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Assessment of Aquatic Ecological Health : A Case Study of Lake Rewalsar, Himachal Pradesh

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ABSTRACT

The present study was conducted for two years to analyze the water quality of the sacred lake Rewalsar. Water quality of different seasons was evaluated by water quality index. Various statistical techniques, such as correlation, principal component analysis were applied. Based on Water Quality Index, water quality of the lake was in the range of 33-80 in different seasons. Cluster analysis of similarity indicates the relationship intensity between the seasons as cluster ranged 80-100% during the study period. In the principal component analysis maximum variables (Conductivity, Alkalinity, Biochemical Oxygen Demand, Nitrates, Phosphates, and Chloride) shows maximum influence during the summer and monsoon. The outcome revealed that the major driving factors of water quality deterioration are the runoff of effluent from the domestic area and offering food materials to the fishes. So, it is necessary to implement effective management strategies for the conservation of the Rewalsar lake..

KEYWORDS

Water quality index, Rewalsar lake, Principal component analysis (PCA), Ecological health, Parameters

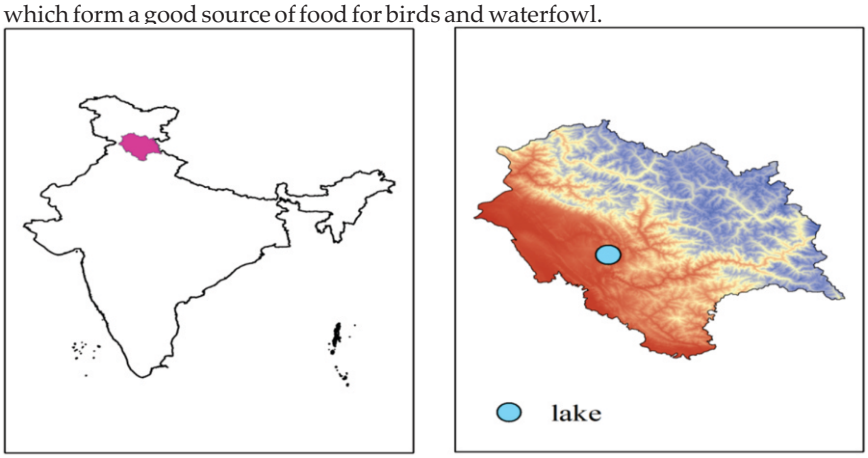
INTRODUCTION

Lakes are considered as Earth's most crucial store of freshwater, which provides shelter for many aquatic lives (Abir, 2014). The degradation of the water quality of lakes and wetlands has been observed over the last centuries. The lakes, which are located inside the cities and human habitations, are more susceptible to water quality degradation (Chandra *et al.*, 2010). This freshwater gets affected day by day due to population explosion, high encroachments rate and discharge of sewage effluents, etc., which results in the water quality deterioration and also hampers flora and fauna of the lake. The major environmental stress for lakes is due to excess nutrient loading resulting from the discharge of domestic, municipal and industrial waste. Other several factors like religious offerings, recreational and constructional activities in the catchment areas consequently affect the Physico-chemical properties of the lake ecosystem (Bhat *et al.*, 2015; Panda *et al.*, 1991). Access to safe drinking water is a significant issue for health and development not only at national but at regional and local levels also. Therefore, regular and effective monitoring of water bodies has become an urgent need to overcome the escalating incidents of water pollution and their impacts on human health. Himachal Pradesh, the land of gods, known as 'Dev Bhoomi' has several sacred sites, sacred mountains, natural springs and lakes. One of them is a mid-altitude holy lake, the Rewalsar lake located in Mandi District, worshiped by a large number of Hindus, Sikhs and Buddhists. Anthropogenic pressure like urbanization and religious offerings in this sacred lake leads to nutrients enrichment, which degrades the water quality of the holy lake. Maintaining the physical and chemical properties of the water is very important for the conservation of the lake ecosystem. A large number of tourists and pilgrims visit the lake throughout the year. Therefore, the present investigation has been carried out to assess the health of the Rewalsar lake ecosystem through monitoring seasonal variations in physicochemical parameters and to check the status of water quality.

MATERIALS AND METHODS

Study area

Rewalsar lake is a mid-altitude lake situated at an altitude of 1,330 m above mean sea level on a mountain spur in Mandi district, 22.5 km south-west from Mandi, Himachal Pradesh at latitude 31° 37' N and longitude 76° 49' E . The approximate area of the lake is 3.12 ha with a maximum depth 6 m (Fig.1). Rewalsar lake supports a large number of fishes, amphibians, mollusks and aquatic insects and their larvae, which form a good source of food for birds and waterfowl.



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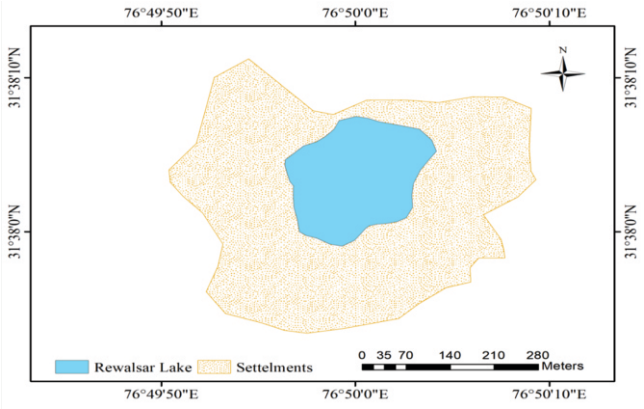


Fig.1: Location map of the study area

Assessment of Rewalsar lake water quality

Physico-chemical characteristics of the Rewalsar lake was studied from November 2014 to October 2016. Five seasons i.e., monsoon (July-August), autumn (September-October), winter (November, December and January), spring (February-March) and summer (April-June) were considered. Standard methods were followed for the collection and analyses of physico-chemical parameters. Centigrade Mercury thermometer (0–110˚C) used for measuring water temperature, electrical conductivity (EC) and pH were analyzed with the help of Toshcon Multi parameter Analyser. Dissolved oxygen, free carbon dioxide, Biochemical oxygen demand (BOD), alkalinity, hardness, chlorides, nitrates, phosphates, Calcium, and Magnesium were analyzed by using standard methods outlined in (Wetzel and Likens, 1991; APHA,1998). Pearson's correlation between various physicochemical parameters was analyzed with the help of SPSS software (16.0). Cluster analysis and principal component analysis (PCA) were also carried out for all the seasons by using PAST software.

Water Quality Index (WQI) was calculated using the weighted arithmetic index method (Brown *et al.*, 1972). WQI accumulate varied parameters and their proportions in a single value that reflects the water quality of the lake. The standards used for the calculation of WQI were the Bureau of Indian Standards (BIS), the World Health Organization (WHO) and the Indian Council for Medical Research (ICMR). Water quality rating index was calculated by following three steps expression.

First Step

To calculate the water quality index, each of the eleven parameters we have calculated by quality rating q_n for this need an estimated value of the parameters and its ideal value and standard permissible value. Following is expression was used.

$$q_n=100[V_n-V_{io}]/[S_n-V_{io}] \quad (1)$$

q_n = Quality rating for n^{th} water quality parameter, V_n = Estimated value of the n^{th} parameter at a given water of the lake, S_n = Standard permissible value of the n^{th} parameter, V_{io} = Ideal value of the n^{th} parameter in water (i.e., 0 for all other parameters except the parameters pH and Dissolve oxygen 7.0 and 14.6 mg/l correspondingly).

Second Step

In second step, we calculate the unit weight W_n for each parameter. The unit weight (W_n) was calculated by a value inversely proportional to the recommended standard value S_n of the corresponding parameter.

$$W_n=k/S_n \quad (2)$$

Where W_n = unit weight for the nth parameter
S_n = standard permissible value for the n^{th} parameter
k = proportionality constant.

Third Step

Overall water quality index was computed by using the product of a quality rating and unit weight divided by the sum of all the unit weight for the corresponding parameters. The overall WQI is calculated by the following equation.

$$WQI=\Sigma q_n W_n/\Sigma W_n \quad (3)$$

RESULT AND DISCUSSIONS

Mean seasonal variation of physico-chemical parameters for both the years has been presented in Table 1. Water temperature acts as an important parameter to influence the aquatic ecosystem. The water temperature of an aquatic body directly influences the amount of dissolved oxygen (DO) present in it (Wetzel, 1966; Kumar *et al.*, 1996). Minimum water temperature (13.06±0.85˚C) was recorded during the

Table 1 : Seasonal variation of physico-chemical variables (X ± S.D.) of Rewalser lake during November 2014 to October 2016

Parameters	Winter ($\bar{x}$±S.D.)	Spring ($\bar{x}$±S.D.)	Summer ($\bar{x}$±S.D.)	Monsoon ($\bar{x}$±S.D.)	Autumn ($\bar{x}$±S.D.)
Water Temperature (^{0}C)	13.06±0.85	17.05±0.42	25±0.28	21.975±1.38	18.275±0.39
pH	8.39±0.04	8.42±0.16	7.40±0.3	6.34±0.17	6.99±0.11
EC (μScm^{-1})	210.83±3.54	282.25±10.96	458.33±2.36	352.5±4.95	315.25±3.18
Dissolved oxygen (mg/l)	7.61±0.55	7.00±0.49	4.93±0.04	5.18±0.04	6.35±0.52
BOD (mg/l)	2.44±0.26	2.65±0.21	5.06±0.66	4.1±0.28	2.72±0.46
FreeCO_2 (mg/l)	2.54±0.54	1.77±0.46	6.6±0.42	5.97±0.04	4.3±0.57
Alkalinity(mg/l)	98.165±7.3	124.25±1.06	170.5±14.85	83.25±3.89	80.25±0.35
Hardness(mg/l)	104.79±8.65	73.08±7.95	169.69±10.59	153.02±1.45	125.4±13.72
Chlorides(mg/l)	46.98±8.36	41.455±9.11	53.285±0.6	83.04±3.48	62.56±4.09
Nitrates(mg/l)	0.09±0.01	0.12±0.01	0.39±0.02	0.65±0.04	0.275±0.01
Phosphates(mg/l)	0.139±0.05	0.089±0.013	0.33±0.01	0.460±0.02	0.39±0.00
Calcium(mg/l)	23.12±5.54	24.65±4.94	32.43±3.3	28.44±1.68	23.08±3.43
Magnesium(mg/l)	21.32±1.35	13.13±1.2	34.07±2.34	30.96±1.05	27.21±0.83

winter season and maximum 25±0.28 ˚C during summer, which is in concordance with the findings of Kannan and Job (1979); Surve *et al.* (2005).

A significant positive relationship between water temperature and electrical conductivity EC (r=0.979**), BOD (r=0.892**) and free CO_2 (r=0.846**) with level of significance p<0.01 was recorded (Table 2). pH denotes hydrogen ions concentration in water and it is a measure of acidic and alkaline nature of the water. There are different reasons which cause changes in the pH of water. The decrease in the rate of photosynthesis decreased the absorption rate of carbon dioxide and bicarbonates resulting in the high pH of water bodies (Bhateria and Jain, 2016). According to Khan and Khan (1985) and Murhekar (2011), the higher the range of pH shows higher the productivity status of water bodies. During the present investigation, the pH of the Rewalsar lake was observed lower (6.34±0.17) during the monsoon season. This may be due to mixing and entering of surrounding run-off (e.g detergent). Sarkar *et al.* (2016) studied the two diverse rates of the sedimentation in Rewalsar lake, first in top 50-cm part of the core which shows 2.78 cm/year, while the second 50–200cm part of the core exhibits 3.92 cm/year, which indicate these rapid and major changes occurred by the surrounding run-off. Minimum pH during monsoon was also reported byDhanalakshmi *et al.* (2013).

The higher value (458.33±.36 µScm-1) of EC was observed during the summer season, whereas it was low (210.83±3. μScm^{-1}) during the winter season. Rao *et al.* (1990); Gupta (2013) and Bhatt *et al.* (1999) also reported high electrical conductivity during the summer season. Electrical conductivity have shown positive correlation (p<0.01) with water temperature (r=0.979**), free CO2 (r=0.831**) and BOD (r=0.869**); whereas, electrical conductivity have negative correlation (p<0.01) with pH (r= -0.564) and DO (r= -0.928**). Dissolved oxygen is known to be an important parameter for the survival of fishes and other aquatic organisms present in a water body. The concentration of dissolved oxygen was lowest (4.93±0.04 mg/l) in the summer season and maximum (7.61±0.55 mg/l) in winter season at Rewalsar lake. Edmondson (1965) observed that the low concentration of dissolved oxygen in the summer season might be due to a high metabolic rate of organisms during the summer season. The higher concentration of dissolved oxygen in the winter season was also similar to the findings of Rawat and Sharma (2005). Dissolved oxygen have significant negative correlation (p<0.01) with water temperature (r = - 0.943**) and BOD (r = - 0.859**). However, it expresses a significant positive relation (p<0.01) with pH (r = 0.720**). BOD directly affects the amount of dissolved oxygen present in any water body. The higher rate of BOD is an indicator of a high level of pollution of organic matter. The biochemical oxygen demand of Rewalsar lake was recorded minimum (2.44±0.26 mg/l) during the winter season and maximum (5.06±0.66 mg/l) during the summer season, similar findings were also reported by Bhatt *et al.* (1999); Devaraju *et al.* (2005). Leaves, woody waste; dead plants and animal manure and effluents from sewage water are some of the sources which increase the concentration of BOD in a water body (Paul and Mukherjee, 2006). The BOD showed high significant positive correlation (p<0.01 level) with water temperature (r= 0.892**), free carbon dioxide (r=0.893**) and EC (r=0.869**). However, it showed a negative correlation with DO (r= -0.943**). The concentration of carbon dioxide content in water depends upon the various factors like water temperature, depth, the rate of respiration, decomposition of organic matter, chemical nature of the bottom substrate and geographical features of the terrain surrounding the water body (Sakhare and Joshi, 2002; Garg *et al.*, 2010). The lowest value of free CO_2 was recorded in the winter season (1.2 mg/l) whereas, it was recorded high (6.6±0.42 mg/l) in the summer season. The higher values of free CO_2 in the summer season in Gharana wetland have also been reported by Tara *et al.* (2011). The concentration of total alkalinity was highest (170.5±14.85) during the summer season whereas, it was found to be lowest (98.165±7.3) in the winter season. The increase in alkalinity during the summer season may be due to an increase in the concentration of carbonates and bicarbonates in the water body (Bhalera, 2012).

Total alkalinity showed a positive correlation with water temperature (r=0.576), conductivity (r=0.620*) and BOD (r=0.684*). Hardness in water is mostly caused by calcium and magnesium ions, with all other divalent cations also contributing to the concentration. In the present study, the value of total hardness varied between 62.37 mg/l and 190.41 mg/l. The maximum value of the total hardness was recorded during the summer season.Khan and Chowdhury (1994) observed that a higher concentration of total hardness during the summer season may be due to the higher temperature, resulting in an increased concentration of salts by excessive evaporation. The minimum value (23.12±5.54 mg/l) of calcium was found in winter season whereas, maximum 32.435±3.3 mg/l during the summer season. Increase in the calcium concentration from winter to summer season due to rapid oxidation of organic matter. Calcium occurs in greater quantity in all-natural water as its main source is weathering of rocks from which it leaches out (Jemi and Balasingh, 2011). The lower value of calcium concentration during the winter season may be due to the absorption of calcium by living aquatic organisms in winter (Pulugandi 2014). The values of calcium were higher than magnesium, a fact well supported by Patil *et al.* (2004). The amount of magnesium recorded in the water body of Rewalsar ranged between 10.59 mg/l and 38.34 mg/l. The maximum amount (38.34 mg/l) of magnesium was recorded during the summer season and the minimum (10.59 mg/l) during the winter season. Magnesium showed a significant positive correlation with total hardness. Lower values of magnesium than calcium may be attributed to plankton and algal uptake (Rath*et al.*, 2000).

Chloride is an inorganic anion in water, which is highly soluble so that it is found in all kinds of water. In the present investigation, the chloride concentration was found in the range of 32.4 mg/l and 83.20 mg/l. The high value (83.04±3.48 mg/l) of chloride concentration during monsoon is an indicator of pollution by sewage (Dahiya and Kaur, 1999; Murhekar, 2011). Nitrate is known to be the most chemically stable form of nitrogen. A higher concentration of nitrates can

result in excess algal blooms in a water body. Maximum 0.682 mg/L concentration of nitrates was recorded during monsoon season and minimum (0.068 mg/l) during the winter season. The present findings were similar to the results reported by Sexena*et al.* (2012); Mustapha *et al.* (2008). Phosphate is an important nutrient required for the growth and richness of plankton in the water body (Namrata and Khushwah, 2014). The concentration of phosphates obtained in the range of (0.054 to 0.491 mg/l). A higher value of phosphates was recorded during monsoon. It gets support from the findings of Kannan and Job (1979); Mishra *et al.* (2008) and Parikh and Mankodi (2012).

During the study, it was found that, during the Baisakhi festival in April, most of the local people of Mandi district and the surrounding areas come here and witness the festival. It was observed as the peak period of tourism during the study period. There is a belief that during this time if people take bath and offer the food (biscuit or wheat flour) to fishes of this sacred lake, they will get their wishes fulfilled in return. But this act is disastrous for the aquatic life and ecosystem of the sacred lake because excess loading of food material in the lake is a cause of morality to several fishes causing foul smell in the vicinity.

Table 2: Pearson's Correlation coefficient calculated between various physico-chemical parameters of water of Rewalsar lake, during November 2014-October 2016

	WT	EC	DO	pH	BOD	FCO	Alkalinity	Hardness	Chloride	Nitrates	Phosphate	Calcium	Magnesium
WT	1												
EC	.979**	1											
DO	-.943**	-.928**	1										
pH	-.637*	-0.564	.720*	1									
BOD	.892**	.869**	-.859**	-0.512	1								
FCO	.846**	.831**	-.868**	-.752**	.893**	1							
Alkalinity	0.576	.620*	-0.412	0.212	.684*	0.389	1						
Hardness	.814**	.798**	-.835**	-.719*	.892**	.986**	0.398	1					
Chloride	0.457	0.363	-0.587	-.931**	0.377	.642*	-0.386	0.599	1				
Nitrates	.713*	.622*	-.757**	-.909**	.692*	.833**	0.024	.797**	.870**	1			
Phosphate	.647*	.610*	-.738**	-.953**	0.572	.850**	-0.121	.817**	.894**	.859**	1		
Calcium	.856**	.851**	-.779**	-0.428	.948**	.851**	.725*	.824**	0.308	.663*	0.498	1	
Magnesium	.779**	.766**	-.823**	-.753**	.827**	.964**	0.306	.987**	.625*	.771**	.852**	.731*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
Abbreviations: WT: Water temperature, EC: Electrical conductivity, DO: Dissolved oxygen, BOD: Biochemical Oxygen Demand, FCO: Free Carbon dioxide

Water Quality Index

The Water Quality Index (WQI) is used as a tool to understand the level of water quality. Water quality index values also indicate that at what extent water is useful (Kumari and Sharma, 2018). The water quality index signifies as scale of water quality if the WQI between 0-25 means "excellent"

Table 3: Water quality index (WQI) for Rewalsarlake during November 2014-October 2016

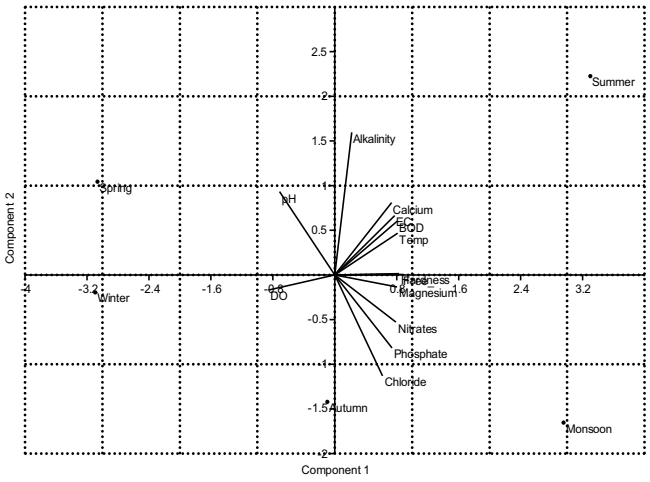
Parameters	W_n	S_n	Winter	Spring	Summer	Monsoon	Autumn
pH	0.093	6.5-8.5	9.964	11.284	3.247	-5.404	-0.04
EC (μScm^{-1})	0.003	300	0.214	0.286	0.465	0.357	0.32
Dissolved oxygen (mg/l)	0.159	5	9.216	10.024	12.758	12.422	10.885
BOD (mg/l)	0.159	2	11.614	25.34	60.242	64.933	33.157
Alkalinity (mg/l)	0.007	120	0.155	0.197	0.271	0.132	0.127
Hardness(mg/l)	0.003	300	0.166	0.116	0.269	0.242	0.199
Chlorides (mg/l)	0.003	250	0.26	0.278	0.365	0.323	0.26
Calcium (mg/l)	0.011	75	0.003	0.004	0.013	0.02	0.009
Nitrates (mg/l)	0.018	45	1.501	0.924	2.399	2.179	1.915
Phosphates (mg/l)	0.53	1.5	0.048	0.042	0.054	0.084	0.063
WQI			33.141	48.495	80.083	75.288	46.895

quality of water, 25-50 means "good" water quality, 51-75 range means "poor" water quality, 76-100 means "very poor" water quality and if it found more than100 means the water is "unsuitable" for drinking (Etim*et al.,* 2013). Therefore, ten physico-chemical parameters, namely dissolved oxygen, pH, BOD, alkalinity, total hardness,Calcium, chlorides, nitrates and phosphateshave been considered for calculating the WQI (Table 3). WQI of Rewalsarlake calculated in the range of 29-49. A remarkable difference in the water quality index was observed during winter (33.14), spring (48.49), autumn season (46.89), monsoon season (75.28) and summer season (80.08). Deterioration in the water quality during summer and monsoon seasons may be attributed to the high value of Biochemical Oxygen Demand (BOD).

Principal Component Analysis

Principal component analysis (PCA) is a statistical tool that was applied on the physico-chemical data to reduce the dimensionality of a data set, which consists of a large number of interrelated variables, at the same time it retains the variation possibility of the data(Joliffe, 2002). This was successfully done in the present study for the two year study period. Based on the correlation values, thirteen physico-chemical variables were considered for PCA ordination. A PCA bi-plot was made to analyze the variation pattern of physico-chemical variables during different seasons (Fig. 2). The percentage of variance for the first two components represented up to PC1-74.21% and PC2-20.83% of the total variance in the data set. The total score of the first two components PC1 and PC2 were explained 95.04% of the total variance. At PC1 the positive loading of the free carbon dioxide (FCO_2), hardness, biochemical oxygen demand (BOD), temperature, Magnesium (Mg), nitrates (NO_3) and phosphates in monsoon and summer seasons have been associated with surrounding sewage runoff in both the year. Whereas, negative loading of pH and dissolved oxygen (DO) represents anthropogenic pollution sources as high levels of dissolved organic matter consume a large amount of oxygen for decomposition and also leads to a decrease in pH due to hydrolysis and nitrification process in Rewalsar lake during the summer and monsoon seasons.

Fig. 2: Bi-plots for principal component analysis during the period from November 2014 to October 2016



CONCLUSION

Data on physico-chemical parameters and WQI of Rewalsarlake revealed that water quality was degraded during summer and monsoon seasons. The outcomes from PCA showed the maximum positive relation in monsoon and summer seasons. This may be due to the heavy influx of pilgrims visiting the Lake during April (summer season) offering food materials to the fishes. Whereas, during monsoon, the main cause of deterioration was observed the mixing of surrounding sewage run-off (chemicals, sanitary sewer and detergent, etc.) enter into the lake. The present study provides baseline data for the conservation and management of sacred Rewalsarlake. As per WQI calculated for different seasons showed that if adequate measures are not adapted for the management of the lake, it will degrade the water quality of sacred lakeRewalsar in the coming time. Keeping in the view the condition of the Rewalsarlake, some conservation measures are recommended. Implementation of proper sewage management plan, regulator distillation, regular scientific monitoring of the lake and raising awareness are important point should be taken into consideration.

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