrasagar rose between 28°C and 33°C in summer and dropped between 18°C to 22°C in winter

(Fig. 2). Low SD (4.47), CoV (0.17), kurtosis (–1.08) and skewness (–0.27) suggests the distribution of temperature was rather flat (Table 2). No distinct yearly trend of temperature could be found (Fig. 2 and Table 3).

3.2. pH

pH of Rudrasagar spanned from 6.4 to 8.9 (Table 1) having the mean value of 7.53 (Table 2). Most of the samples had pH within permissible limits according to IS 10500: 2012 (6.5–8.5). 85% of the samples from this lake had pH below 8.2 (Table 2).

pH of the lake decreased a bit (6.4–6.8) in post monsoon but increased (7.6–8.9) in monsoon (probably due to the inflow of sediments) and winter (due to decrease in temperature). Low SD (0.62), CoV (0.08), kurtosis (–0.35) and skewness (0.34) suggests the distribution of pH was rather flat (Table 2). pH is observed to decrease in spring, monsoon and post monsoon and to increase in summer (Fig. 3 and Table 3) every year.

3.3. Electrical conductivity

EC of Rudrasagar ranged from 29 to 136 µS/cm (Table 1) having the mean value of 86.50 µS/cm (Table 2). EC range of this lake was within permissible limits according to IS 2296: 1992 (<250 µS/cm). 85% of the samples from this lake had EC below 124.75 µS/cm (Table 2).

EC of the lake rose in summer probably due to the increased ionic concentration for increased temperature and decreased water volume due to increased evaporation. EC dropped in post monsoon probably due to lowering of ionic concentration for increase in water volume for significant inflow during monsoon. Low CoV (0.39), kurtosis (–1.27) and skewness (–0.20) suggests the distribution of EC was rather flat (Table 2). A slight yearly increase in EC was observed in all seasons (Fig. 4 and Table 3).

3.4. Dissolved oxygen

DO in this lake varied between 3.92 and 9.16 ppm (Table 1) having the mean value of 6.38 ppm (Table 2). DO of the samples was always below the desirable limit, except in winter, according to IS 2296: 1992 (6 ppm). 85% of the samples from this lake had DO below 8.53 ppm (Table 2).

The concentration gradually decreases with increasing temperature and reaches the lowest values recorded in summer and highest values recorded in winter. Significant SD (1.48), but low CoV (0.23), kurtosis (–0.82) and skewness (0.31) suggests that there was significant variations in the DO of this lake (Table 2). DO was found to decrease yearly in spring and increase in summer during the study period (Fig. 5 and Table 3).

3.5. Biochemical oxygen demand

BOD in Rudrasagar Lake ranged from 1.18 to 4.92 ppm (Table 1) having the mean value of 2.64 ppm (Table 2). BOD of the lake was mostly beyond the desirable limit according to IS 2296: 1992 (2 ppm) during study period. 85% of the samples from this lake had BOD below 3.28 ppm (Table 2).

BOD is a method to estimate the organic load in water [23]. BOD of the lake was maximum in summer and

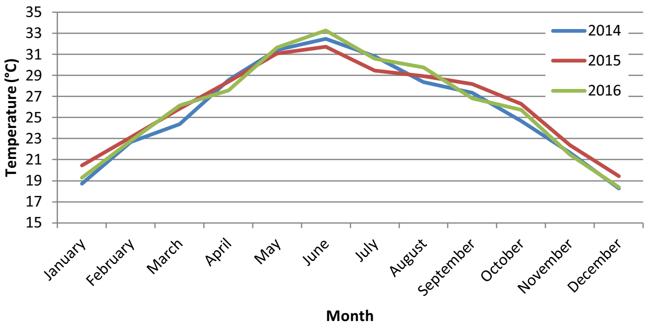

Fig. 2. Year wise distribution of temperature in Rudrasagar Lake.

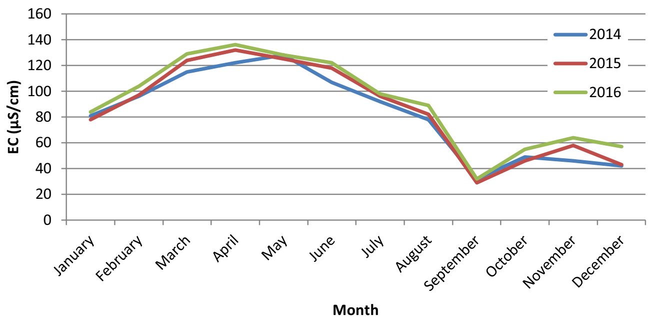

Fig. 4. Year wise distribution of EC in Rudrasagar Lake.

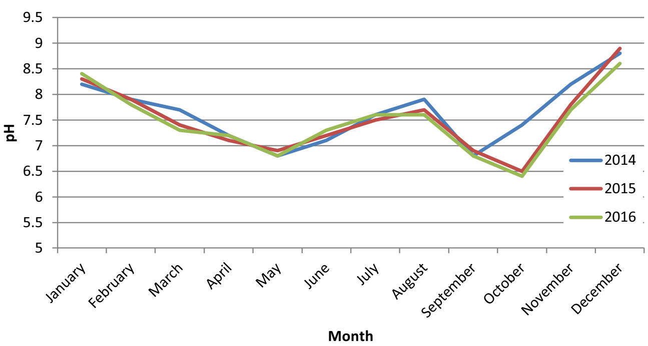

Fig. 3. Year wise distribution of pH in Rudrasagar Lake.

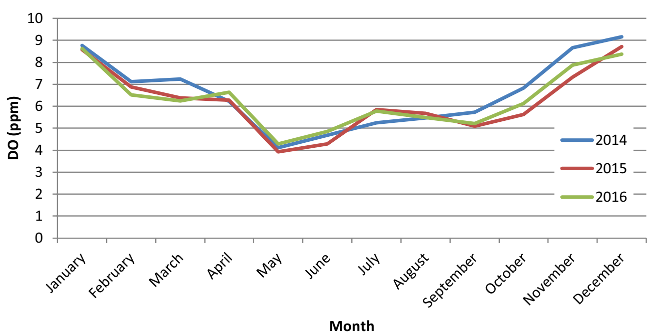

Fig. 5. Year wise distribution of DO in Rudrasagar Lake.

minimum in winter during study period. Higher SD (0.88), but lower CoV (0.33), kurtosis (0.46) and skewness (0.75) suggests the distribution of BOD was rather flat (Table 2). A yearly increase in BOD was observed in summer, spring and post monsoon (Fig. 6 and Table 3).

3.6. Chemical oxygen demand

COD of Rudrasagar Lake varied between 17.72 and 72.28 ppm (Table 1) having the mean value of 38.65 ppm (Table 2). Thus, COD of the lake was always much higher than the desirable limit, prescribed by ECE (7 ppm). 85% of the samples from this lake had COD below 60.31 ppm (Table 2).

COD increased in summer and decreased in winter – similar to BOD. Low CoV (0.44), kurtosis (–0.97) and skewness (0.56) suggests the distribution of COD was rather flat (Table 2). COD tend to increase yearly during all seasons in study period (Fig. 7 and Table 3).

3.7. Total suspended solids

TSS of Rudrasagar Lake ranged between 32.66 and 112.23 ppm (Table 1) having the mean value of 66.82 ppm (Table 2). As per ECE TSS of the lake was always beyond desirable limit (25 ppm), except in monsoon 2015. 85% of the samples from this lake had TSS below 88.74 ppm (Table 2).

TSS of Rudrasagar increased in monsoon (Fig. 8) which may be due to the sediments carried in through excess runoff. Lowest TSS were observed during winter. Higher SD (20.99) but low CoV (0.31), kurtosis (–0.99) and skewness (0.11) suggests the variations among TSS values were moderate (Table 2). TSS increased in 2015, especially in monsoon, during the study period (Fig. 8). TSS tended to decrease in early summer (Fig. 8 and Table 3).

3.8. Total dissolved solids

TDS of Rudrasagar varied from 22.84 to 89.68 ppm (Table 1) having the mean value of 56.55 ppm (Table 2). TDS of the lake was always below the desirable limit according to IS 10500: 2012 (500 ppm). 85% of the samples from this lake had TDS below 83 ppm (Table 2).

TDS increased in summer and decreased in winter. Higher SD (21.62) but lower CoV (0.38), kurtosis (–1.30) and skewness (–0.15) suggests that considerable variations existed among the values of TDS (Table 2). A yearly increase of TDS was observed in spring, monsoon and winter during study period (Fig. 9 and Table 3).

3.9. Total hardness

Hardness of Rudrasagar Lake ranged between 12.62 and 94.27 ppm (Table 1) having the mean value of 51.22 ppm (Table 2). Hardness of the lake was always below desirable limit according to IS 10500: 2012 (200 ppm). 85% of the samples from this lake had hardness below 76 ppm (Table 2).

Hardness of the lake intensified in summer and monsoon and reduced at winter. Higher SD (23.35) but low CoV (0.46), kurtosis (–1.08) and skewness (0.10) suggests that considerable variations existed among the values of TH (Table 2). Hardness showed a tendency to increase yearly in all seasons, except winter (Fig. 10 and Table 3).

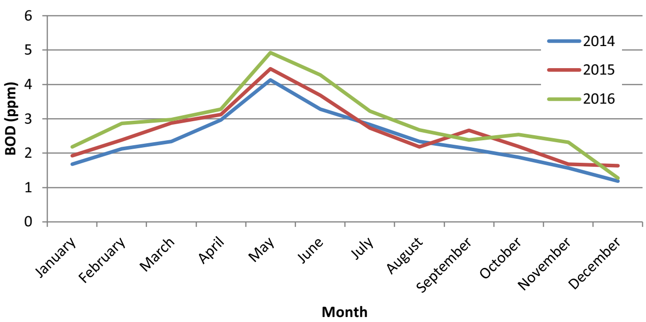

Fig. 6. Year wise distribution of BOD in Rudrasagar Lake.

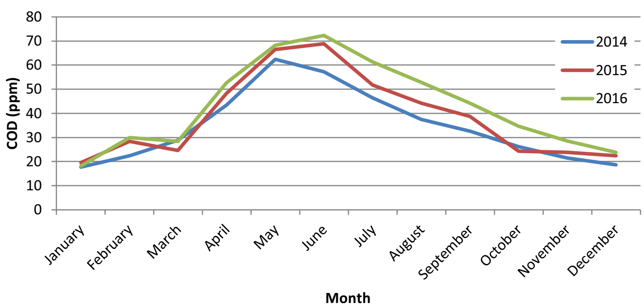

Fig. 7. Year wise distribution of COD in Rudrasagar Lake.

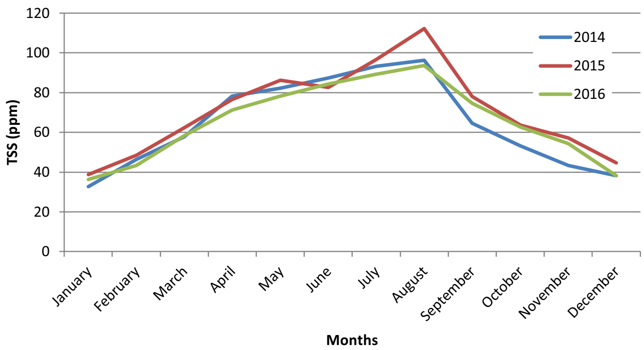

Fig. 8. Year wise distribution of TSS in Rudrasagar Lake.

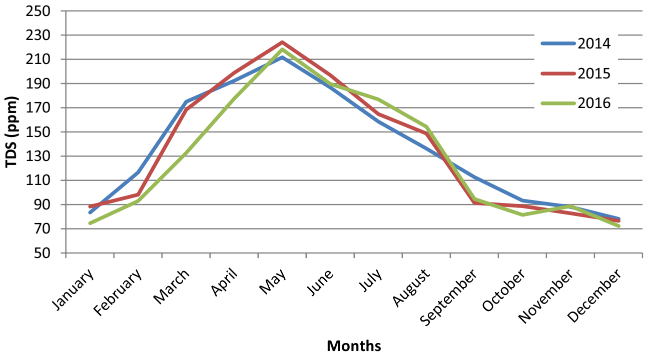

Fig. 9. Year wise distribution of TDS in Rudrasagar Lake.

3.10. Total nitrate

Nitrate of Rudrasagar varied between 1.18 and 4.32 ppm (Table 1) having the mean value of 2.95 ppm (Table 2). All nitrate values were below the desirable limit according to IS 10500: 2012 (45 ppm). 85% of the samples from this lake had nitrate below 4.05 ppm (Table 2).

Nitrate rose during post monsoon and dropped during summer. Higher SD (0.97) but low CoV (0.46), kurtosis (–1.08) and skewness (0.10) suggests that there were some variations among the nitrate values (Table 2). Nitrate decreased yearly in summer and increased in post monsoon (Fig. 11 and Table 3).

3.11. Total phosphate

The phosphate of Rudrasagar ranged between 0.22 and 0.86 ppm (Table 1) having the mean value of 0.48 ppm (Table 2). Thus, phosphate of Rudrasagar always exceeded the desirable limit (0.01 ppm) as per ECE. 85% of the samples from this lake had phosphate below 0.63 ppm (Table 2).

Phosphate peaked in monsoon and lowered in winter during the study period. Higher SD (0.17), but low CoV (0.35), kurtosis (–0.46) and skewness (0.40) suggests that there were some variations among the phosphate values of this lake (Table 2). Phosphate exhibited a tendency of increasing yearly in spring, summer and winter and decreasing in monsoon (Fig. 12 and Table 3).

3.12. Turbidity

The turbidity of Rudrasagar varied between 17.3 and 57.2 NTU (Table 1) having the mean value of 34.49 NTU (Table 2). The lake was found to be turbid always more than the desirable limit according to IS 10500: 2012 (5 NTU). 85% of the samples from this lake had turbidity below 48 NTU (Table 2).

Turbidity of Rudrasagar rose in summer and dropped in winter. Moderate SD (11.88), low CoV (0.34), kurtosis (–1.20) and skewness (0.15) suggests that moderate variations were existed among the turbidity values of this lake (Table 2). Turbidity of Rudrasagar increased yearly in summer, post monsoon and winter (Fig. 13 and Table 3).

The overall trends of the parameters, as observed in this study, were temperature, EC, BOD, TDS, hardness and nitrate of the lake were always and pH was mostly found within permissible limits for the entire period of study. TSS of the lake was always within desirable limit except during monsoon in 2015. Except in winter, DO values were always below the desirable limit. The values of COD and phosphates were much beyond the permissible limits throughout the study period. The lake was also more turbid than ideal, probably due to continuous inflow of silty water and heavy boating and fishing in this shallow lake. Similar results were also found in some other studies [5,24,25]. Such trends are comparable to the trends of other lakes in North East India, like Loktak Lake [22] Deepor Beel [26] and Umiam Lake [27].

Overall seasonal variations found were temperature, EC, BOD, COD, TDS and turbidity rose in summer, while nitrate dropped. TSS and phosphate increased during monsoon.

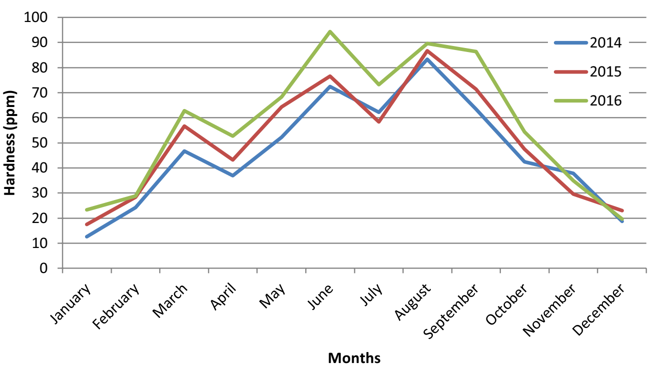

Fig. 10. Year wise distribution of hardness in Rudrasagar Lake.

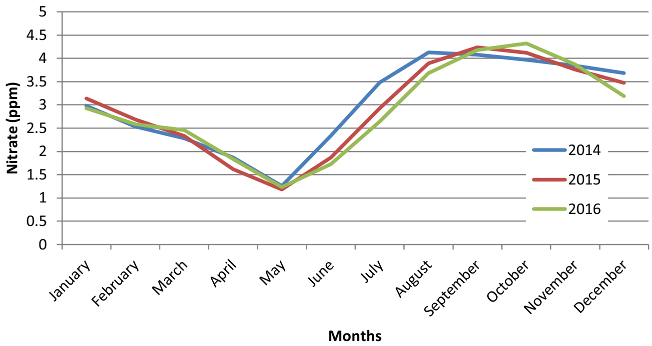

Fig. 11. Year wise distribution of nitrate in Rudrasagar Lake.

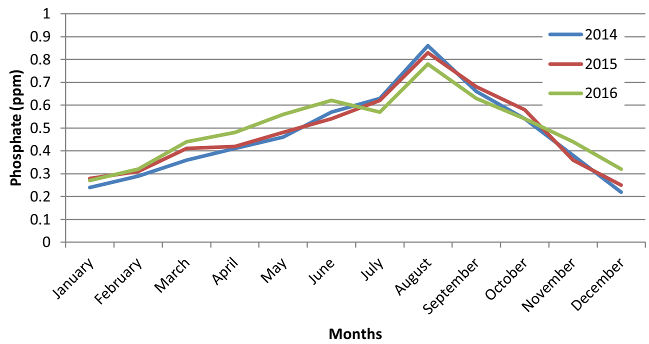

Fig. 12. Year wise distribution of phosphate in Rudrasagar Lake.

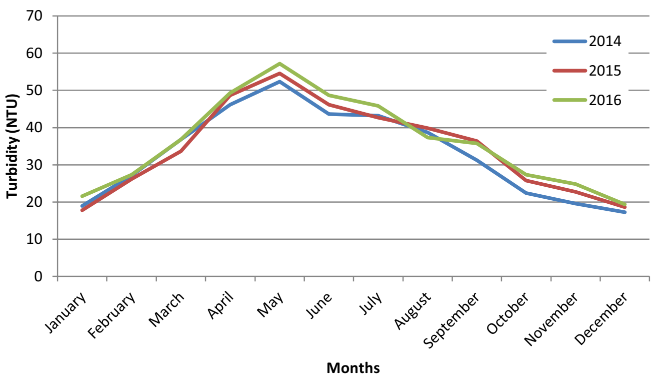

Fig. 13. Year wise distribution of turbidity in Rudrasagar Lake.

Increase in hardness was observed during summer and monsoon. EC and pH dropped, while nitrate increased in post monsoon. During winter temperature, COD, BOD, TDS, hardness, TSS, phosphate and turbidity decreased and DO increased. The lake used to be slightly alkaline in monsoon and winter. Observations of some other related studies were also similar [28,29]. Similar water quality trends can be observed in some other water bodies in Tripura [13,30,31].

In summer, the increased temperature of water causes less DO in water, which is responsible for higher mortality of the aquatic organisms. Decomposition of the dead organisms further decreases the DO and increases organic load in water. Again, due to higher evaporation, quantity of water decreases and intensifies the organic load. Thus, overall quality of water deteriorates in summer. During monsoon inflow of water increases volume and DO of water, which improves the overall quality. However, runoff carries sediments which increase TSS and turbidity of water. TSS decreases in post monsoon period and lower temperatures increases DO, which, in turn, decreases the organic load. So, water quality improves further in post monsoon. High DO and least organic load and turbidity contributes to the best overall quality of water during winter among all the seasons. As per Trophic State Index [2] the lake was oligotrophic in nature.

The functions of distribution for the parameters are presented in Table 4. These functions were yielded from polynomial regression of 6th order of the month wise values of the parameters. These functions depict the trends of individual WQP mathematically.

Within the study period, yearly trends were also observed in some WQP. Yearly increases were observed in EC, COD and hardness. The lake was becoming more acidic per annum during spring and post monsoon in the period of study. DO decreased yearly during spring. BOD increased yearly during spring, summer and winter. A yearly decrease in TDS was found during spring. Nitrate and phosphate decreased yearly in monsoon. Phosphate increased yearly during spring and summer. The lake was becoming more turbid per annum in summer during the period of study.

According to CCME WQI, overall quality of Rudrasagar was excellent for the entire period of study (WQI ~ 100) (Fig. 14). Observations, however, indicate substantial deterioration of water quality in monsoon (Fig. 14). Such seasonal deterioration was becoming less prominent across the years (Fig. 14). The water used to become excellent during winter in the study period (Fig. 14). A slight yearly deterioration was observed during winter, spring and summer (Fig. 14).

NSF WQI suggests the overall quality of the lake ranged from medium to good (index values 67–85) during period of study (Fig. 15). Deteriorations in the overall quality of the lake were observed in summer and improvement was observed during winter (Fig. 15). A slight yearly deterioration was observed during winter (Fig. 15 and Table 3).

WSM WQI shows similar results as NSF WQI (Fig. 16). WSM WQI, however, is expected to express water

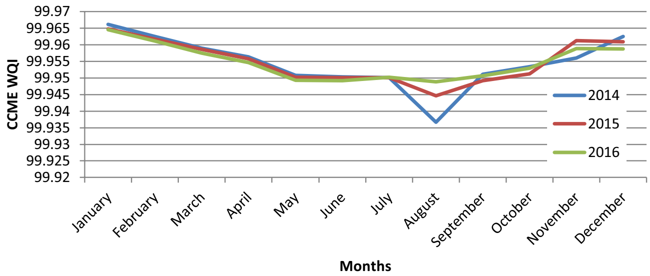

Fig. 14. Year wise distribution of CCME WQI in Rudrasagar Lake.

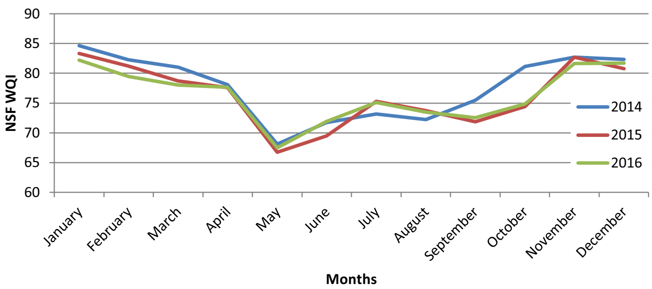

Fig. 15. Year wise distribution of NSF WQI in Rudrasagar Lake.

Table 4
Functions of distribution for the parameters

Parameters	Functions of distribution	r	R^2
T	$-0.000x^6 + 0.006x^5 - 0.064x^4 + 0.197x^3 + 0.156x^2 + 1.765x + 17.54$	0.98	0.97
pH	$-0.000x^6 + 0.009x^5 - 0.143x^4 + 1.094x^3 - 4.014x^2 + 6.096x + 5.205$	0.90	0.80
EC	$-0.005x^6 + 0.203x^5 - 2.655x^4 + 16.25x^3 - 52.31x^2 + 100.5x + 17.85$	0.97	0.93
DO	$7 \times 10^{-06}x^6 - 0.000x^5 + 0.003x^4 - 0.024x^3 + 0.214x^2 - 1.755x + 10.09$	0.91	0.83
BOD	$-8\text{E-}05x^6 + 0.002x^5 - 0.013x^4 - 0.056x^3 + 0.740x^2 - 1.466x + 2.786$	0.89	0.80
COD	$-0.002x^6 + 0.073x^5 - 0.845x^4 + 3.470x^3 - 0.962x^2 - 8.555x + 26.43$	0.94	0.89
TSS	$-3\text{E-}05x^6 + 0.007x^5 - 0.191x^4 + 1.543x^3 - 5.453x^2 + 20.55x + 18.86$	0.95	0.91
TDS	$-0.002x^6 + 0.076x^5 - 0.904x^4 + 4.555x^3 - 11.53x^2 + 26.03x + 35.11$	0.96	0.93
TH	$0.002x^6 - 0.063x^5 + 0.734x^4 - 3.828x^3 + 8.017x^2 + 9.115x + 2.873$	0.91	0.84
N	$9 \times 10^{-05}x^6 - 0.002x^5 + 0.013x^4 + 0.073x^3 - 0.832x^2 + 1.662x + 2.052$	0.97	0.94
P	$2 \times 10^{-05}x^6 - 0.000x^5 + 0.010x^4 - 0.061x^3 + 0.174x^2 - 0.167x + 0.303$	0.96	0.92
Turb	$-0.000x^6 + 0.027x^5 - 0.444x^4 + 3.628x^3 - 14.87x^2 + 24.46x + 69.81$	0.98	0.96

Table 5
Functions of distribution for the indices

WQI	Functions of distribution	r	R^2
CCME	$-7 \times 10^{-07}x^6 + 3\text{E-}05x^5 - 0.000x^4 + 0.002x^3 - 0.008x^2 + 0.009x + 99.96$	0.93	0.87
NSF	$-0.000x^6 + 0.028x^5 - 0.462x^4 + 3.746x^3 - 15.3x^2 + 25.47x + 69.44$	0.87	0.76
WSM	$-0.000x^6 + 0.027x^5 - 0.444x^4 + 3.628x^3 - 14.87x^2 + 24.46x + 69.81$	0.88	0.78

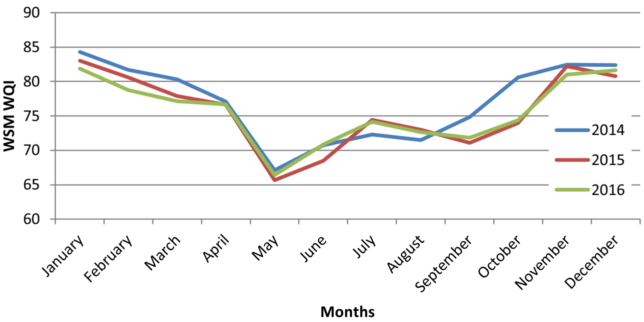

Fig. 16. Year wise distribution of WSM WQI in Rudrasagar Lake.

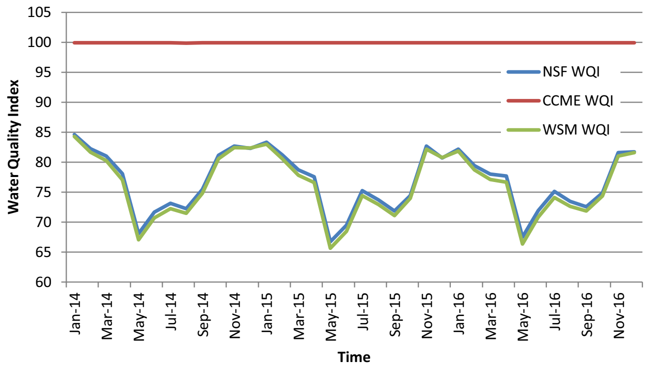

Fig. 17. Comparison between different WQI.

quality in more holistic and reliable way as it was based upon some important criteria.

Among the indices used in this study, CCME was meant for durational quality, but NSF and WSM were point indices. Considering the nature of the indices, the overall quality of water may be taken as excellent with negligible seasonal variance of water quality on durational aspect. According to point indices, however, the overall quality varied from good to medium with substantial seasonal fluctuations (Fig. 17).

Assessment of the parameters also points out to the fact that water quality of Rudrasagar not being good for the entire period of study and they did have fluctuations across the different seasons. Now, CCME relies on the occurrence of deviation from the desirable limits. Thus, it may exaggerate the overall water quality. So, the interpretation of the overall quality seems to be more realistic to indicate non ideal water quality, especially in summer, with seasonal fluctuations.

The functions of distribution for the parameters are mentioned in Table 5. These functions were yielded from polynomial regression of 6th order of the month wise WQI values. These functions depict the trends of individual WQI mathematically.

As Rudrasagar is a Ramsar site, the quality, along with its trend, of this lake is of global concern. So, in the present study assessment of water quality and its trend for this lake was undertaken for a longer period of 3 y. Trends of water quality were determined both qualitatively (Mann–Kendall test) and quantitatively (distribution functions). Mann–Kendall test only shows whether any parameter or WQI was increasing or decreasing during study period. Distribution functions, on the other hand, the actual mathematical expression with respect to time. Thus, distribution functions are more useful in determining trend of water quality. Also the values of the WQP or WQI can be determined approximately with the distribution functions at any month. However, both the methods exhibit similar trends in this study. This serves as a validation for both of them.

As per the trends, water quality of the lake varied from medium to good with range of WQI from 67–85. In summer, some deterioration in water quality was observed (WQI: 73–78). In winter, however, water quality improved with WQI between 81 and 85. Water quality was also observed to deteriorate every year in winter in a range of WQI 1–3.

The information, generated in this study, may be useful for proper management planning of this lake for effective conservation. Methodologies adopted here can also be used for the similar assessment of any other water body in the world.

4. Conclusion

12 important WQP of Rudrasagar Lake were estimated for 3 y in monthly intervals to analyze water quality trend of this lake both qualitatively and quantitatively. Results suggest that quality of water was fair (ranged from medium to good) during the study period, with some deteriorations in summer and improvement in winter. However, the lake contained less DO (except in winter) and was turbid throughout the study period. COD, nitrate and phosphate of the lake were also much higher during the study period. Seasonal variations of different WQP were observed. pH decreased during spring and post monsoon. DO decreased in spring and BOD increased in spring, summer and winter. However, TDS decreased during spring, while nitrate decreased in monsoon. Phosphate decreased in monsoon but increased in spring and summer. Turbidity increased in summer. Seasonal variation of DO was due to seasonal temperature variation. Deceased DO in warmer seasons cause mortality of aquatic organisms and thereby causes increase in BOD and TDS. In monsoon, increased runoff carrying sediments causes

increase in TSS and turbidity. Thus, lower DO and higher BOD and TSS make the water quality deteriorated in summer and the reverse the water quality in winter. A slight yearly degradation of the water quality was also found in winter. Thus, it can be concluded that the overall health of the lake was fair in the study period, but some better management should be planned during summer. The functions of distribution for the WQP and WQI may be useful for approximate prediction of water quality instantly at any point of time till any considerable change in the scenario.

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