Proc. Indian natn. Sci. Acad. B47 No. 2 pp. 194-203 (1981)

Seasonal Variation in Physico-Chemical Limnology of Shallow Zones of Nainital Lake, Western Himalaya (India)

REKHA PUROHIT and S P SINGH
Botany Department, Kumaun University, Nainital 263002

(Received 5 July 1979; after revision 14 October 1980)

Data were collected on the sasonal variations in physico-chemical parameters of water from various depths for Nainital lake. The lake experiences warm monomictic type of circulation, and thermal stratification during the summer season is well established. A clinograde type of dissolved oxygen curve was noticed during the summer. Although the surface water generally remains supersaturated with dissolved O_2, the bottom water becomes severely depleted in dissolved O_2 during certain periods. Water is rich in bicarbonates (76–228 mg/l), calcium (30–66.4 mg/l) and poor in phosphate contents (traces—0.01 mg/l). However, free CO_2 content increases with increasing depth, while the CO_3^{--}contents decline. In surface water, *p*H varies from 7.8 to 8.5 and in bottom water from 6.0 to 7.6.

Key Words: **Nainital lake, Eutrophication, Warm monomictic, Dissolved oxygen**

Introduction

Deterioration in the water quality of Kumaun lakes because of the intense cultural activities in their catchment areas has been recognised recently (Das & Pandey 1978). Before any step is taken to check the increasing eutrophication of these water bodies a thorough documentation of the facts is necessary. The trophic status of a waterbody is determined, to a large extent, by the physico-chemical features of the water, and therefore, a knowledge of the seasonal variations in these characteristics is a prerequisite for an understanding of the structure and functioning of lake ecosystems. The present study describes the seasonal variations in physico-chemical parameters at various depths of the Nainital Lake—a lake which experiences maximum biotic stress compared to other Kumaun lakes.

The Lake

The kidney-shaped lake (figure 1) is situated at an altitude of 1937 m in a valley running from West to East at 29° 25′N Lat. and 79° 28′E Long. Its maximum length, maximum width, maximum depth and circumference are, 1372 m, 366 m, 27.3m and 3492 m respectively (Executive Engineer, P.W.D., Personal Communication). The lake has two V-shaped basins, one with a maximum depth of 27.3 m and other with 25.5 m (figure 2).

The catchment of the lake is drained by a network of "nullahs" which bring in the run-off water and also the town refuse into the water body. However, at the South-East end of the lake there is only one outlet 'Ballia ravine', which is used to regulate the water flow during the rainy season.

Vegetation

In the lake only rooted macrophytes such as *Potamogeton pectinatus* Linn., *P. crispus* Linn., *Hydrilla verticillata* Casp., *Polygonum amphibium* Linn., *P. glabrum* Willd. and *P. hydropiper* Linn. have been seen.

Figure 1 Photograph of Nainital Lake from Talli Tal

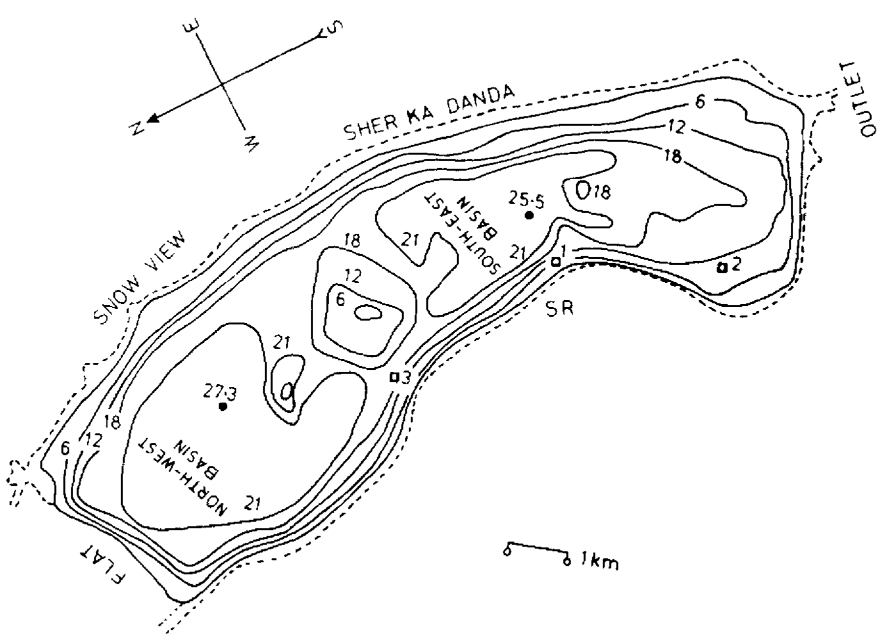

Figure 2 Contour map of Nainital Lake; squares represent sampling stations, and closed circles indicate maximum depth in each basin

Climate

The region under study experiences five seasons through the year: spring (March–April), summer (May–June), rainy (mid-June–mid September), autumn (from second half of September to third week of November) and winter (from last week of November to February).

The total annual rainfall recorded during the year 1978–79 (from March to February) was 2821.6 mm, and most of this (2504.8 mm) was recorded during June to September (figure 3).

The mean monthly maximum temperature (ambient) varied between 16 and 34.5°C and the mean monthly minimum from 0 to 15°C. The minimum (11°C) and maximum (22.5°C) diurnal variations in the temperature were noted during August and May respectively.

Methods

Two stations (I and II) exhibiting dense growth of *P. pectinatus*, and one station (III) sustaining only a scanty growth of the species, in the shallower zone of the lake were sampled during the middle of each month between 10 AM and 12 noon from March 1978 to February 1979. The location of three sampling stations is shown in figure 2. At station I water samples from various depths (Surface, 1 m, 3 m, 5 m, 7 m and 9 m) were collected by using a Ruttner water sampler. At stations II and III, where the growth of *P. pectinatus* was scanty only surface water was sampled. The following determinations were done: temperature of the water was noted in all stations at surface and at depths of 1, 3, 5, 7 and 9 m by using a maximum-minimum thermometer (Misra 1968), transparency by a Secchi disc (Welch 1948), dissolved oxygen by unmodified Winkler's method (Welch 1948); *p*H by a Phillips *p*H meter, Free CO_2 (Phenolphthalein—N/44 NaOH), carbonate alkalinity (Phenolphthalein) and bicarbonate alkalinity (Methyl-orange) by methods following Welch (1948), nitrate nitrogen (Phenoldisulphonic acid) by APHA standard methods (1965) orthophosphate by Denige's method, and calcium and total nitrogen following Misra (1968).

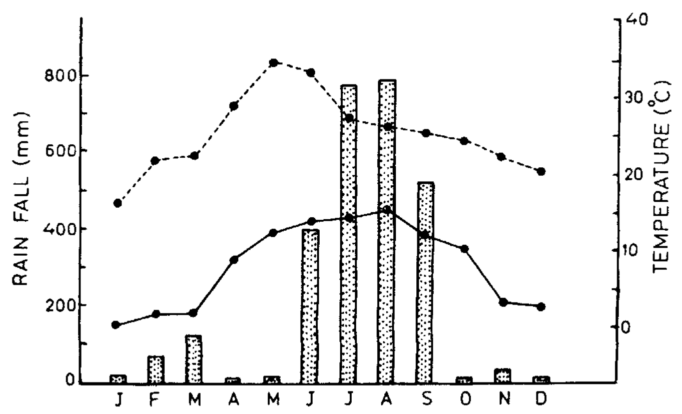

Figure 3 Climatic data for Nainital; Dashed line, mean monthly maximum temperature; continuous line, mean monthly minimum temperature; Bar (histograms), rain fall. Data were supplied from UP State Observatory, Nainital

Results

The observations on temperature, transparency, dissolved O_2, free CO_2, and carbonate and bicarbonate alkalinity are described below separately for different stations. However, since no significant difference either in magnitude or in trend occurred among different stations for *p*H, calcium, phosphate, nitrate and total nitrogen, results for these were averaged across stations.

Temperature

Temperature of surface water fluctuated between 9°C (January and February) and 26°C (July). A marked thermal stratification occurred at each station during the summer season, when the temperature of the surface water was as high as 23°C and that of the bottom water (9 m) only 10°C. More or less a similar condition persisted till August. Thereafter, autumnal circulation set in and at the time of the onset of winter the temperature became uniform (8 to 9°C) throughout the depth (figure 4a). The temperature of the bottom water increased from June (10°C at all stations) to October (19°C at station I and 18°C at stations II and III).

Transparency

It was minimum in rainy season (65–78.5 cm in July) and maximum in spring (200–205 cm in March).

Dissolved oxygen

The surface water remained supersaturated throughout the year except for the winter season. The dissolved O_2 decreased with an increase in depth and this stratification was most pronounced in October (12.8 mg/l at surface and 4.8 mg/ l at bottom). On average across the stations, the surface water exhibited two seasonal maxima—one in March (12.6 mg/l) and the other in September (13.3 mg/l). Among the stations the dissolved O_2 varied between 5.8 and 12.8 5.6 and 14.4 and 4 and 13.6 mg/l at stations I, II and III respectively in surface water, and between 4 and 4.8 mg/l (recorded for only station I) in bottom water.

Free carbon dioxide

It was recorded in water at all depths in July, when the sky was overcast, and during winter (December to February) when the primary producers were undergoing mortality and decay. However, in July free CO_2 was much higher than that in winter. During both the periods it increased along the depth gradient. During rest of the period, free CO_2 was present only at 7 and 9 m depths (figure 4b).

Alkalinity

Carbonate

In contrast to free CO_2 content, the carbonate content showed a decline with increasing depth. In surface water it fluctuated from 20 to 64 mg/l at station I, from 18 to 64 mg/l at station II and from 16 to 58 mg/l at station III. On an average (across stations) it ranged from 18.0 to 60.6 mg/l (figure 5d). The carbonate was absent from all depths in July and during the winter season, and the bottom water remained devoid of it throughout the year (figure 4 b).

Bicarbonate

It increased invariably with the increase in depth (figure 4 b), fluctuating from 76 mg/l (September) to 188 mg/l (December) at station I, and from 80 mg/l (August) to 226 mg/l (March) at station II and 84 mg/l (August) to 228 mg/l (March) at station III. The bicarbonate content at all stations exhibited two maxima—one in summer and the other in winter—and the minimum values occurred in early autumn (figure 5).

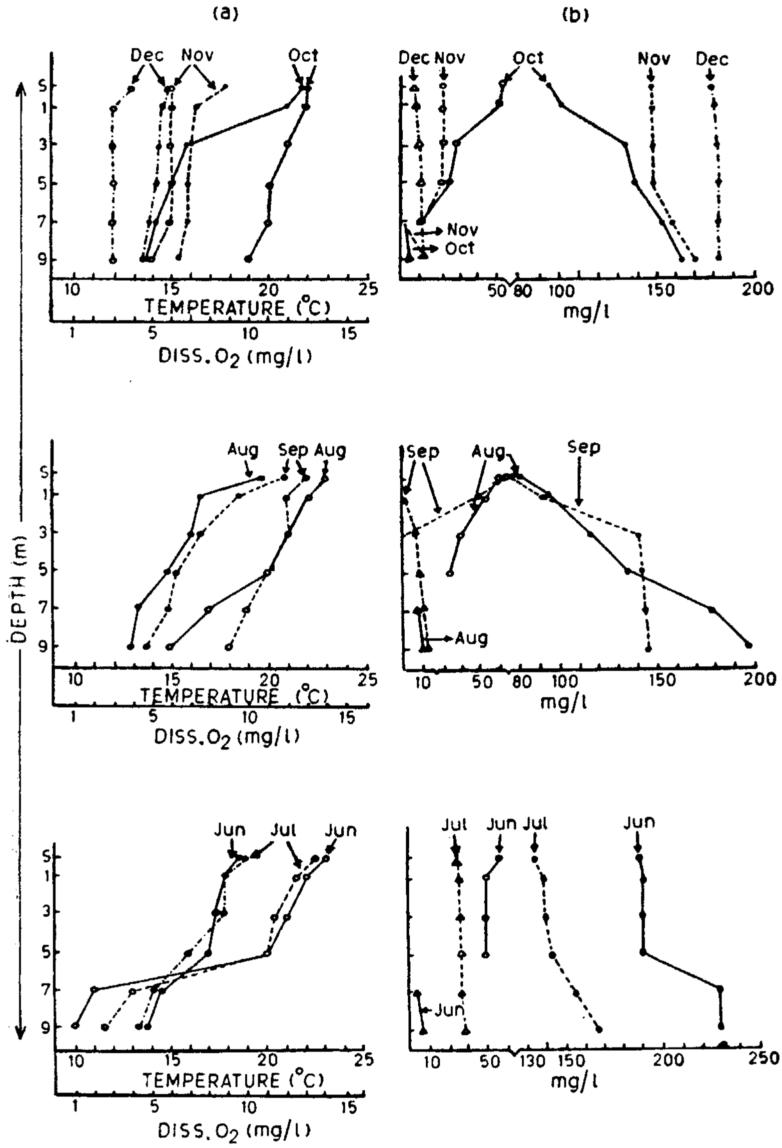

Figure 4 *a*, Profiles of Temperature, (open circle) and dissolved Oxygen (closed circle) in Nainital lake. *S* represents surface; *b*, Profiles of free CO_2 (Open triangle), Carbonate alkalinity (open circle) and Bicarbonate alkalinity (closed circle) in Nainital Lake. *S* represents surface

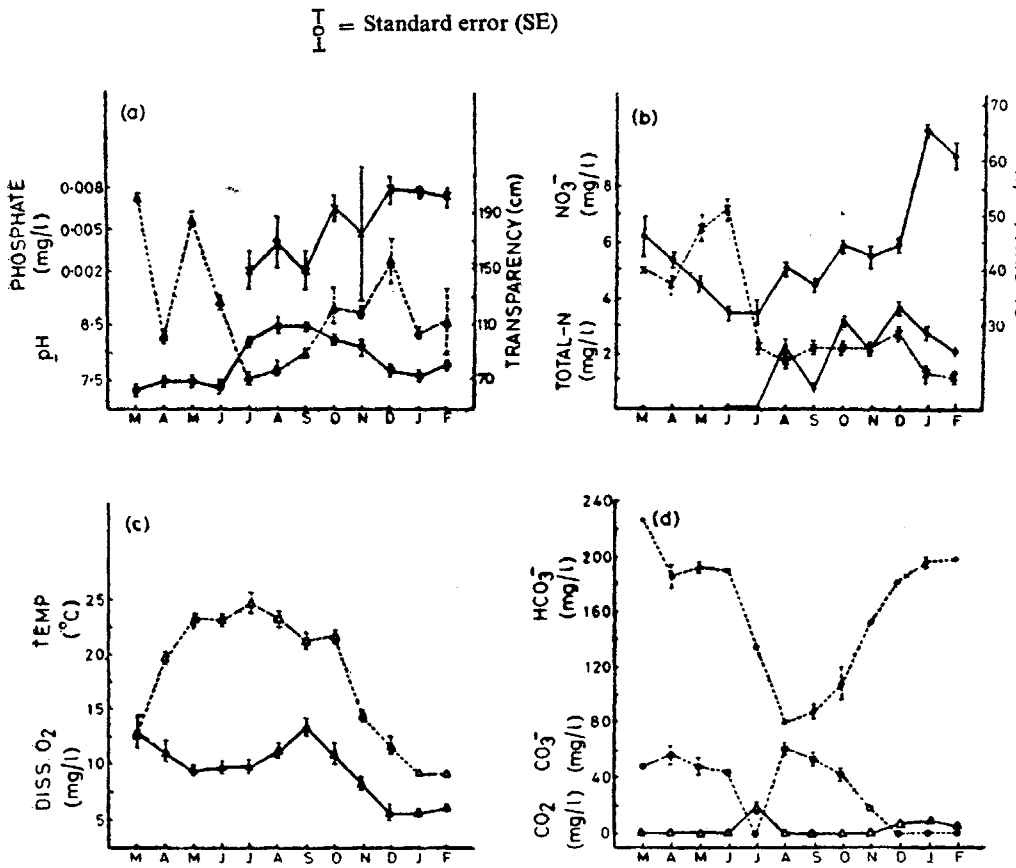

Figure 5 Seasonal value for different Physico-Chemical parameters of Nainital Lake. *a*, Half black circle with continuous line, *p*H; cross with continuous line, phosphate; Closed triangle with dashed line, transparency; *b*, Open circle with continuous line, calcium; cross with dashed line, total nitrogen; closed circle with continuous line, nitrate nitrogen; *c*, Open triangle with dashed line, temperature; closed triangle with continuous line, dissolved oxygen; *d*, Closed circle with dashed line, bicarbonate alkalinity (HCO_3^-); Open circle with dashed line is carbonate alakalinity (CO_3^{--}) and open triangle with continuous line, free carbon dioxide (CO_2)

*p*H

In contrast to bicarbonate alkalinity, the *p*H declined from surface to bottom (table 1). However, the range of seasonal fluctuation in bottom water (6.0–7.6, 1.6 units) was more than twice of that in surface water (7.8–8.5, 0.7 units). Maximum difference in *p*H of bottom and surface waters was noticed in July (2.2 units) and the minimum in December (0.2 units). At all stations, however, the surface water exhibited higher *p*H from July to November. (figure 5).

Calcium

The maximum values for Calcium were recorded in January (66.4 mg/l) against the minimum in July (30 mg/l). However, no definite seasonal trend was noticeable (figure 5).

Phosphate

It varied from traces to 0.01 mg/l. The minimum value was recorded in September, November and July at stations I, II and III respectively, while the maximum was recorded in December, August and February at stations I, II and III respectively.

Table 1 p*H along the depth gradient*

	July	Sept.	Oct.	Dec.
Surface	8.2	8.5	8.2	7.8
1 metre	8.2	8.5	8.2	7.8
3 metre	8.15	8.5	8.0	7.7
5 metre	8.05	8.2	7.8	7.6
7 metre	7.9	8.0	7.6	7.6
9 metre	6.0	7.0	7.4	7.6

Nitrate nitrogen

Seasonal variation in nitrate content was rather marked; the values ranging between 0.05 and 3.7 mg/l. Although there was no consistent seasonal trend (figure 5), maximum values for nitrate-nitrogen were recorded in December and the minimum in June and July.

Total nitrogen

It varied between 1.25 and 7.5 mg/l, the highest values prevailing in June and the lowest in February at all the stations (figure 5).

Discussion

The thermal profiles indicate the shallower zones of the present lake to be of warm monomictic type, with waters never cooling below 4°C at any depth. Zafar (1971) pointed out the stability of stratification being twice as much in tropical waters as in temperate waters, since the phenomenon is related to density and temperature of water. In "Hussain Sagar" the lake density differed by 0.0018 between 28°C and 34°C (a difference of 6°C) (Zafar 1971). In the present case, with a temperature difference of 13°C (10–23°C) the difference in density was 0.00216. A similar degree of stability in stratification was reported for another deep lake of the Kumaun region where the density difference between bottom and surface water amounted to 0.00271 (Singh 1975).

The temperature of bottom water was highest in October at all the stations. Brige et al. (1928) while working on lake Mendota, observed a similar phenomenon and explained it on the basis of release of heat from mud stored during the summer.

A significant positive relationship was observed by us between the *p*H and water temperature (table 2). This is in conformity

Table 2 *Correlation Co-efficient (r) between different Physico-Chemical parameters of the Nainital lake at 0.05 level (only significant correlation are given)*

Parameters	(A)	(B)			
		June	August	October	December
$CO_3^{--}-HCO_3^-$	–	−.99	−.98	−.99	–
Temp. O_2	+.62	+.99	+.92	+.92	–
Temp. CO_3^{--}	+.58	+.98	+.97	+.97	–
Temp. HCO_3^-	−.56	−.98	−.83	−.90	+.86
$O_2-CO_3^{--}$	+.83	+.97	+.93	+.95	–
$CO_2-CO_3^{--}$	−.72	−.90	−.91	–	–
HCO_3-pH	−.95	–	−.97	−.93	−.89
O_2-Ca	−.58				
$O_2-PO_4^{---}$	−.70				
Temp.—Ca	−.88				
Temp.—NO_3^-	−.62				
HCO_3^-—PO_4^{---}	+.65				
Temp.—PO_4^{---}	−.79				
Ca—NO_3^{--}	+.62				
Ca—PO_4^{---}	+.78				
NO_3^-—PO_4^{---}	−.91				
pH—Tol.N_2	−.65				
pH—PO_4^{---}	−.70				
O_2—CO_2	–	−.92	−.72	–	−.99
Temp.—CO_2	–	−.91	−.94	–	–
Temp.—pH	–	–	+.84	+.97	–
O_2—HCO_3^-	–	–	−.93	−.97	−.78
O_2—pH	–	—	—	+.87	+.87
CO_2—HCO_3^-	–	+.92	+.90	–	+.84

A = Temporal valnes of surface water

B = Values along the aepth gradient (June to December) with the observations on other Himalayan lakes (Singh 1975, Zutshi & Khan 1977, Zutshi & Vass 1978).

A positive relation also existed between temperature and dissolved O_2 in surface water (table 2). It may be argued that low temperatures, in winter may constitute one of the major limiting factors for photosynthesis at high altitudes, thus causing a decrease in the oxygen centent of water. The warmer temperatures during summer stimulate photosynthesis (Kaul et al. 1978, Khan & Zutshi 1979) resulting in increased amount of dissolved O_2. Similar relationship between the two parameters was also observed in certain other water bodies of India located in places with severe winters (Singh 1975, Kaul 1977, Zutshi & Khan 1977, Zutshi & Vass 1977, 1978). However, in the present case, the thermal stratification and low transparency did not perhaps allow such relationship to exist between dissolved O_2 and temperature in the bottom water ($r = +0.36$).

In the morning hours of January 5, 1979, a mass fish mortality occurred in the shallower water. At this time the lake had developed a near anoxic condition throughout the water column, with dissolved oxygen being 0.8 mg/l at the bottom and 1.6 mg/l in surface water.

A clinograde dissolved O_2 curve was established in the water during the summer season, and this followed with the thermal stratification (figure 4). Near the bottom in June the oxygen saturation was as low as 55% compared to 145 % in the surface water. This may be viewed, as also suggested by Willoughby (1974), as being partially caused by decomposing leaf-litter which accumulated on the lake bottom during the preceding leaf-fall of *Q. incana* and *Q. dilatata*, the dominant tree species in the lake catchment.

The HCO^-_3 alkalinity was maximum in deeper layer where the *p*H usually was near 7. According to the classification, as given by Philipose (1960), the water of Nainital lake is of high-alkalinity type. A reverse clinograde HCO^-_3 curve as also ound in the present lake, has been treated as a characteristic of the eutrophic water by Hutchinson (1957).

A negative relation existed between HCO^-_3 and *p*H; between HCO^-_3 and temperature; between HCO^-_3 and dissolved O_2; and between CO_2 and CO_3 (table 2). According to Hutchinson (1957) when clinograde dissolved O_2 curve develops, an inverse clinograde curve for free CO_2 may be expected. In the present lake an inverse clinograde type of free CO_2 curve was found in winter too, when dissolved O_2 was homogenous throughout the water column (figure 4a).

Hutchinson (1957) pointed out a high production of free CO_2 causing a relatively small lowering of the *p*H in well buffered lakes. In spite of the presence of an appreciable amount of free CO_2, particularly in July and during the winter months, the lake water remained alkaline, the very fact indicating its high buffering capacity.

Transparency is very low (65–205 cm) as compared to that of the nearby Naukuchiyatal lake (210–945 cm; Singh 1975). This may be related to the fact that the catchment of Naukuchiyatal experiences little tourism and other biotic interferences (negligible population, Singh 1975) as compared to that of Nainital (according to Pant et al. 1980; 40,000 permanent population and 0.13 millions tourist influx per year). The marked increase in human population and associated cultural activities has caused massive deforestation and waste generation in the catchment of Nainital lake, which, in turn, has resulted in increased amounts of suspended particles in the lake water causing a reduction in transparency.

An increase in HCO^-_3, calcium and phosphate was observed in the winter season (figure 5). Kollman and Wali (1976) attributed the occurrence of such a phenomenon in winter to the decrease in *p*H which changes insoluble calcium carbonate into soluble calcium bicarbonate.

Acknowledgement

We are grateful to Dr J S Singh (Department of Botany, Kumaun University, Nainital) for his constructive criticism of the manuscript.

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