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Responses of Physico-chemical Variables to Hypolimnetic Aeration in Lake Naukuchiyatal, Central Himalaya, India

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ABSTRACT

The effect of hypolimnetic aeration on the water quality of Lake Naukuchiyatal , Central Himalaya was studied during 2017-2018 with the objective of determining the changes in physico-chemical variables of the lake due to aeration. It was noticed that aeration destroyed the thermal stratification and changed the anoxic hypolimnion into oxic zone. The pattern of clinograde distribution of oxygen during pre – aeration, was altered during aeration. The dissolved oxygen was distributed throughout the water column. As a result of aeration, the secchi disc transparency was increased considerably while the hydrogen ion concentration declined significantly. The BOD and the concentration of free carbon dioxide got reduced as a result of aeration. The concentrations of phosphate - phosphorus and nitrate - nitrogen were increased while the concentration of ammonium nitrogen and nitrite nitrogen were dropped. The N:P ratio was also reduced during aeration as compared to unaerated time.

Key words: *Lake Naukuchiyatal, Hypolimnetic aeration, Anoxic hypolimnion, Physico-chemical variables.*

Introduction

Water is the most essential and most abundant of all substances on the earth. However,a major amount of water is unusable by man due to pollution and eutrophication. In last many years eutrophication has affected the water quality of many water bodies throughout the globe (e.g, Vollenweider, 1968; Cooke and Williams, 1973; Cooke *et al.*, 1977; Harper, 1978; Anon, 1986; Abbiscott, 1988; Person and Jansson, 1988; Barica, 1990) Nevertheless, many techniques have been evolved to mitigate the process and level of eutrophication. Hypolimnetic aeration is one of the several techniques which has great influence on the water quality of eutrophic lakes

Lake Naukuchiyatal, which is the subject matter of present study, was oligotrophic in 1981 when it was studied for the first time (Singh, 1981). After a time span of about 20 years the lake became highly eutrophic (Bhagat, 2002; Bhagat and Gupta, 2005). To mitigate the level of eutrophication, hypolimnetic aeration was initiated in the lake in 2015. The purpose of this study was to determine the impact of aeration on physico - chemical variables of the lake.

A search on literature indicates that hypolimnetic aeration have been used in many lakes of the world (e.g. Brzozowska and Gawronska, 2005, 06, 09; Mehner *et al*., 2008; Van Dijk and Van Vuuren, 2009; Huang *et al.*, 2014; Gafsi *et al*., 2016; Niemsto *et al*., 2016, 2019; Tian *et al*., 2017; Kozak *et al*., 2017; Goncu, 2020; Ruuhijarvi *et al*., 2020, etc.) and effects of aeration on physico- chemical variables have been documented. But in India, works on this aspect are limited (Gupta, 2008, Gupta and Gupta , 2012 a, Joshi, 2013, Maindoli *et al*., 2019).

The Lake

Nestling at an altitude of 1220m above sea level in the Central Himalaya, Lake Naukuchiyatal lies between $29^0 45'$and $30^0 34'$N latitude and $78^0 45'$and $80^0 90'$E longitude. The surface area of the lake is 45 ha , the maximum depth is 40.3 m and the width is 692m. The climate of the area in which the lake is situated is sub - tropical. The human settlement in the catchment area is low. Some amount of agricultural activities also take place in the catchment area. Details of catchment can be found in Bhagat (2002). The lake provides several ecosystem services to humans and has significant place in improving socio-economic conditions of the hill people.

Materials and Methods

To secure data on physico-chemical parameters, one sampling site at the mid lake was selected. Samplings were done at monthly intervals. Few parameters, viz., temperature, transparency, pH, carbon-dioxide and dissolved oxygen were measured on the spot itself while for other parameters (viz., NH_4-N, NO_3-N, NO_2-N, PO_4-P, BOD), deeper water samples, collected by Van-Dorn sampler and surface water samples collected directly by lowering the rim of the collection bottle were brought to the laboratory under ideal conditions for further analysis. Water samples were secured from 3 depths (0m, 10m and 20m). Temperature was measured by a temperature sensor, attached with oxygen meter, which was direct reading display system. Hydrogen ion concentration (pH) was measured by a high grade pH paper (Qualigen), water transparency was determined by a White and Black Secchi disc and the concentrations of dissolved oxygen and free carbon dioxide were measured by titration method ((APHA, 1989). Phosphorus in the form of PO_4-P and nitrogen in the forms of NO_2-N, NO_3-N and NH_4-N were analysed using YSI Photometer (Model-9300, US make). This is a microprocessor based photometer with direct reading display system. The method of analysis were based on APHA (1989). Biochemical Oxygen Demand was determined as BOD_5 by the method described in APHA (1989). N:P ratio was calculated with the concentration of phosphate phosphorus and total inorganic nitrogen (nitrate nitrogen + nitrite nitrogen + ammonium nitrogen).

Results and Discussion

Temperature

Prior to hypolimnetic aeration, the lake was found to be circulating during winters and remained thermally stratified during rest of the year (monomictic water body) (Singh, 1981, Bhagat, 2002, Bhagat and Gupta, 2005). Due to hypolimnetic aeration the thermal stratification was broken and the lake underwent circulation throughout the year. The mean temperature at each depth is plotted in Fig. 1 which indicates the destruction of thermal stratification. Temporally, the water temperature varied from a minimum of 11 °C to a maximum of 26.2 °C during first year of study and 11.4 °C to 27.1°C during the second year of study (Table 1). The temperature data before aeration (Bhagat, 2002) were compared with temperature data of aeration period (present study) which indicated that aeration increased the temperature of the lake water (Table 2). During the aeration period, the biannual mean water temperature for the whole lake was 19.1 °C.

Continuous mixing of the water transported large quantity of heat from surface to all the layers of the lake. This considerably increased the water temperature in hypolimnion. Similar to the present findings

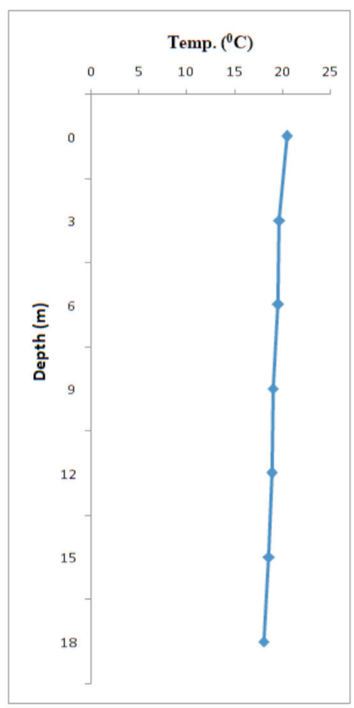

Fig. 1. Mean water temperature at various depths during aeration in Lake Naukuchiyatal

Grochowska and Gawronska (2004); Gupta and Gupta (2012 a) and Joshi (2013) reported increase in water temperature during aeration as compared to pre- aeration period in their studied water bodies. Elimination of thermal stratification and overall increase in temperature because of aeration have also been reported by Heo and Kim (2004) while studying the impact of aeration in lake Dalbang, South Korea.

Hydrogen ion concentration

The water was slightly acidic almost throughout the study period except at few occasions. The monthly mean values ranged from 6.6 to 6.9 during the first year and 6.5 to 7.2 during the second year (Table 1). Vertically, the pH declined in the bottom water during aeration period. The overall mean pH during aeration was 6.8. A comparision of pH data of pre-aeration and that of the aeration suggested that the water pH decreased in the lake due to aeration (Table 2). Seasonally the mean pH varied from 7 to 8.3 during pre- aeration. Thus, the water pH decreased because of aeration. The reduction in pH during the aeration period could be attributed to the low concentration of carbon dioxide and high concentration of carbonic acid formed with combination of water and carbon dioxide. Besides, the heterotrophic degradation and oxidation of dead organic matter, microbial methane fermentation, nitrification of ammonia and oxidation of sulphate could serve to generate the carbon dioxide which in turn increase the concentration of H_2CO_3 causing pH reduction (Wetzel, 2001).

Water transparency

The water transparency varied from 170 to 300 cm being minimum in August and maximum in January during the first year of study. During the second year, the data indicated almost similar pattern in variation, the values being 180 cm (minimum) to 300 cm (maximum) (Fig. 2). The overall mean (biannual mean) of water transparency for the whole lake was computed at 253 cm during aeration against 136.5 cm during pre-aeration (85% increase during aeration) (Table 2). Several factors such as quantity of silts, suspended organic matter and planktonic populations present in the water affect the Secchi disc transparency in natural ecosystems (Wetzel, 1983). Increase in transparency during aeration suggested the related reduction in particulate and suspended particles and planktonic population. The

Table 1. Seasonal variation in some physico-chemical parameters of water in Lake Naukuchiyatal during aeration

Parameters	Months																							
	Jan-2017	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan-2018	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (ºC)	11	13	15	18	19	19	24	26	26	20	19	14	11.4	12	17	21	23	21	24	27	27	22	19	15
pH	6.9	6.9	6.7	6.9	6.9	6.8	6.9	6.8	6.6	6.8	6.8	6.9	7.2	7	6.7	6.8	6.5	6.5	6.7	7	6.7	6.9	6.7	6.6
CO_2	2.7	4.2	4.5	3.2	3.4	3.1	3.8	4	3	4	5.5	3.8	2.4	3	3.3	4.4	3.6	4.3	3	3.7	4	5.2	4.2	3.6
BOD	10.3	3	3.6	2.6	3.6	11	7	4.3	4.3	6.3	14	12	11.3	12	5.3	5.3	12	14	7.3	5	5.6	4.3	14	13
NO_2-N (µg/l)	12	12	12	15	13	12	28	21	24	20	6	7	26	13	20	23	4	22	24	37	24	31	6	10

concentration of plankton have also been found to be reduced during the aeration period (Pant *et al.*, 2022). Gupta and Gupta (2012a) and Joshi (2013) while studying the influence of aeration on water quality of Nainital lake also reported the similar results.

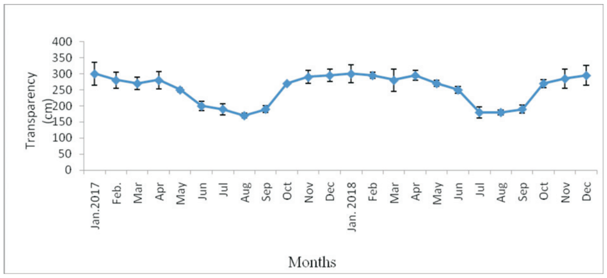

Fig. 2. Seasonal variation in mean tansparency in Lake Naukuchiyatal during the study period. Vertical bars indicate the standard error (±) of the mean.

Free carbon-dioxide

The distribution of free carbon dioxide was almost uniform throughout the depth. Vertically, it ranged from 3.4 mg/l at 20 m depth to 4.0 mg/l at the surface. Seasonally, the overall mean concentrations of carbon dioxide varied from 2.7 to 5.5 mg/l during first year and 2.4 to 5.2 mg/l during the second year of the study (Table 1). Importantly, some amount of free carbon-dioxide was always present in the lake. The overall mean concentration of free carbon dioxide for the whole lake (biannual mean) was found to be 3.75 mg/l. A perusal of data of pre-aeration (Bhagat, 2002) and aeration period indicated that aeration reduced the concentration of free CO_2 in the lake (Table 2). Hypolimnion of the lake is main pool of CO_2 (Odum, 1971). This CO_2 was upwelled from hypolimnion to epilimnion where it reacted with water and formed H_2CO_3. Some of the CO_2 could well go into the atmosphere.

Concentration of dissolved oxygen

During aeration period the dissolved oxygen concentration showed almost uniform distribution throughout the water column. In bottom also, oxygen concentration was always more than 4 mg/l. Seasonally, the mean concentration of dissolved oxygen varied from a minimum of 7 mg/l (July and September) to 10.1 mg/l (November) (Fig. 3). Vertically, the concentration decreased with increasing depth. The aeration produced profound effects on dissolved oxygen concentration. The overall mean concentration of dissolved oxygen for the whole lake was 8.8 mg/l (n=72). It is noteworthy that during pre-aeration there was marked difference in DO concentrations between the surface and bottom water (clinograde pattern). This difference was sharply reduced during the aeration during which almost uniform concentration of oxygen from top to bottom

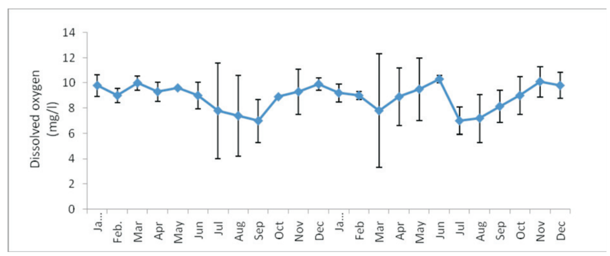

Fig. 3. Seasonal variation in dissolved oxygen concentration in Lake Naukuchiyatal during the study period . Vertical bars indicate the standard error (±) of the mean.

Table 2. Comparison of physico-chemical parameters of Lake Naukuchiyatal during aerated (current study, 2017-2018) and unaerated period (Bhagat, 2002). Data are expressed as biannual mean. M=mean and n= number of samples.

S. No.	Variables	Unerated period	Aerated period
1.	Temperature(^{0}C)	12.2 - 24.5	11 – 27.1M= 19.1 (n = 72)
2.	pH	7 – 8.3	6.5-7.2M= 6.8 (n= 72)
3.	Transparency(cm)	55 - 213 M= 136	170-300M= 253 (n=72)
4.	Free CO_2(mg/l)	0-5.6	2.4-5.5M= 3.75 (n=72)
5.	DO(mg/l)	5 - 15.2	7 – 10.1 M=8.8 (n=72)
6.	BOD(mg/l)	2.6 - 26	2.6-14 M= 7.4 (n=72)
7.	PO_4-P(μg/l)	5 - 160 M= 42	32.7-57.3M= 44 (n= 72)
8.	NO_3-N(μg/l)	0-75 M=42	24.2-106.8 M= 79 (n=72)
9.	NH_4-N(μg/l)	110 - 210 M = 200	68.4- 126M=101.9 (n=72)
10.	NO_2-N(μg/l)	2 - 153 M = 140	4- 37 M=17 (n= 72)
11.	N:P	6.1	4.5

of the lake was found. A thorough observation on the oxygen concentration data of the lake during pre-aeration and aeration indicated that the concentration of oxygen increased considerably due to aeration (Table 2). Importantly during pre-aeration period the hypolimnetic zone of the lake was anoxic (Bhagat, 2002), which became oxic during the aeration period. This was a significant change and has been found in almost all studies of aeration (e.g. Gupta and Gupta 2012 a, Joshi, 2013, etc.).

Biochemical oxygen demand (BOD)

Although its values were high, a comparison of data from the pre-aeration period indicated that there was a considerable decrease in BOD due to aeration. The monthly values of BOD varied from 2.6 mg/l (minimum) in April to 13.6 mg/l (maximum) in December during the first year of the study. During the second year, the values ranged from 4.3 mg/l (minimum) in October to 14 mg/l (maximum) in November (Table 1). During the pre-aeration period a range from 5.1 to 26 mg/l was reported by Bhagat (2002), while a range of 2.6 to 14 mg/l was recorded in the present investigation during two years of study (Table 2). Biochemical oxygen demand is related with the amount of decomposing organic matter and concentration of oxidizing chemicals in the water body. Since these impurities got oxidized and better mineralized by aeration, the BOD was reduced during the aeration period (Table 1)

Phosphate- phosphorus

The concentration of phosphate-phosphorus did not show a great fluctuation from one sampling occasion to another. During 24 months of study, the mean concentration ranged from 32.6 µg/l to 57.3 µg/l (Fig. 4). During pre-aeration period, the concentration varied from 5 µg/l to 160 µg/l (Bhagat, 2002). Vertically, the concentration did not differ considerably from one depth to another. The biannual mean concentration at surface, 10m and 20m depths were: 42 µg/l, 47 µg/l and 43.4µg/l, respectively. The overall mean concentration of the phosphorus for the whole lake (n=72) during the aeration period was 44 µg/l against 42 µg/l during the pre-aeration period (Table 2). Thus, although a slight increase in concentration during aeration was noticed, the difference between the mean concentrations of phosphorus during aeration and pre-aeration was not significant. Similar to the present result, Gawronska *et al.,* (2003); Gupta and Gupta (2012 a),

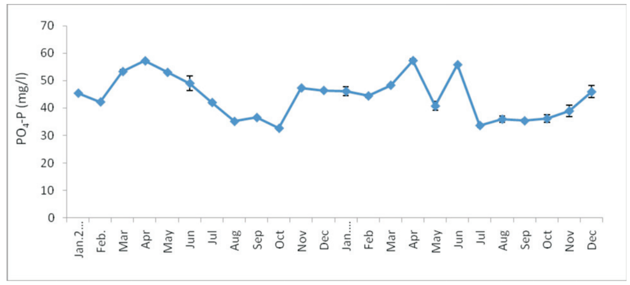

Fig. 4. Seasonal variation in phosphate-phosphorus concentration in Lake Naukuchiyatal during the study period. Vertical bars indicate the standard error (±) of the mean.

Nurnberg *et al.,* (2013, b); Niemisto *et al.,* (2016, 2019) and several others have reported higher concentration of PO_4-P during aeration. The upwelling ofP rich hypolimnetic water throughout the water column including epilimnion was the main cause of increase in phosphorous concentration. Another cause of increase in concentration of phosphate phosphorus could be the entry of phosphorus from the catchment area. It has been demonstrated by Mortimer as early as in 1941 and 1942 that phosphorus released from lake sediments is released at its minimum under aerobic conditions. According to him an oxidized microzone is formed at the mud –water- interface which acts as an efficient barrier for phosphate phosphorus. Thus under oxidised conditions of the mud - water interface, phosphate phosphorus is not allowed to be released from the sediment to the overlying water. Although this happened in the present case also, the amount of phosphorus in the hypolimnion was already enough to increase the concentration in circulating water. In contrast to the results of the Naukuchiytal lake regarding phosphorus, several workers have reported lower concentration of phosphate phosphorus during aeration in their respective studied water bodies (e.g. La Baugh, 1980; Burgi and Stadelman, 2002). Several other studies have found accumulation of phosphorus in the hypolimnion and reduction of it in the epilimnion and metalimnion due to aeration (Grochowska and Gawronska, 2004, Engstorm, 2005; Liboriussen *et al.,* 2009). In some studies it has been found that artificial aeration had no dramatic effect on phosphorus concentration (Heo and Kim, 2004). In such case, the author concluded that the internal phosphorus loading was not a major cause of phosphorus loading to the lake, rather, entry of phosphorus from the catchment area was important.

Nitrate- nitrogen (NO_3-N)

The nitrate - nitrogen also behaved like phosphate - phosphorus. The depth variability was low during the aeration period. Seasonally, the mean concentration during the study period varied from 24.2μg/l to 106.8 μg/l during the first year and 40.2μg/l to 111.5 μg/l during the second year of study (Fig. 5). The overall mean concentration for the whole lake (n=72) was 79 μg/l during the aeration period against 42 μg/l during pre-aeration time (Table 2). Thus, the aeration significantly increased the concentration of nitrate-nitrogen in the lake.

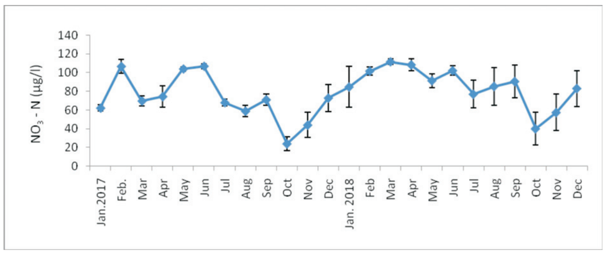

Fig. 5. Seasonal variation in nitrate-nitrogen concentration in Lake Naukuchiyatal during the study period . Vertical bars indicate the standard error (±) of the mean.

Ammonium- nitrogen (NH_4-N)

During the first year, the concentration varied from 68.4 μg/l to 126 μg/l with the minimum concentration in August and maximum in January. During the second year, the concentration was found between 90.4 μg/l (July) and 125.6 μg/l (August) (Fig. 6). Although the concentration values were different at different sampling occasions, the trends in variability were almost similar during both years of aeration. Vertically, there was not great variation in concentration of ammonium-nitrogen. At 0m , 10 m and 20m water depths, the concentrations were: 95.4 μg/l, 106.2 μg/l and 104 μg/l, respectively. The overall biannual mean concentration for the whole lake was 101.9 μg/l as compared to 200 μg/l during unaerated time (Table 2). Thus, there was a sharp decline (about 49% decrease) in the concentration of ammonium-nitrogen due to aeration.

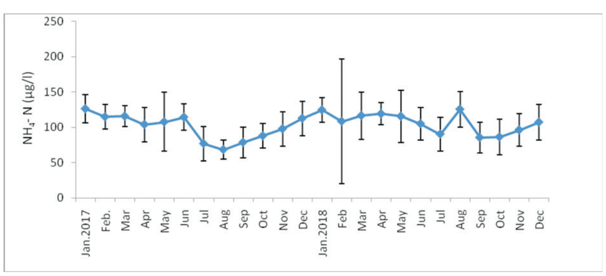

Fig. 6. Seasonal variation in ammonium-nitrogen concentration in Lake Naukuchiyatal during the study period. Vertical bars indicate the standard error (±) of the mean.

Nitrite- nitrogen (NO_2-N)

The concentration varied from 6 μg/l to 28 μg/l during the first year and 4 μg/l to 37 μg/l during the second year (Table 1). Vertically, there was no great variability during the study period although values differed temporally. The overall mean concentration of nitrite- nitrogen for the whole lake (n=72) was 17 μg/l during aeration as compared to 40μg/l prior to aeration (Table 2). Thus, the concentration of NO_2-N also decreased by 57.5% as a result of aeration.

The aeration dramatically influenced the components of nitrogen cycle. It is a known fact that the nitrogen compounds are released from the bottom sediments mainly as ammonia and nitrogen (Brzozowska *et al.*, 2001). Ammonia released from sediments was subsequently subjected to nitrification which was manifested by a high concentration of nitrates in the water of present lake. Several other workers (e.g. Brzozowska and Gawronska, 2005, 2009; Gupta and Gupta, 2012, a; Zou *et al.*, 2020) have reported increased concentration of nitrate during aeration due to nitrification.

N:P ratio

The overall mean concentrations of inorganic nitrogen (i.e., nitrate nitrogen plus ammonium nitrogen plus nitrite nitrogen) were used to compute the N:P ratio. Based on this calculation the N:P ratio during the study period was computed at 4.5. Prior to aeration, the similar ratio (N:P) was reported as 6.1 by Bhagat (2002) (Table 2). It appeared, therefore, that the aeration reduced the N:P ratio significantly

Conclusion

The physico-chemical variables of the lake responded quickly to the hypolimnetic aeration. The concentration of PO_4-P, however, was not reduced, rather it increased during aeration. This increase in phosphorus concentration may revert the development of cyanophytes if the aeration is stopped. Under this situation it will be wise to withdraw the P rich water from the lake. In conjuction with the water withdrawl, biomanipulation is also recommended to reduce the nutrients especially phosphorus.

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