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Long-term Changes in Physico-chemical Variables of Lake Khurpatal, Kumaun Himalaya, India

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ABSTRACT

This research was designed to obtain information on long term changes in water quality of Lake Khurpatal, (Kumaun Himalaya, India). The study was conducted during 2016-17 and 2017-18. The results of the study were compared with the studies carried out about 35 years back. It was noticed that water transparency and concentration of dissolved oxygen in the lake were lowered by 37.5% and 32.2%, respectively in the last 35 years. The water pH was reduced from 8 to 6.7 in the same period of time. The concentration of silica was increased by 26%, however, the lake water was within the set limit of freshwater with regards to salinity. The concentration of PO_4-P was increased by 26 times while the ammonium - nitrogen and nitrate-nitrogen increased by 23% and 33%, respectively in last 35 years. The studied parameters of water quality suggested that lake has turned to eutrophic state in this duration.

Key words *: Lake Khurpatal, Kumaun Himalaya, Long term changes, Eutrophication.*

Introduction

Lake Khurpatal is a small natural lake with a surface area of 366m^2, the maximum length of 495m and the maximum width of 226m. The lake lies at an altitude of 1600m above sea level between 29^{0}5′ N latitude and 79^{0}27′ E longitude. The word 'Khurpatal' is derived from a Hindi word 'Khur' means horseshoe shaped and 'Taal' means 'lake'. During 1980s when the lake was studied for the first time (Sharma *et al.* 1982; Jaiswal, 1983), it was in oligotrophic state. Thereafter, no study was conducted to understand the ecology of the lake and the changes undergone in last 35 years. The purpose of this study was to determine the long-term changes in physico-chemical properties of the lake water after the lapse of 35 years.

Although several long-term studies have been carried out in many lakes of foreign countries (Magnuson, 1990; Zinabu *et al.*, 2002; Xie and Xie, 2002; Jassby *et al.*,2003; Okamura, 2008; Daloglu *et al.*, 2012; Grochowska *et al.*, 2014; Dove and Chapra, 2015; Bhattral *et al.*, 2017a, 2017b; Wang, 2019), such studies are limited in India (Nagdali, 2002; Maindoli, 2019). Long-term studies have been increasingly recognized for their contribution in understanding of ecosystem functioning. Such studies demonstrate the changes taking place in the catchment areas and other environmental factors.

Materials and Methods

Three sampling sites in the shore area of the lake were selected. Samplings from these sites were done at monthly intervals. Temperature, transparency, pH, concentration of carbon dioxide and dissolved oxygen were measured on the spot itself, while the other parameters were analysed in the laboratory. Temperature was measured by a good grade mercury thermometer, pH by pH paper (Qualigen make), and water transparency was measured by a black and white Secchi disc. The concentrations of CO_2 and dissolved oxygen were determined by titration method (A.P.H.A, 1989). The concentration of silica, total dissolved solids and salinity were determined by methods describe in A.P.H.A. The other parameters were analysed by a microprocessor based YSI photometer (model 9300, US make).

Results and Discussion

Temperature

The monthly mean water temperature in the lake varied from a minimum of 9.4 °C (January, 2017) to a maximum of 27 ^{0}C (June, 2017) during the first year of the study. The pattern of variation in water temperature during the next six months followed the pattern of first year. During this period the minimum temperature was in the month of December, 2017 (9.5^{0}C) and maximum in April, 2018 (23.7^{0}C) (Fig.1). Usually the temperature followed the pattern similar to ambient temperature.

Secchi disc transparency

Relatively the water transparency of Lake Khurpatal was low. It ranged from a minimum of 1m (August, 2017) to a maximum of 2.3m (February, 2017) during the first year of study. In the next six months the Secchi disc reading fluctuated from 1.5m (April, 2018) to 2.5m (February, 2018) (Fig. 2). The pattern of seasonality in transparency during both years was more or less similar. The annual mean water transparency was 1.55m. There was significant seasonal variation in secchi disc transparency ($p<0.05$).

Hydrogen ion concentration (pH)

The lake water was found to be slightly acidic for

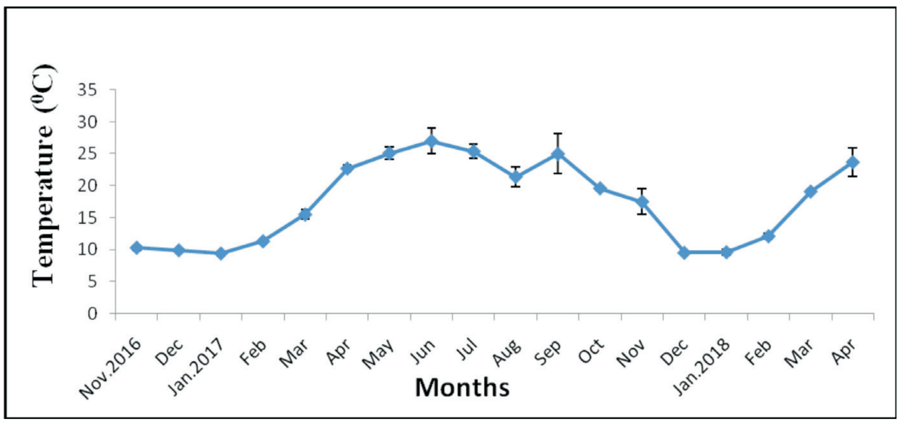

Fig. 1. Seasonal variation in mean temperature in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

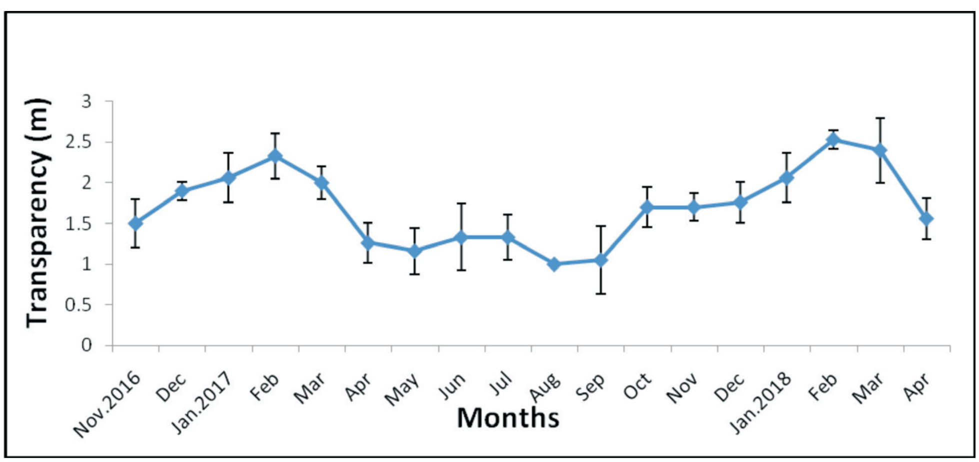

Fig. 2. Seasonal variation in mean transparency in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

the most part of the year. It was only one occasion (January, 2017), when the water was slightly alkaline (7.1). Temporally, the pH varied from 6.2 to 7.1 being minimum in the month of November, 2016 and maximum in the month of January, 2017. The trend in pH variation during the next six months was similar to the previous year and data during this period varied from 6.7 to 7.1 (Table 1). The annual mean pH was computed at 6.7.

Concentration of free carbon dioxide

The concentration of free carbon dioxide was comparatively low. Within a year the values ranged from a minimum of 1.5 mg/l (September, 2017) to a maximum of 4.6 mg/l (April, 2017) during the first year of the study (Table 1). During the next six months the concentration oscillated from 3.3 to 4.5 mg/l. The annual mean concentration of free carbon dioxide was 3.7 mg/l.

Concentration of dissolved oxygen

The lake maintained a good level of dissolved oxygen. Within a year, the mean concentration varied from 5.2 mg/l (November, 2016) to 7.3 mg/l (August, 2017). During the next six months the concentration ranged between 5.6 mg/l (November, 2017) and 6.5 mg/l (March and April, 2018) (Fig. 3). The annual mean value was 6.1 mg/l during the first year. There was no marked difference in the next six months of study.

Total dissolved solids

The amount of total dissolved solids in the lake water ranged from 156.3 mg/l (December, 2016) to 252 mg/l (August, 2017). In the next six months of study the concentration of total dissolved solids was found between 158 mg/l (November, 2017) and 185.8 mg/l (March, 2018) of water (Table 1). The annual mean concentration was computed at 185.1 mg/l.

Salinity

Seasonally, there was a great variability in water salinity of the lake. During the first year the salinity varied from a minimum of 0.005% (November, 2016) to a maximum of 0.031% (August, 2017). In the next six months the values ranged between 0.012% (December, 2017 and March, 2018) and 0.022% (April, 2018). The annual mean salinity was computed at 0.01 % (Table 1).

Silica

Within a year the concentration of silica varied from a minimum of 257 µg/l to a maximum of 581 µg/l of water. The minimum concentration was recorded in the month of March 2017, while maximum was noted in August 2017 within a year. During the next six months, the concentration fluctuated between 352 µg/l (March, 2018) and 610 µg/l (December, 2017) (Table 1). The annual mean concentration during first year of the study was computed at 471.3µg/

Table 1. Seasonal variation in some parameters of water in Lake Khurpatal during the study period.

Months	pH	CO_2 (mg/l)	TDS (mg/l)	Salinity (%)	Silica (µg/l)	NO_2-N (mg/l)
November, 2016	6.2	4.1	163	0.005	516	0.002
December	6.7	4.3	156	0.01	529	0
January, 2017	7.1	4.3	160	0.006	436	0.001
February	6.6	4.3	162	0.014	461	0.1
March	7	4.5	165	0.015	257	0
April	6.7	4.5	181	0.02	569	0
May	6.6	4.4	196	0.023	530	0
June	6.9	3.3	210	0.026	470	0
July	6.7	3.6	218	0.026	424	0.1
August	6.6	2.1	252	0.030	581	0.1
September	7	1.5	191	0.031	379	0
October	6.6	3.6	168	0.027	506	0
November	6.4	4.1	58	0.020	664	0
December	6.8	4.2	166	0.012	610	0
January, 2018	6.7	5.2	160	0.014	367	0.003
February	7	4.4	163	0.015	414	0.2
March	7	5.1	186	0.012	352	0
April	6.8	4.5	172	0.022	586	0

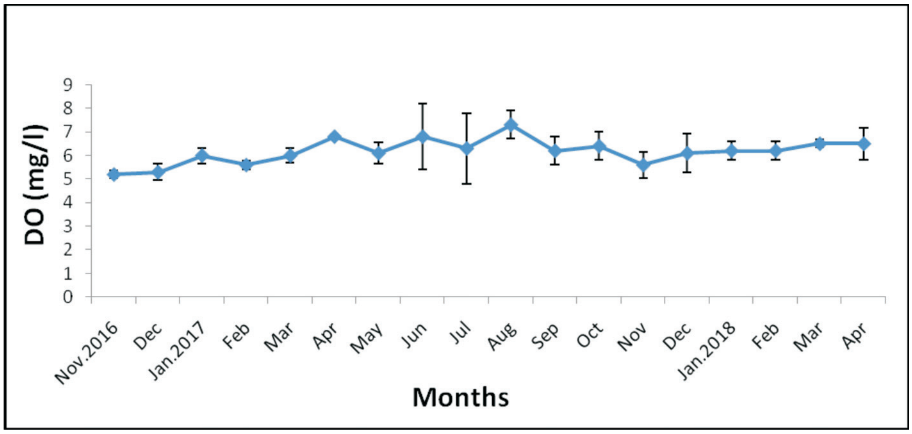

Fig. 3. Seasonal variation in mean concentration of dissolved oxygen in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

l. The analysis of variance showed significant ($p<0.05$) seasonal variation in concentration of silica.

Phosphate phosphorus

The concentration of phosphate-phosphorus in the lake water was high during the study period. As shown in Fig. 4 it ranged from a minimum of 0.001 mg/l (December, 2016) to a maximum of 0.32 mg/l (March, 2017). The annual mean concentration of phosphate phosphorus was 0.129 mg/l during the first year of the study. The values in the next six months of study ranged between 0.009 mg/l (November, 2016) and 0.375 mg/l (March, 2017). Statistically, the seasonality in phosphate-phosphorus concentration was significant ($p<0.05$).

Nitrogen

The concentration of all forms of nitrogen was found to be high. Seasonally the concentration of nitrate-nitrogen varied from a minimum of 0.31mg/l (March, 2017) to a maximum of 0.8 mg/l (August, 2017) with an annual mean of 0.51 mg/l. The seasonality in variation was significant ($p<0.05$). During the next six months the values ranged from 0.30 mg/l (November, 2017) to 0.49 mg/l (April, 2018) (Fig.5).

The mean concentration of ammonium-nitrogen showed great variability ($p<0.05$) from one sampling occasion to another. During the first year the concentration ranged from 0.005 mg/l to 0.548 mg/l with minimum concentration in the month of December, 2016 and maximum concentration in the month of November, 2016. The annual mean concentration was 0.127 mg/l. During the next six months the concentration varied between 0.02 mg/l and 0.80 mg/l (Fig.6). The maximum concentration

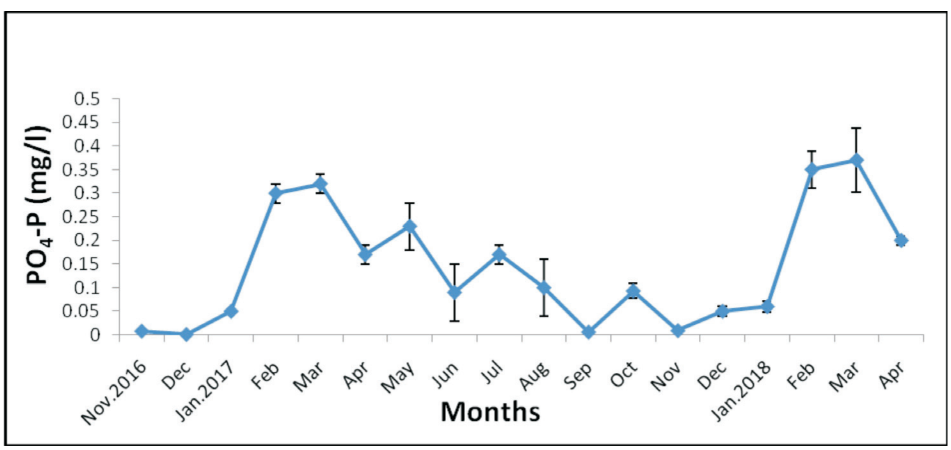

Fig. 4. Seasonal variation in mean concentration of phosphate phosphorous in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

during this period occurred in January, 2018.

As usual, the concentration of nitrite-nitrogen was comparatively low. Within a year nitrite-nitrogen was found to be undetectable at most of the time (December 2016, Mar, April, May, June, September and October 2017). The maximum concentration with 0.1 mg/l was found in the month of ebruary and July-August 2017. During the next six months of study the concentration was undetectable in December, 2017, January and April, 2018 (Table 1). The maximum concentration during this time occurred in the month of February, 2018.

The amount of heat in any water body greatly affects the metabolism of biota. Apart from this the amount of heat stored and released controls the microclimate of the area. The data on temperature of Lake Khurpatal showed that the lake stores a substantial amount of heat during the summer months and releases it during winters. This release and uptake of heat should have a great effect on the climate of the area. Previous studies (Jaiswal, 1983) showed variation in water temperature from 7 to 25 ^{0}C within a year. The values of present study are greater than that of 35 years back. The variability in water temperature depends on several factors: the timing of measurement and the weather conditions play a greater role in temperature variability. Therefore, it cannot be said definitely which factor was really responsible for the increase of temperature during the present study.

Transparency of the lake water is a good parameter to indicate the level of eutrophication and thus the trophic state of the water body (Vollenweider, 1968, Kratzer and Brezonik, 1981). The Khurpatal lake with an annual mean transparency of 1.5 m showed poor penetration of light. Sharma *et al*. (1982) had reported an annual mean transparency of Lake Khurpatal as 2.4 m. Thus, in 35 years of time span 37.5% decrease in the water transparency was noticed (Table 2). As per norms of various limnologists (OECD, 1982), the hypereutrophic lakes generally show the maximum transparency values less than or equal to 1.5m. The annual mean transparency of Khurpatal lake during the present study (1.5m) signified the eutrophic nature of the water body. The reduction in transparency can be attributed to higher concentration of phytoplankton during the present study. Which has increased considerably in last 35 years (ms under preperation). Beside phytoplankton, the amount of humic acid and total dissolved solids could also affect the water transparency adversely. But these parameters were not measured in the present study. The lower transparency of the lake can preclude the sunlight penetration into the deeper areas, therefore, it can be expected that the lake will absorb lesser amount of heat. This, in turn, may result in warmer climate of the area in future.

The carbon dioxide is the raw material of photosynthesis and is produced in the lake mainly due to respiration. The other sources are decomposition of organic matter and other oxidizing compounds. Its concentration depends on the respiratory activities of the organisms, amount of organic matter present in the water and photosynthetic activity of the autotrophs. The annual mean concentration of carbon dioxide (3.7 mg/l) appeared to have increased 3.6 times in last 35 years. This increase can be attributed to high metabolic activities of organisms and high amount of organic matter in the lake. Although

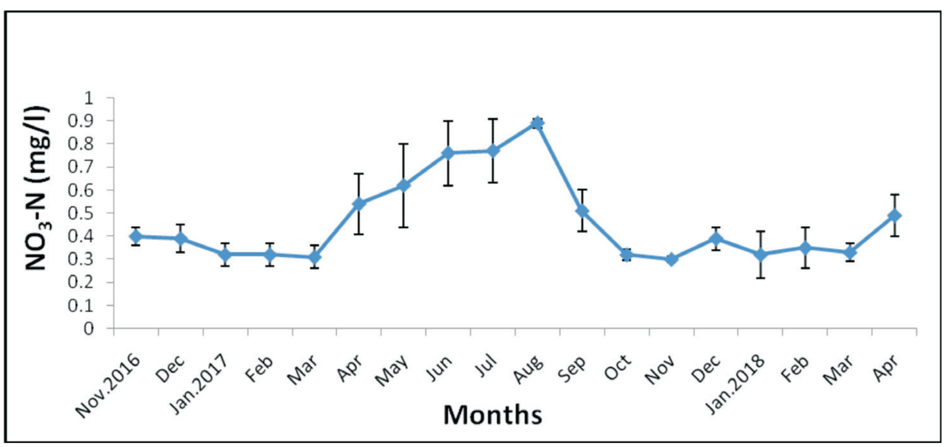

Fig. 5. Seasonal variation in mean concentration of nitrate nitrogen in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

greater number of phytoplankton could utilize carbon dioxide in photosynthesis the high amount of carbon dioxide available indicated the greater respiratory rate than production of carbohydrate (R>P).

The hydrogen ion concentration is mainly controlled by photosynthetic activity of autotrophs. The greater amount of carbon dioxide indicated the production of carbonic acid after reaction with water. In the present study the annual mean pH 6.7 was considerably lower as compared to 8 (Table 2) in the previous study (Sharma *et al.*, 1982). The decrease in pH was, perhaps due to combination of carbon dioxide with water resulting into the formation of carbonic acid which displayed an acidic nature of the water.

Several factors affect the concentration of dissolved oxygen in the water bodies. The rate of photosynthesis increases the concentration on one hand while the respiratory activities consume the oxygen at the other hand. When we compare the data with the data of 35 years back (Sharma *et al.*, 1982), we find 32.2% reduction in DO concentration (Table 1). The concentration of dissolved oxygen was always more than 5 mg/l. Hence, there was no deficiency of oxygen for fish in the lake.

The concentration of silica plays important role in biotic activities of lake. It has been reported by many authors (Kilham, 1971, Struyf *et al.* 2005, Viaroli *et al.* 2013, Schoelynck and Struyf, 2016, Bucher *et al.* 2017, Liu *et al.*, 2019; Messinna *et al.*, 2020 etc.) that silica acts as a limiting factor for the growth of diatoms because diatoms assimilate large quantity of silica in the synthesis of their cell structure (Wetzel, 1975). During 1980s the concentration of silica was lower as compared to that of the present time: the concentration during 1980s was between 33 and 600 µg/l (Jaiswal, 1983) as compared to 256 and 664 µg/l in the present study (Table 2). There was 26% increase in the concentration of silica in last 35 years. This has probably increased the concentration of diatoms (ms under preparation) in the present study. The major source of silica for the lake system is weathering of silica containing rocks (Hutchinson, 1967). The increase in concentration in present study can be attributed to weathering of silica containing rocks in the catchment area of the lake.

Salinity is defined as the amount of salts in gm in1l of water. The salts are mainly found in the form of compounds including sodium chloride, magnesium sulfate, potassium sulfate and sodium bicarbonates. These are dissolved as ions. In the present investigation values of salinity did not vary considerably from one sampling occasion to another. The annual mean salinity was 0.019%. Thus, the salinity was enough for sustaining the life of biota and it did not cross the limit of criterion set for freshwater bodies.

The data on concentration of total dissolved solids of the past studies are not available. In the present investigation its annual mean concentration was found to be 185 mg/l with seasonal oscillation of 156 to 252 mg/l.

Phosphorus is the main constituent of ATP hence, important for all biota of the earth. This is the main chemical, causing eutrophication (Table 2). In last 35 years, the concentration of phosphate phosphorus has increased 26 times. This increase can be attributed to the agricultural activities in the catchment because farmers use manure and inorganic fertilizers in the field. These fertilizers and manure along

Table 2. A comparison of various Physico-chemical variables of Lake Khurpatal between 1980s (Jaiswal, 1983; Sharma *et al.*, 1982) and present study. M=mean and N=number of samples.

S. No.	Variables	In 1980s	In Present study
1.	Temperature (^{0}C)	7-25—	9.4-27M= 18.5(N = 36)
2.	Transparency (m)	3-6M=2.4-	1-2.3M= 1.55(N= 36)
3.	pH	7.7-9.5M=8-	6.2-7.1M= 6.7(N=36)
4.	Free CO_2 (mg/l)	7.2-8.8M=0.8-	1.5-4.6M= 3.7(N=36)
5.	DO (mg/l)	5.7-13M=9-	5.2-7.3M=6.1(N=36)
6.	TDS (mg/l)	—-	56.3-252M= 185.1(N=36)
7.	Salinity (%)	—-	0.005-0.31M= 0.01(N= 36)
8.	Silica (µg/l)	40- 1470M=374-	256.6-581M= 471.3(N=36)
9.	PO_4-P (mg/l)	0.001-0.011M=0.0048-	0.001-0.32M=0.129(N=36)
10.	NO_3-N (mg/l)	0.002- 0.153M=0.382-	0.31-0.89M=0.51(N= 36)
11.	NH_4-N (mg/l)	0.040- 0.170M=0.103	0.005-0.54M=0.127(N= 36)
12.	NO_2-N (mg/l)	-M=0.23	0.0005-0.09M=0.24(N= 36)

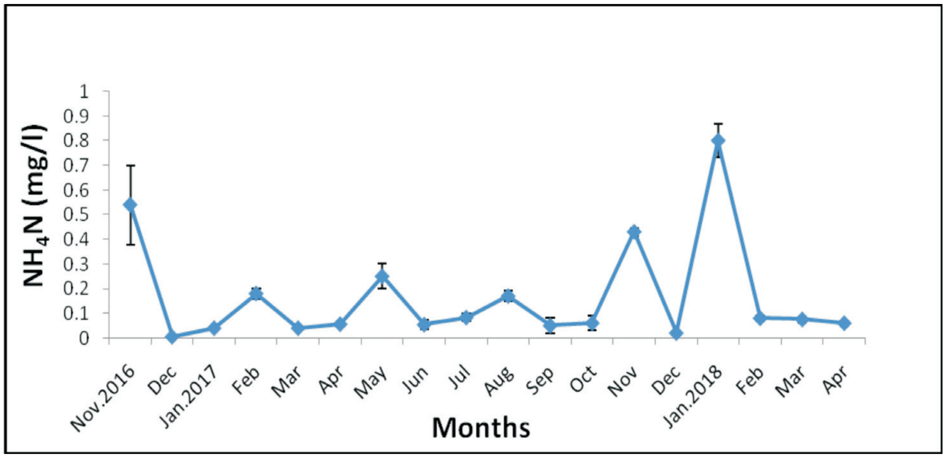

Fig. 6. Seasonal variation in mean concentration of ammonium nitrogen in Lake Khurpatal during the study period. Vertical bars indicate the standard error (±) of the mean.

with surface run off could find their way into the lake after rains. Another reason for the increase in concentration of phosphorus may be the weathering of phosphorus containing rocks in the catchment which could enter into the lake along with the rainwater. It can be noted that the increase in concentration of phosphorus increases the phytoplankton productivity in the lake. Although small, the third source of phosphorus may be the usage of detergents because the locals also use to wash clothes in the lake. The detergent containing phosphorus may enter the lake through this source also.

In Khurpatal lake, the concentration of nitrogen was quiet high. Three forms of nitrogen in decreasing concentration could be arranged as nitrate nitrogen> ammonium nitrogen> nitrite nitrogen. There was marked increase in concentration of nitrate nitrogen (33%) in last 35 years. Ammonium-nitrogen also increased significantly with a 23% increase during the same period of time (Table 2.). According to Sawyer (1966) high concentration of nitrate-nitrogen should be taken as an index of eutrophication. A concentration more than 0.15 mg/l is an indicative of eutrophication. In the present water body the mean concentration of nitrate nitrogen was 0.51 mg/l which was 3.4 times greater than the criterion set for eutrophication. The concentration of nitrate was greater than the ammonium nitrogen. Cairns *et al.* (1972) has stated that the phytoplankton increase in concentration when nitrogen in the form of ammonia is greater than nitrogen in the form of nitrate. In the present situation the condition was reverse. It appeared, therefore, that the factors other than nitrogen were responsible for the higher concentration of phytoplankton as compared to 1980s. On the basis of concentration of nitrogen and phosphorus the lake can now be considered as eutrophic. As mentioned earlier it was reported to be oligotrophic during 1980s. This was also a major event. The nitrite concentration was very low in the present investigation. It appeared that nitrite was continuously changing into nitrate as a result of nitrification concentration of nitrite in their studied water bodies, some even have reported total absence of nitrite in their studies. With regards to total inorganic nitrogen the lake was also found to be eutrophic. According to Vollenweider (1968), a concentration of 500-1500µg/l has been assigned for eupolytrophic lakes. The annual mean concentration of total inorganic nitrogen in Lake Khurpatal was 661µg/l, which indicated eupolytrophic nature of the lake.

Conclusion

The results of the present study demonstrated that almost all parameters of water quality have changed markedly in last 35 years. Especially, there have been pronounced increase in concentrations of phosphorus and nitrogen. The lake is presently at eutrophic state.

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