Proc. Indian natn. Sci. Acad. B 46 No. 4 pp 528–541 (1980)

Physico-Chemical Characteristics of Nilnag—A High Altitude Forest Lake in Kashmir—and Its Comparison with the Valley Lakes

V KAUL, J K HANDOO and R RAINA*
Post-Graduate Department of Botany, University of Kashmir, Srinagar 190 006

(Received 3 November 1979; after revision 3 April 1980)

The paper presents the results of investigations carried out for the last two years on morphometry, thermics, optics and water chemistry of the Nilnag lake, found in the pine forests at 2180 m. The annual cycle of nutrients is influenced greatly by the changes in the atmospheric temperature; as a result of this thermal stratification develops both during summer and winter when the lake remains under 5–6 cm thick sheet of ice cover. During stratification depletion of oxygen in the bottom waters is responsible for the increase in nutrient content while in the surface water higher concentration of nutrients is obtained during homothermy in November and March. During summer stratification nutrient levels of surface waters are considerably reduced.

Anion levels are similar to other lakes in the valley. In the absence of any major sewage contamination, the values of phosphorus and nitrogen, especially during summer, are low. However, the major cause of trophication of the lake appears to be the enrichment by run-off from the surrounding forests which are under severe biotic interference.

Key Words: Thermal gradient, Startification, Oligotrophic eutrophic, Allochthonous, Trophogenesis

Introduction

Kashmir is known for its innumerable natural freshwater lakes situated at different altitudes (Kaul 1977) in the valley (1600 m), at the foothills of the forests and also amidst them (2000 m) and on the surrounding mountains above the tree line (Zutshi et al. 1972). While enough of data has been published on the hydrobiological aspects of the valley lakes over several years (Zutshi 1968, Zutshi et al. 1973, Vass 1973, Kaul et al. 1978) there is no addition to the scanty information given by Zutshi et al. (1972) in regard to the other two lake types. The importance of such data on Nilnag becomes all the more necessary vis-a-vis the accelerated tourist influx into the beautiful valley of Yus—where the lake is situated, coupled with the associated urbanization so that effective measures can be adopted for its future preservation for productivity and bio-aesthetic purposes.

Location

The Nilnag is a typical high-altitude forest

---

* G. M. College, Srinagar 190 001, Kashmir

lake situated at 2180 m, 40 km south of Srinagar. The lake formed as a result of tectonic movements (Zutshi et al. 1972), lies amidst the pine forests and is fed by an ephemeral stream on its south-western end, which adds to its water depth during the rainy season as compared to that in autumn and winter. It has an outlet on north-eastern end for regulating the water depth. The water formed by the melting snow at higher elevations enters the lake along with the run-off from the surrounding partially denuded mountains and patches of arable land, bringing in a heavy load of silt, allochthonous material and other plant nutrients year after year, resulting in dense growth of aquatic weeds.

Macrophytic Vegetation

The macrophytic vegetation of the lake is grouped under three main growth forms viz., (i) emergents (ii) rooted floating-leaf and (iii) submerged types. Among the emergents, the tall-growing species of *Phragmites communis* Trin., *Typha angustata* Bory and Chaub, *Scirpus lacustris* L. and *Sparganium ramosum* Huds. are represented in a very small belt along the margin while the low-growing species like *Polygonum amplexicaule* D. Don, *P. amphibium* L., *Marsilea quadrifolia* L., *Eleocharis palustris* (L.) R. Br., *Sagittaria sagittifola* L. and *Alisma plantago* L. colonize the partly exposed edges. These species together with other low-growing types like *Galium hertifolium* C.B. Cl, *Dryopteris odontoloma* (Moore) C. Chr., *Carex nubigena* D. Don., *C. wallichiana* Presc., *Sium latijugum* C.B. Cl, *Lycopus europaeus* L., *Bidens tripartita* L., *Hippuris vulgaris* L., *Menyanthes trifoliata* L., *Eleocharis uniglumis* Link Schultes Mant. and *Scirpus palustris* L. show dense growth on the small pieces of floating islands formed chiefly by the underground left-over portions of *Typha angustata* Bory and Chaub, *Phragmites communis* Trin. and *Cladium mariscus* (L.) Pohl towards the outlet.

The common rooted-floating leaf types comprising *Nymphoides peltatum* Link., *Nymphaea alba* L., *Potamogeton natans* L. and *Trapa natans* L. grow up to a maximum depth of 4.5 cm, while the submergeds include *Ceratophyllum demersum* L., *Myriophyllum spicatum* L., *Potamogeton leucens* L. and *P. crispus* L., which colonize up to a depth of 5 m. These plant species are divisible into nine life forms viz. (i) *Ceratophyllids*, (ii) *Myriophyllids*, (iii) *Parvopotamids*, (iv) *Magnopotamids*, (v) *Batrachiids*, (vi) *Marsileids*, (vii) *Nymphoids*, (viii) *Trapids*, and (iv) *Helophytes* (Hogeweg & Brenkert 1969).

Materials and Methods

The bathymetric maps and morphometric features were calculated after Welch (1948), the lake being studied for this purpose in March, 1977. For surveying and laying of depth points enlarged geographical map prepared by Geological Survey of India and loaned temporarily from State Forest Department was used. The water samples for analysis purposes were collected on regular monthly visits to the lake sites from September, 1977–August, 1978. Water temperature and dissolved oxygen were measured on the spot at 1 m depth intervals using maximum and minimum thermometer and the unmodified Winkler technique (Mackereth 1963) respectively. Alkalinity, calcium (Ca) and magnesium (Mg) were determined titrimetrically according to the methods given by Mackereth (1963). Sodium (Na) and potassium (K) were measured by flame photometery. Colorimetric procedures as given in APHA (1970) were employed for estimation of ammonia (NH_4–N), nitrite (NO_2–N) and nitrate (NO_3–N) nitrogen and phosphates (PO_4), while specific conductivity and *p*H were measured by Philips conductivity bridge and *p*H meter respectively.

Observations

Morphometry: The detailed bathymetric features and the morphometric parameters of the lake are set in figure 1 and table 1. The lake has a total volume of 137.72 × $10^3 m^3$ of which a maximum of 120.33 × $10^3 m^3$ (87.37%) lies in 0.4 m depth zone while the remaining 17.39 × $10^3 m^3$ (12.63%) is constituted by 4–7 m depth zone. The shore line is somewhat irregular with an index of 1.44 which gives the lake an elliptical shape. The lake has a maximum depth of 7 m and the mean depth is calculated at 2.67 m. The ratio of mean depth to maximum depth (0.37) gives the basin V-shape. The volume development (1.12) is very much near the unity and indicates the convexity of the lake basin walls towards the surface.

Temperature: Changes in the water temparature of the lake show a close proportionality to that of the air. Beginning from October, the cool nights resulting in the loss of heat from surface layers, bring about deep mixing on account of highly reduced density gradients. The lake waters, thus, evince a complete mixing in November and are isothermal at 6°C. From December onwards the thermal stratification is of the reverse order while during January-February, the lake remains covered over by 5–6 cm thick sheet of ice.

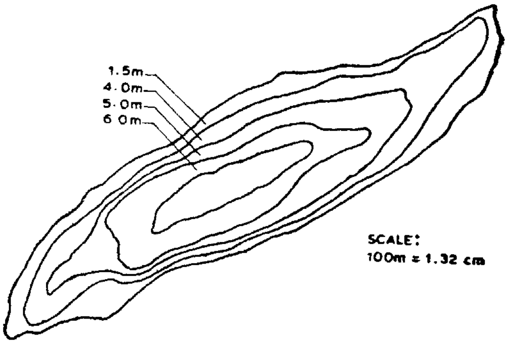

Figure 1 Bathymetric map of Nilnag lake

Table 1 *Morphometric Features of the Nilnag Lake*

Maximum length (l) m	456
Maximum width (bx) m	125
Maximum depth (Z max) m	7
Mean depth (Z) m	2.63
Surface area (A) 10^3 m^2	0.523
Length of shore (L) m	117
Index of shore development (DL)	1·44
Volume development (DV)	1.12
Total volume (V) 10^3 m^3	137.72
Mean depth/maximum depth	0.37

The thickness of ice towards east and north-east is nearly double than that towards north-west. The water temperature just below the ice sheet showed an increase from 0°C in January to 1.50°C in February, presumably due to increased radiation or as a result of the convectional currents arising from the bottom. The bottom temperature during this period fluctuates between 5.6–5.0°C and does not show much change from the autumnal circulation temperature; this is mainly due to the exothermal decomposition reactions in the bottom sediments. The warming up of the water under ice has been shown by Matusiak and Wojciechowski (1975) to be dependent both upon the intensity of exothermal reactions and the shallowness of a lake, while for lake Mendota, U.S.A., Juday et al. (1931) have reported that in winter one fourth of heat comes from the mud and three fourth from the solar radiation.

With the increase in atmospheric temperature, a distinct stratification of water, with distinct thermal layers of epilimnion, thermocline and hypolimnion, was noticed after thawing of ice and a brief period of homothermy in early March. On 28th of March, a temperature gradient of 3.4°C was thus developed between the surface and bottom layers with surface water showing a temperature of 11.1°C against 7.7°C of the bottom water. By April, a well developed epilimnion (0–1 m), thermocline (1–4 m) and hypolimnion were discernible, the thermocline showing a thermal step of 3.1, 2.8 and 1.6°C between 1–2, 2–3 and 3–4 m depth zones respectively (figure 2). May and June depicted a thermal gradient of 6.6°C and 5.5°C between the surface and bottom layers respectively. In July, with the onset of rains, the air temperature dropped down to 13.3°C; and both these factors together with the cold water (11.2°C) brought down from the surrounding mountains along the inflowing stream lowered the surface water temperature from 21.1°C in June to 14.4°C in July. The temperature of bottom waters, however, hardly showed any change and remained constant at 15.5°C. The warmer months of August and September again depicted the development of a thermal gradient of 2.5°C and 4°C between the surface and bottom water temperatures respectively. In September, a temperature gradient of more than 1°C/m was evinced between 1–2 m (2.3°C) and 2–3 m (1.1°C) zones only while the temperature in the lower layers was recorded uniformly at 18°C.

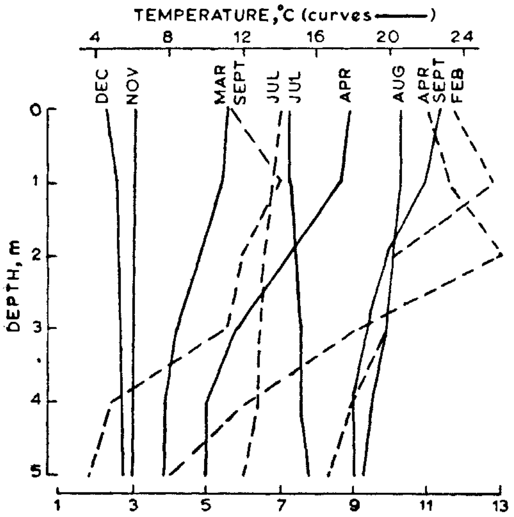

Figure 2 Temperature profiles and oxygen curves of Nilnag lake

Transparency: The light penetration varies a great deal from month to month. Secchi disc visibility ranges from 0.8–2.0 m of depth. The lowest values are recorded in February when the lake is covered over by ice. The visibility increases to a maximum of 2.0 m in April, the values thereafter recording a continuous fall up to July when the suspended material brought in by the feeding channel reduces transparency to 1.1 m only. In August, the values show a slight increase by 0.5 m. From August onwards the light penetration becomes limited to lesser depths and in December the secchi disc was visible up to 1.0 m depth only.

Oxygen: Oxygen content in the surface waters ranged between 5.7–11.7 mg/l. The oxygen cycle in the water involves a rapid decrease during summer and a steady increase through autumn till maximum content is reached in winter, following the well-known law of solubility of gases. According to this law the changes in the oxygen content are inversely related to the changes in the atmospheric temperature. The oxygen concentration in the bottom waters was always of a lesser magnitude. This was true even when the upper layers had the same oxygen content and the waters circulated freely. This difference, being indicative of the decomposition processes in the bottom sediments, increased during the summer and winter stagnation periods. The hypolimnetic oxygen concentration decreased from 9.8mg/l

(104.8%) in December to 5.3mg/l (87.77%) in February against a decrease from 7.4mg/l (62.53%) in March to 3.4mg/l (51.09%) in June, which further fell to 1.8mg/l (24.80%) in September. Thus, the exhaustion of oxygen in the hypolimnion is slow in winter and fast in summer, most probably due to the lower temperature of water layer close to the bottom putting checks on the metabolic activity of microorganisms.

The vertical oxygen profile also varied greatly during the course of the year. In March, the various depth layers depicted a gradual fall in oxygen concentration from 9.8mg/l (107.90%) at the surface to 7.4mg/l (82.53%) at the bottom while in April the values recorded at surface, 2m and 5m depths were 11.0 mg/l (157.28%), 13.0 mg/l (174.23%) and 4.0 mg/l (48.42%) respectively, indicating a tendency towards the development of a positive heterograde type of oxygen curve. In June, the oxygen gradient between the surface and bottom layers fell to 5.6 mg/l while in July due to the mixing of rain and cold water from the surrounding mountains with the lake waters, this gradient was reduced to 1 mg/l only. The oxygen gradient, however, increased to 4.8 mg/l and 3.9 mg/l in August and September respectively (figure 2).

Homothermy in November was characterized by homo-oxygeny in all but the bottom layer where the oxygen concentration was 0.5 mg/l less than that at the surface. In February, when the lake was covered by ice, a maximum oxygen concentration of 12.8 mg/l (117.90%) was recorded in the 1 m depth zone, the concentration in the surface and bottom layers during this period being 11.70(104.04%) and 8.3 mg/l (87.77%) respectively.

The oxygen content of surface waters was close to saturation during spring and summer while in autumn when the macrophytic stands were on decline the values were slightly below 100% saturation. Marked differences evinced in the % saturation of the hypolimnion are probably associated with the variation in the production and consumption of oxygen. Higher % saturation values are obtained in winter when under low temperature conditions the metabolic activities remain at a minimum. In July, the rain and comparatively low temperatures resulted in an increase in the saturation values of the hypolimnion; the saturation values of 81.22% in this month being maximum for the summer season.

Alkalinity: Alkalinity is constituted mainly by the bicarbonate ions, which represent the main carbon source for assimilation during photosynthesis. With the increase in the atmospheric temperature and the consequent increase in the photosynthetic processes in summer, alkalinity values depict a significant fall from the spring values. The alkalinity of the surface waters during this period fluctuated between 210 mg/l in April to 174 mg/l in September. A continuous increase in alkalinity values was recorded from September till a maximum of 218 mg/l was reached in February, the increase being maximum during September–October (16mg/l) and December–January (26mg/l). From February–April the trend was irregular; the fall of 12 mg/l in March being probably associated with dilution due to melting of ice (figure 3).

Marked differences were observed in the alkalinity values of the surface and bottom waters; the alkalinity in the surface waters being always lower than in the bottom waters. The vertical stratification showed a difference of 22 mg/l between surface and bottom waters in December, which rose to 26 mg/l by February. In March a difference of only 6 mg/l was recorded; whereafter the vertical gradient continued to rise till a maximum of 42 mg/l was reached in June. In July the inflow of cold run-off water with rains, resulted in a fall of vertical gradient to a minimum of 2 mg/l. With the setting in of the thermal stratification during August–September, the alkalinity became stratified again and the vertical gradient increased to 26 mg/l in September. During homothermy in November, alkalinity was same throughout the water column.

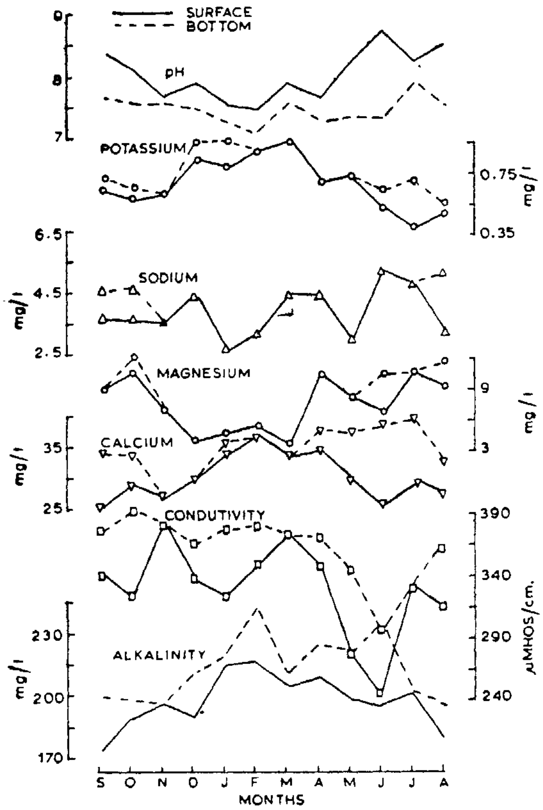

Figure 3 Seasonal variation in the concentration of cations, pH, conductivity and alkalinity in Nilnag lake

Conductivity: Throughout the study period conductivity in the surface waters ranged between 241–380 μ mhos/cm^2, following a trend similar to that of alkalinity. The minimum values were obtained in June and the maximum in November. During summer the assimilation of ions by photosynthesising organisms results in a fall in conductance from 371 μ mhos in March to 241 μ mhos in June and from 331 μ mhos in July to 321 μ mhos in November against an increase (337 μ mhos in December to 371 μ mhos in March) during winter when the dominance of decomposition over assimilation results in the liberation of ions (figure 3).

The differential vertical gradient in conductance was observed in both summer and winter months. In these periods the mineralization of the organic matter under the influence of reducing conditions (Mortimer 1941) prevailing in the bottom waters is accompanied by a release of minerals and as a result the bottom waters show higher conductance than the surface waters. The differences in the surface and bottom waters of the lake increased from 23 μ mhos in April to 83 μ mhos in June and from 50 μ mhos in August to 69 μ mhos in February. The mixing of water in November, however, results in the prevalence of the same conductance values throughout the vertical profile of water.

p*H:* The lake water is alkaline and pH did not vary greatly with changing season; the range being 7.7–8.8 for the surface waters and 7.1–7.6 for the bottom waters. The increased values of surface waters obtained during summer obviously are related to the metabolic activities of the autotrophs which by utilizing carbon-dioxide and liberation of oxygen during photosynthesis reduce the H-ion concentration greatly (Kaul & Handoo 1980). In the bottom waters the liberation of acids from the decomposing organic matter under low oxygen conditions resulted in lower pH values. The differences in pH between the surface and bottom waters, thus created, were maximum in June (1.4 units) and minimum (0.1) during homo-oxygeny in November (figure 3).

Cation concentrations: The average concentration of Ca, Mg, Na and K (30 mg/l, 7.4 mg/l, 3.9 mg/l and 0.68 mg/l respectively) indicates the cation progression for the lake to be of the order of Ca>Mg>Na>K. Such a progression, according to Rodhe (1949), is characteristic for fresh waters; the dominance of Ca over other cations being probably related to its leaching from the surrounding calcareous deposits. Ca concentration involves an increase in its values from October to February and a significant decrease during summer (figure 3). The depletion of Ca is related to the photosynthetic activity of the macrophytic species attaining their peak growth and production during summer (Kaul et al. 1978). The uptake of CO_2 during photosynthetic activity results in the loss of Ca due to preiepitation of $CaCO_3$ as per below given equation after Berner (1965):

$$Ca^{++} + 2HCO_3 = CaCO_3 + CO_2 + H_2O$$

Mg content fluctuates between 3.4 mg/l in March to 10.6 mg/l in July. The seasonal trend involves an irregular rise and fall in the various months (figure 3). Increased Mg content in the bottom waters was recorded in June, August and October.

Na, like Mg also does not record a regular seasonal variation. Its concentration ranges between 2.7 mg/l in January and 5.4 mg/l in June. The difference in the surface and bottom water fluctuated between 0–1.6 mg/l during the various months of the year.

K, like Ca, also recorded decreased values during summer, though its loss through precipitation is unknown. K content was minimum (0.39 mg/l) in July and maximum (0.94 mg/l) in February.

In the bottom waters, increased amounts of K were obtained from May–October and December–January (figure 3).

Anion concentration: The seasonal trend of $NO_3 - N$ in surface waters is characterised by an increase in concentration during winter and a decrease during summer (figure 4). The values, fluctuating between 69–217 μg/l, record a close parallel to the fluctuations in oxygen concentration. An increase by 45 μg/l during June–July was probably caused by its leaching from the surrounding terrestrial vegetation during rains.

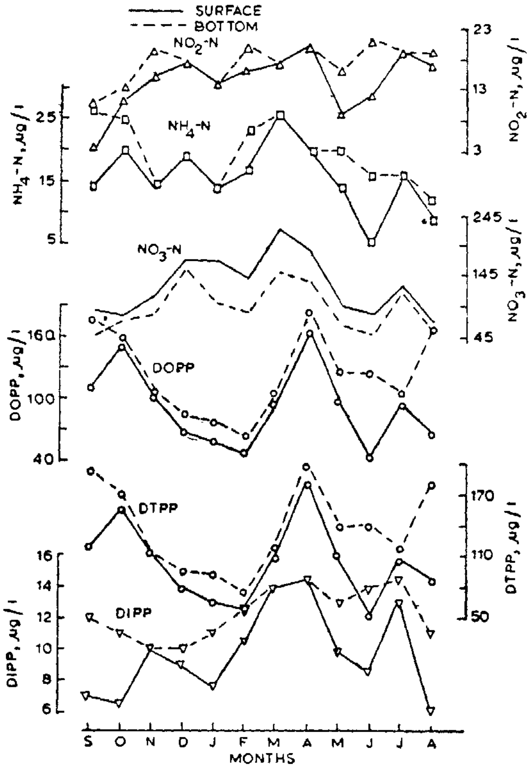

Figure 4 Seasonal variation in the concentration of nitrogen and phosphorus at Nilnag lake

In the bottom waters the NO_3-N concentration recorded a continuous decrease during thermal stratifications in summer and winter months and an increase in November, March and July when the waters were freely mixing. The higher O_2 content in the bottom waters during homothermy favours nitrification at the mud water interface, the nitrification being especially rapid in the calcareous sediments (Cheng et al. 1972).

NH_4–N and NO_2–N, in comparison to NO_3–N, are present in small quantities and their concentration fluctuates between 5–26 μg/l and 3–21 μg/l respectively during the year. The seasonal trend involves an increase from fall-spring and a decrease during summer when minimum values are recorded (figure 4).

In the bottom water higher levels of both these nitrogen forms were obtained in September, October, February, May, June and August months (figure 4), the maximum difference between the surface and bottom water being attained in June for NO_2–N and in September for NH_4–N.

The low concentrations of NO_2–N are in consonance with its insignificant role in the environment and also with its short residence time in water (Malhotra & Zanoni 1970). NH_4–N is liberated from the decomposing organic matter of the lakes, its release in the deeper layers being governed by the anoxic conditions. Under low oxygen conditions NH_4–N is the end product of NO_3–N metabolism (Reid 1961). In the surface waters, however, low concentrations of NH_4–N may result through its utilization by plankton and other plants (Prochazkova et al. 1970). Among the various forms of phosphorus, soluble inorganic-phosphate-phosphorus is found in smaller quantities; its concentration during the year fluctuates between 6–14 μg/l. The concentration was maximum during April and minimum during August (figure 4). Such a seasonal trend is synchronous with the precipitation of $CaCO_3$ with which it gets absorbed and coprecipitated (Otsuki & Wetzel 1972, Kaul et al. 1978). In addition, the uptake by phytoplankton and macrophytes provides a kind of a biological sink during this period.

The maximum content of total phosphate phosphorus (180 μg/l) recorded in April fell to a minimum of 50 μg/l in June; the values in the subsequent months showing an irregular rise and fall. During winter the concentration of total phosphate phosphorus showed an appreciable fall and the values were nearly half the concentration values recorded in autumn (figure 4).

Organic-phosphate-phosphorus constituted a significant part of the total phosphate phosphorus and followed a seasonal trend similar to it (figure 4). From the large amounts of organic-phosphate-phosphorus present in comparison to inorganic-phosphate-phosphorus most of the PO_4–P is apparently unavailable for assimilation and is bound in the complex colloidal particles from which it is liberated slowly.

The various forms of PO_4–P revealed higher concentration in the bottom waters, little or no differences between the surface and bottom waters being obtained only during homothermy when the waters are freely circulating and oxygen gradients are absent. During stagnation the higher content of phosphorus in the bottom waters may result from decomposition of organic matter and its release from sediments under the anoxic conditions prevailing during this period.

Discussion

Ever since the establishment of trophic concept by Lindmann (1942), a number of investigators have attempted to categorise or rank the lakes on the basis of one or more parameters. The factors involved may be present within or outside the lake. Schindler

(1971) while working on the ELA lakes in Canada put forth a hypothesis to the effect that the changes in the lake morphometry involve the changes in the nutrient regime of the lake as well. The most common change to be expected is, however, the filling of the lake basin with sediment as the lake ages. All oligotrophic lakes examined by Rawson (1955) were 20 meters or more deep against those with a mean depth of 10 meters or less which were usually eutrophic. Small volume and shallowness intensify eutrophy by reducing the dilution factor (amount of plant nutrients per unit volume of lake) and by reducing the distance between the heterotrophic recycling layer (bottom) and the productive surface layer (Cook & Kennedy 1970, Schindler 1971).

The special interest in the Nilnag lake lies in its location among the pine forests. A comparison of the morphometrics characteristics of the lake with the valley lakes (the Dal, Anchar and Manasbal) on which the data has already been published (Kaul 1977) indicates significant differences.

In volume and surface area the Nilnag lake is smallest as compared to the Valley lakes; being smaller than the smallest Gagribal basin of the Dal lake which has a volume of 930×10^3 m^3 and surface area of 1.30 km^2. However, Nilnag is deeper than the Nagin, the deepest basin of the Dal, but is shallower than the Manasbal lake which has a maximum depth of 12 meters. All the lakes are, however, shallow basined types which together with highly gentle slope (volume development index ranging between 0.61–0.78) places them in eutrophic series of Naumann (1919) and Thienemann (1925), the oligotrophic lakes according to these authors being deep and steep basined.

In the development of inverse thermal stratification the Nilnag lake is unlike any valley lake. The valley lakes remain isothermal throughout the winter and may freeze for a brief period only in extreme cold. This difference may, however, result from the situation of the lake at a higher altitude and among the forests; the factors that are known to reduce the temperature and the atmospheric pressure simultaneously increasing the amount of precipitation (Kaul & Sarin 1974).

The summer thermal stratification is somewhat similar to that in the Manasbal lake of the valley in as much as three distinct layers of epilimnion, thermocline and hypolimnion lasting for 6–8 months are discernible. However, the Nilnag lake differs from the Manasbal in having a single thermocline throughout the spring as against the early multiple thermocline of the latter. The thermal gradients developed in the Nagin and Hazratbal basins of the Dal lake, without any detectable thermocline are in no way near the true thermal stratification of the Nilnag lake. These differences together with the differences in the relative thickness of the varying thermal layers can be explained on the basis of low visibility and sheltering effects of forests in Nilnag—creating favourable thermal conditions for the upper layers of water—shallower depth and different altitudinal locations. Patalas (1960) while working on several lakes of Wiegorzowa district of Poland classified the thermally stratified lakes into groups I and II which he further differentiated on the basis of the thickness of thermocline and the temperature of the bottom waters. The thickness of the thermocline ranging between 2–3 m and the temperature in the bottom waters recording more than 4°C in the Nilnag lake would put it in Group II, which is very much in agreement with its low relative depth.

Dissolved oxygen, because of its role in the lake metabolism, has been used as a most reliable parameter of lake eutrophication. The organic matter produced during photosynthesis ultimately gets deposited in the lake mud where for its decomposition it utilizes the oxygen present in the water layer close to it. The amount of trophogenesis occuring in the epilimnion is correlated with the hypolimnetic oxygen depletion (Hutchinson 1938, Tarnefelt 1958) and is thus a reflection of its degree of eutrophy (Hutchinson 1938, Storm 1931, Baldi et al. 1953).

During summer stagnation period, the oxygen profile in the Nilnag lake becomes characteristically stratified. The clinograde and positive heterograde type of oxygen curve obtained early in the spring is similar to that of Nagin basin but dissimilar to that in the Manasbal lake or other basins of the Dal lake. Such a type of oxygen profile with high concentration of oxygen in the metalimnion has been attributed to the photosynthetic activity of phytoplankton than only the physical causes (Vass 1973). In all these lakes the depletion of oxygen in the lower layers near the bottom is an indication of a tendency towards eutrophication (Kaul 1977). The differences in the oxygen deficiency of these lakes arise as a result of the variation in the thickness of the hypolimnion as has also been opined by Matusiak and Wogciechowski (1975) who found that lake Czarne, Poland with thicker hypolimnion (in comparison to lake Bialskie) stored more oxygen during the period of circulation and its loss during stagnation period was slower and smaller than in lake Bialskie. However, the decreases in hypolimnetic oxygen also occur during the decomposition of sedimented organic matter, whose nature and quality have been opined to affect the oxygen uptake significantly (Edherg & Hofsten 1973). In the present study, a fast and more intensive utilization of hypolimnetic oxygen, immediately after the heavy rains during July–August, can be said to 'be due to the inflow of organic matter from the surrounding forests into the lake system, where it settled and subsequently decomposed. The freshly sedimented organic matter because of higher proportion of less resistant tissue, appears to be highly refractory to oxidative breakdown by aerobic bacteria.

The depth of disappearance of secchi disc, because of its dependence on lake productivity, also aids in evolving the trophic status of lakes. Such studies usually involve long term observations of light penetration values. However, as opined by Yoshimura (1933) for some Japanese lakes showing transparency values of 1.50m or less, the Nilnag lake, with transparency values of 0.8–2.0 m can be said to be showing a tendency towards higher trophic status.

The lake waters were always alkaline and because of the narrow range appear to be highly bufferred, a phenomenon common to all valley lakes of Kashmir.

Total alkalinity for the Nilnag lake (174–260 mg/l) is considerably higher than that of any of the valley lakes (35–160 mg/l), suggesting the lake to be of extremely hard water 'β meso-area type' of Søensen (1948). The alkalinity is constituted mainly by bicarbonates and the higher values may result by conversion of sediment $CaCO_3$ into bicarbonates under the influence of carbonic acid, formed during stratification by the anoxic decomposition of organic matter at the sediment surface. The bicarbonate thus formed gets mixed up with the surface waters during homothermy and is used as a carbon source by the photosynthesizing organisms in the active period.

An increase in the trophic status of a lake is associated with an increase in its nutrient status and hence an increase in the conductivity values indicates a tendency towards higher level of trophication (Berg et al. 1958).

A comparison of the conductivity values of the valley lakes indicates the Gagribal and the Hazratbal basins of the Dal lake as having lower conductivity values while the same for the Anchar lake, the Manasbal lake and the Nagin basin (132–380μ mhos) are higher.

The conductivity values for the surface waters of Nilnag lake ranged between 241–380 μ mhos while the values for the bottom waters during stratification were higher. The lake together with the Anchar lake, the Manasbal lake and the Nagin basin of the Dal lake would fall in the β'meso-area' of Olson (1950). The causative factors for the increased conductance values for the lake are, however, (i) the run-off from the surrounding dense-partially denuded forests and the arable lands and (ii) the inflowing sewage and domestic refuse, which as indicated by the July data result in considerable addition of minerals to the lake system.

The calcium content of the Nilnag lake is similar to the Anchar lake, the Hazratbal basin and the Gagribal basin, all being 'Calcium rich' types of Ohle (1934). The marked deposits of $CaCO_3$ both in the sediments and other types of substrates, in addition to the run-off from the surrounding calcareous deposits of the drainage basin, appear to be the chief source of calcium. The content of other cations like Mg, Na and K in the lake under study are not much different from those of other valley lakes of Kashmir.

The content of the two of the most important elements of phosphorus and nitrogen has been widely used as an index of eutrophication. The critical levels for lakes as given by Sawyer et al. (1945) 30 μg/1 of phosphorus and 150 μg/1 of nitrate-nitrogen when crossed, result in algal blooms. The concentration of these nutrients is more closely related to external factors such as cultural influences, fertilization and rate of flow (Hutchinson 1938, Sawyer et al. 1945).

In the Nilnag lake the maximum concentration of inorganic-phosphate-phosphorus is less than half the critical value while that of nitrate-nitrogen is crossed only during winter and early spring months. During these months the oxygen rich hypolimnion greatly favours nitrification at the mud-water interface (Cheng et al. 1972, Serruya et al. 1975) while its utilization under low temperatures is minimum. However, the concentration of both nitrate-nitrogen and inorganic-phosphate-phosphorus in comparison to the valley lakes remains much lower at all times of the year, which in fact is in consonance with the little cultural influences along its drainage basin.

On an overall basis the ionic composition of the Nilnag lake is quite close to the standard composition of Rodhe (1949); the noticeable feature being the higher values of calcium which were always more than three times the magnesium concentration. Among anions, bicarbonate is the most dominant ion thereby indicating that calcium bicarbonate is the most dominant buffer—a fact which the lake shares with most of the hardwater lakes (Ruttner 1963). According to Reid (1961) these hard water lakes have little or no carbonate alkalinity and the bicarbonate alkalinity results in high buffer capacity which keep the *p*H relatively constant.

The various physico-chemical characteristics indicate that the Nilnag lake has a mesotrophic character, the higher trophication of the lake is a result of the natural causes, but the process is accelerated by human activities such as deforestation, habitation and cultivation along its catchment. The allochthonous material washed out from the top soil of the forest area is sooner or later transferred into the lake. The loss of nutrients from these areas is accelerated by the destruction of vegetation as has been exemplified by Borman and Likens (1970) in a 3.8 acre watershed in an experimental forest in New Hampshire. The study indicated that the output of nutrients into stream water greatly enhanced when the capacity of the ecosystem to retain nutrients was disturbed by deforestation.

In the present study such a release of nutrients from the surrounding areas is indicated by the results of measurement of electrolytic conductivity of water during July–August. In this period, the heavy rainfall induced run-off from the surrounding mountain forests which are under severe biotic interference, resulting in a considerable increase in the electrolytic conductivity in comparison to the spring season. During periods of low rainfall an accumulation of nutrients takes place in the soils of the drainage basin. These nutrients enrich the lake intensively with the activation of run off during the period of abundant rainfall. However, the increased input of water in August, when the rains are much severe than in July, had a dilution effect while in the subsequent months of late summer-early autumn low precipitation inhibited run-off and the conductivity recorded a gradual fall; the minerals being either incorporated within the algal biomass or getting lost through the outflow towards north. The importance of outflow in reducing the salt accumulation has been demonstrated by Zutshi and Khan (1978).

The participation of shore erosion in supplying biogens appears to be only moderate, as the shore line is less developed. In lake Mikolajskie, Poland, with considerable part of the banks overgrown with forests, the soil erosion has been found to constitute only 0.1% of the total flow of phosphorus to the lake (Wojciechowskie 1976). However, the steeper shores of the Nilnag lake as compared to most of the valley lakes would indicate a greater contribution, the fact that needs further investigation.

There has also been significant increase in the number of tourists using camping ground along the shore in recent years which again must be exerting some influence on the eutrophication of the lake. Since they affect mostly the drainage basin and indirectly the lake through the run-off, it may be difficult to estimate their impact quantitatively.

Acknowledgements

The authors are thankful to Professor P Kachroo, Head, Department of Botany, University of Kashmir for providing the laboratory facilities. The financial assistance by Department of Science and Technology, New Delhi for carrying out the research is gratefully acknowledged.

References

APHA 1970 Standard Methods for the Examination of Water, Sewage and Wastes; *Amer. Publ. Health Ass. Inc.* New York

Baldi E, Tonolli V and Tonolli P L 1953 La differents evoluzione di due lagligia constituents un unico bacino II. lag Maggiore ed it lago di; *Mergozzo. Mem. Inst. Ital. Idrobiol* 7 49–107

Berg K, Anderson K, Christensen T, Ebert F, Lyshede E J M, Mathiesen H, Nygaard G, Olsen S, Roen U, Otterstrom C V, Skadhauge A, and Nelsen E S 1958 Furesundersgelser 1950–54. Limnological studies over Fure's Kultur-pavirkning; *Folia Limnol. Scand.* 10 189

Berner R A 1965 Activity coefficients of bicarbonate and calcium ions in sea water; *Geochim Cosmochin Acta* 29 947–965

Borman F H and Likens G E 1970 The nutrient cycles of an ecosystem; *Scientific Amer.* **223** 92–101

Cheng R L, Keeney D R and Konard J G 1972

Nitrification in lake sediments; *J. Environ. Qual.* **1** 151-154

Cook G D 1966 Physico-chemical measurements of Miller's Bay, Lake West Okoboji, summer, 1964 *Iowa Academy of Science* **73** 374-383

—— and Kennedy R L 1970 Eutrophication of North eastern Ohio lakes. I. Introduction, morphometery and certain physicochemical data of Dollar lakes; *The Ohio Journal of Science* **70** 150

Edberg N and Hofsten B V 1973 Oxygen uptake of bottom sediments studied *in situ* and in the laboratory; *Water Research.* **7** 1285-94 Pergamon Press

Hogeweg P and Brenkert A I 1969 Structure of aquatic vegetation: a comparison of aquatic vegetation in India, the Netherlands and Czechoslovakia; *Trop. Ecol.* **10** 139-162

Hutchinson G E 1938 On the relation between the oxygen deficit and the productivity and typology of lakes; *Int. Rev. Hydrobiol.* **36** 336-355

Hutchinson G E 1957 *A treatise on Limnology.* 1015p Vol. I. (New York: John Wiley and Sons)

Juday E, Brige E A and Melache V M 1935 The carbon dioxide and hydrogen ion concentration of the lake waters of north-eastern Wisconsin; *Acad. Sir Arts Lett.* **29** 1-82

Kaul V 1971 Production and ecology of some macrophytes of Kashmir lakes; *Hydrobiologia;* Bucharest **12** 63-69

—— 1977 Limnological survey of Kashmir lakes with reference to trophic status and conservation; *Int. J. Environ. Sci.* **3** 29-44

—— Zutshi D P and Vass K K 1971 Biomass production of some macrophytes of Srinagar lakes. pp 295-311, in *Trop. Ecol. emphasizing Organic production* ed F B Golley

—— and Sarin Y K 1974 Studies on the vegetation of the Bhadarwah Hills. I. Altitudinal Zonation; *Bot. Notiser* **127** 500-507

—— Trisal C L and Handoo J K 1978 Distribution and production of macrophytes in some aquatic bodies of Kashmir; pp 313-334 in *Concepts of Ecology* ed J S Singh and B Gopal

—— and Handoo J K 1980 Water characteristics of some fresh water bodies of Kashmir (In Press)

Lindman R L 1942 The trophic dynamic aspect of ecology; *Ecology* **23** 399-418

Mackereth F J H 1963 Water analysis for limnologists; *Fresh water biological association* **21** 1-70

Malhotra S K and Zanoni A E 1970 Chloride interference in nitrate-nitrogen determination; *J. Amer. Wat. works. Assoc.* **62** 568-71

Matusiak K and Wojciechowski I 1975 Some physical factors as the ecological background in the pelagial of the Sosnowickie lakes; *Acta Hydrobiol.* **17** 103-139

Morimer C H 1941 The exchange of dissolved substances between mud and water in lakes I and II; *J. Ecol.* **29** 280-329

Naumann F 1919 Nagra Synpunkter Angaende Limnoplanktons Okologie. Med Sarskild Hansyn Till Fytoplankton; *Svensk. bot. Tidskr.* **13** 129-163

Ohle W 1934 Chemische und physikalische unter suchunger nordebentscher seen; *Arch Hydrobiol.* **26** 386-464

Olson S 1950 Aquatic plants and hydrospheric factors. I. Aquatic plants in S W Jutland, Denmark; *Svensk. Botanisk. Tidskriff.* **44** 1-34

Otsuki A and Wetzel R G 1972 Coprecipitation of phosphate with carbonates in a marl lake; *Limnol. Oceanogr.* **17** 763-767

—— and Wetzel R G 1974 Calcium and total alkalinity budgets and calcium carbonate precipitation of a small hard water lake; *Arch. Hydrobiol.* **73** 14-30

Patalas K 1960 Stosunki termicznei teenowe Gras przezrocs-stos'c' wody W 44 jeziorach okolic Wegorzewa-Thermal and oxygen conditions and transparency of water in 44 lakes of Wegorzewo District; *Raczn. Nauk. Roln.* B **77** 105-222

Prochazkova L Blazka P and Kralova M 1970 Chemical changes involving nitrogen metabolism in water and particulate matter during primary production experiments; *Limnol. Oceanogr.* **15** 797-807

Rawson D S 1955 Morphometry as a dominant factor in the lake productivity of large lakes; *Verh. int. Verein. theor. angew. Limnol.* **12** 164-175

Reid G K 1961 *Bcology of Inland Waters and Estuaries* (375pp) New York: Reinhold Pub. Corp.

Rodhe W 1949 The ionic composition of lake waters; *Verh. Int. Ver. Limnol.* **10** 377-386

Ruttner F 1963 *Fundamentals of Limnology*, 3rd Ed. (Translated from German by D G Frey and F E J Frey) 295p. (Toronto, Canada: University of Toronto Press)

Sawyer C N, Lackey J B and Lenz A T 1945 Investigation of the odour nuisances in the madison lakes, particularly lakes Monoua, Wanbesa, and Kegnosa from July 1943 to July 1944. (Madison: Univ. Press)

Schindler D W 1971 A hypothesis to explain differences and similarties 'among lakes in the Experimental lakes Area, North-Western Ontario; J. *Fish. Res. Bd. Canada* **28** 295-301

Serruya C, Pollingher U and Cophen 1975 N and P distribution in lake Kinneret (Isreal) with emphasis on dissolved organic nitrogen; *Oikos* **26** 1–8

Sorensen H 1948 Studies on the ecology of Danish water and bog mosses; *Denask. Bot. Ark.* **12** 10

Storm K M 1931 A physiographical and biological study of a mountain lake; *Arch. Hydrobiol.* **22** 491–536

Tarnefelt H 1958 Primary production und seetypen; *Verh. Int. Verein theor. agrew. Limnol.* **13** 121–141

Thienemann A 1925 Die Binuengewasser Mitteleu A ropas. Stuttgart.

Vass K K 1973 Studies on Hydrobiology and primary productivity of some Kashmir lakes. Ph.D. thesis, Kashmir University

Wojciechowskie I 1976 Wplyw Zlewni na eutrofizacje a-mezo-troficznego jeziora piaseczno in a deeutrofizacje stawowego jeziora Bikcze.—Influence of the drainage basin on the eutrophication of the a-mesotrophic lake. Piaseczno and diseutrophication of the pond lake Bikcze; *Acta Hydrobiol.* **18** 23–52

Welch P S 1948 *Limnological Methods* 81pp (New York: McGraw Hill Book Co.)

Yoshimura S 1933 Rapid eutrophication within recent years of lake Haruna, Gunman, Japan; *Jap. J. Geol. Geogr.* **11** 31–41

Zutshi D P 1968 Ecology of Kashmir lakes. Ph.D. thesis, Kashmir University

—— and Vass K K 1973 Variation in the water quality of some Kashmir lakes; *Trop. Ecol.* **14** 182–196

—— and Khan M A 1978 On lake typology of Kashmir; *Environ. Physiol. Plants* 465–472

—— Kaul V and Vass K K 1972 Limnology of high altitude Kashmir lakes; *Verh. Int. Verein. Limnol.* **18** 599–604