IMPACT OF URBANISATION ON THE TROPHIC STATUS OF KUMAUN LAKES, UTTARANCHAL

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ABSTRACT

Lake Nainital is one among a group of lakes occurring in the southern fringe of the Kumaun Lesser Himalaya. Bhimtal, Naukuchiatal and Sattal, popularly known as the Lake Region of Bhimtal are located in close proximity of Nainital Lake. Physiographically, these lakes are in the southern fringe of the Lesser Himalayas in Kumaun region of Uttaranchal. These lakes are being used as drinking water source, irrigation and recreation etc. In the past few decades, unplanned developments and urbanisation in the lakes catchment have caused serious problem related to pollution, eutrophication and accelerated sedimentation.

The total phosphorus recorded, more than 127.25 μg/l, indicates that the lake has entered in the hypereutrophic condition. The Carlson TPTSI used for determining trophic state index of the four lakes revealed that lake Nainital is the most eutrophic lake in the Kumaun region (74) followed by Bhimtal lake (51), Khurpatal (44), Sattal (32) and Naukchiatal (20). Increasing trend of nutrients (i.e., Nitrate nitrogen and total phosphorus) since 1954 clearly indicates that the anthropogenic activities have greatly accelerated the natural process of eutrophication. Further, the study reveals that diversion of drain water away from the lake catchment reduces PO_4-P loading by a significant proportion (60%). It clearly indicates that the increasing population in Nainital lake catchment has accelerated the nutrient loading in the lake and it has reached in hypereutrophic stage in past few decades.

INTRODUCTION

A large number of natural fresh water lakes occurring in the Lesser Himalayan region are famous for their picturesque view and most of them are being used for drinking and irrigation purposes. The increasing population pressure has resulted in deforestation and intensive construction activities within the lake catchment, which has made them vulnerable to problems such as pollution, rapid sedimentation, eutrophication, etc. Eutrophication is carried when the water of a lake is not able to purify itself because its dissolved oxygen is consumed in oxygen-demanding biochemical and chemical processes, thereby, developing anaerobic condition. The prolific growth due to the presence of phosphate and nitrate nutrients and overcrowding of algae and weeds and their eventual death and decay creates the same situation. One of the major causes of eutrophication in lakes is the indiscriminate discharge of untreated domestic waste along with refuse and solid waste through drainage channels resulting in severe impairment of physical, chemical and biological quality of lake water. The inflow of eroded material and other contaminant from the lake catchment have accelerated eutrophication process in the Dal and Wular, Nainital, Bhimtal Mansar etc (Ishaq and Kaul, 1988; Kumar et.al. 1999; Rai et al., 2000). Several workers have evaluated the physical.

chemical and biological characteristics of the lake Naini and other surrounding lakes namely, Bhimtal, Sattal, Naukchiatal and Khurpatal (Pant et al., 1980; 1981; 1985; Sharma et al., 1982; Purohit and Singh 1985, Khulbe and Durgapal, 1994; Kumar et al. 1999; Chakrapani, 2002, Nachiappan et al., 2004). However, the eutophication status of lake Naini and other surrounding lakes is very less discussed. In the present paper an attempt has been made to study the present eutrophication status of Kumaun lakes and Trophic index has also been developed to define the eutophication status of these lakes.

STUDY AREA

The crescent-shaped lake Naini is bounded by the Sher-ka-Danda hill in the east, the landslide Flat deposit in the north, the Ayarpatta hill in the west and Balia ravine in the south The Nainital town is located surrounding the lake Naini and is a major summer resort in north India. The landuse pattern of the lake catchment are reserved forests 21%, other types of forests and shrubs 21%, built-up area 41%, water bodies 10%, barren land 4%, roads 2% and playgrounds 1%. After the independence, the population in Naintal city has increased 40,000 (2001) with the tourist influx of 100,00 per year (Fig. 1). The rapid urbanisation in the region can be gauged from the fact that, in 1971, there were 4,053 buildings, which increased to 7,836 by 1991. Thus, the increasing anthropogenic activities have caused the increased disposal of domestic waste and other pollutants into the lake and degrading the lake water quality. The morphometric details of the lakes are given in table 1.

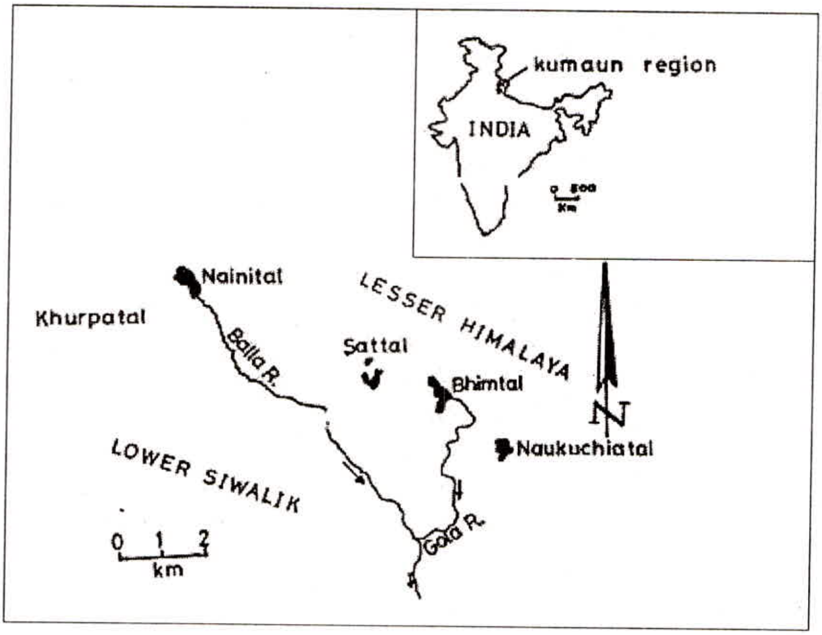


Figure 1: Location map of Kumaun lakes.

Bhimtal, Naukuchiatal and Sattal, popularly known as the Lake Region of Bhimtal are located in close proximity of Nainital Lake. Physiographically, these lakes are in the southern fringe of the Lesser Himalayas in Kumaun region of Uttaranchal. Bhimttal lake is fed by perennial springs and two seasonal. The lake has small island in its center. The estimated sedentary human population of the township is about 20,000. The lake water is used for potable water supply, irrigationand recreation. Sattal is an irregular shaped lake which has two water bodies connected with each other through a narrow channel for most of the year. The lake is surrounded on all sides by oak and pine forest. Naukuchital is a irregular shaped but having maximum depth and volume in Kumaun lakes. The lake water is used for irrigation and drinking purposes.

Table 1: Summary of morphological and meterological features of Kumaun lakes.

Parameters	Bhimtal	Nainital	Naukuchiatal	Sattal	Khurpatal
Height a.m.s.l. (m)	1340	1937	1300	1280	1530
Latitude	29^0 21' N	29^0 24' N	29^0 25' N	29^0 21' N	$29^0$22' N
Longitude	79^0 24' E	79^0 28' E	79^0 20' E	79^0 32' E	$79^0$26'E
Surface Area (km^2)	0.85	0.47	0.37	0.25	0.13
Max. Length (m)	1974	1400	1050	1300	300
Max. Width (m)	457	450	675	190	190
Mean Depth (m)	11.5	16.2	21.89	8	5
Max Depth (m)	25.8	27.3	42.25	20	21
Total Capacity (Mm^3)	4.61	8.58	7.37	0.89	0.72
Catchment Area (km^2)	10.77	4.7	3.25	5.69	0.572
Shoreline (m)	4023	3630	3600	3750	874
Development of Shore Line	1.23	1.2	1.66	1.06	NA
Development of Volume	1.34	1.78	1.59	1.20	NA
Annual Rainfall	1711	2300	NA	1741.2	2000
Max Air Temp. (°C)	33	25	NA	26	28
Min. Air Temp. (°C)	1.5	0.5	NA	NA	3
Max. Water Temp. (°C)	28	25	NA	NA	NA
Min. Water Temp. (°C)	14	10	NA	NA	NA

The Nainital hills encompass a rock succession that includes 1,800-2,000 million years old granites and the sediments, which range in age from 1,600 to 500-600 million years and have thrusted over the very young 2-20 million yr – old Siwaliks along the Main Boundary Thrust (MBT). The MBT is tectonically very active and is manifested in large scale hillside instability in the region (Valdiya, 1988). The lithology around Nainital consists of carbonate rocks, calcareous slates, argillaceous limestones, ferrugious shales, algal dolomites, black shales with marlite, greywacke, siltstones etc. of the Krol Formation (Permo-Triassic). The Bhimtal is comprised of metabasites associated with shallow water quartzites, grits, conglomerates and phyllites. Naukchiatal lake is surrounded by metavolcanics and wuartzites, whereas Sattal lake is developed in quartizitic country (Das et al 1994). Among all the Kumaun lakes, the Nainital is one of the major tourist places of Uttaranchal. Since the 1980s, increased local population pressure and tourist traffic resulted in a sudden spurt in construction activity and unplanned development of infrastructural facilities at Nainital to cater to the demands of the tourist as well as the local population. This has resulted in rapid degradation of the lake and its environment.

METHODOLOGY

In order to assess the lake water chemistry, samples were collected during 1994-96 from 3 locations in the lake at 3 m depth interval. The water samples were collected directly from the sites, filtered and preserved as per standard procedures (Appelo, 1988). These samples were analysed for major cations such as Ca^{++}, Mg^{++}, Na^{+} and K^{+} and anions HCO_3^-, SO_4^{--}, NO_3^-, Cl^- PO_4^- and chlorophyll-a as per standard procedures (APHA, 1992). Chloride was estimated by argentometric method, alkalinity by titrimetric method, sulphate by turbidimetric method, total hardness and calcium hardness by EDTA titrimetric method. Calcium and magnesium concentrations were calculated by stoichiometry from total and calcium hardness. Sodium and potassium was determined using flame photometer. The secchi depth was measured by manually prepared secchi disc. The overall accuracy of the chemical analysis as determined by replicate measurements was found to be better than ±5%.

EUTROPHICATION

The process of eutrophication is defined as the loading of inorganic and organic dissolved and particulate matter to lakes at rates sufficient to increase the potential for high biological production that leads to a decrease in the capacity of the lake. Due to eutrophication, lakes are considered to undergo a process of ageing which has been characterized by three qualitatively defined conditions. The initial condition of a lake is termed oligotrophic and is normally associated with deep lakes and have relatively high levels of dissolved oxygen throughout the year. The eutrophic condition of a lake represents the opposite end of the ageing process. They are characterized by high concentrations of suspended organic matter in the water column and by relatively large sediment depths with high organic contents particularly in the upper layers of the sediment. A third lake condition is mesotrophic which is defined as an intermediate state between oligotrophic and eutrophic.

The boundaries between the three stages are not rigidly defined and may vary with regions of the nation and with beneficial uses of lake waters. Therefore, attempts have been made to establish a trophic state index (TSI) as a function of commonly measured water quality variables.

Factors Affecting Eutrophication

The two nutrients of greatest concern are nitrogen and phosphorus. Nutrient levels in lakes are controlled by external sources to the lake and in-lake processes. External sources of nutrients include municipal and industrial point sources, stream inputs, atmospheric sources, urban drainage, groundwater, agricultural drainage, and other non-point sources surrounding the lake. In-lake processes include sediment release, biological recycling, and nitrogen fixation. In addition to these nutrients, phytoplankton require carbon dioxide and a host of minor elements (potassium, sodium) and trace elements (iron, manganese, cobalt, copper, zinc, boron, and molybdenum) and organic growth factors. Silica is an important nutrient for diatoms, as it forms the basis for their skeletal structure. Aquatic vegetation of the free-floating types, such as algae, depends on dissolved nitrogen and phosphorus compounds for its nutrient supply.

The enrichment of a water body with nutrients is accompanied by a high rate of production of plant material in the water. Troublesome production rates of vegetation presumably occur when optimum supplies of all nutrients are present and available. Phosphorus availability is generally believed to be a critical factor in eutrophication of water bodies, as the nutrient in shortest supply will tend to be the control on production rates.

VARIATION OF NUTRIENTS IN NAINITAL LAKE

The soluble reactive phosphate (SRP) or orthophosphate and nitrate nitrogen in lake water were monitored on the monthly basis. Their vertical variations in lake from surface to bottom were also analysed. The SRP varies between 0.16 mg/l to maximum 0.36 mg/l (Fig 2). In epilimnion zone, the maximum availability of SRP in rainy months and minimum in winter months reveals that lake is receives maximum contribution through runoff. The depth-wise variation shows that the maximum SRP is in the hypolimnion zone. The SRP in bottom water ranged from 0.26 mg/l to 0.58 mg/l (December). The presence of maximum SRP in December reveals that PO_4-P is released from bottom sediments due to overturning of the lake. The SRP concentration in drains varies from 0.2 mg/l to 1.75 mg/l. The maximum has been observed during the May drain water that enters into the lake. It appears that anthropogenic activities are mainly responsible for the increased concentration of SRP in the lake .

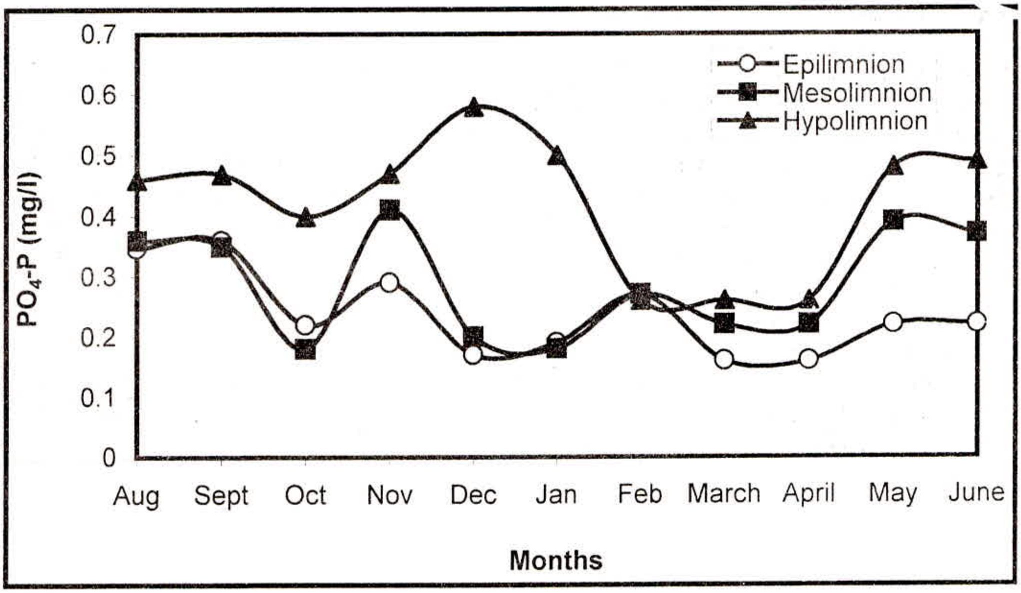
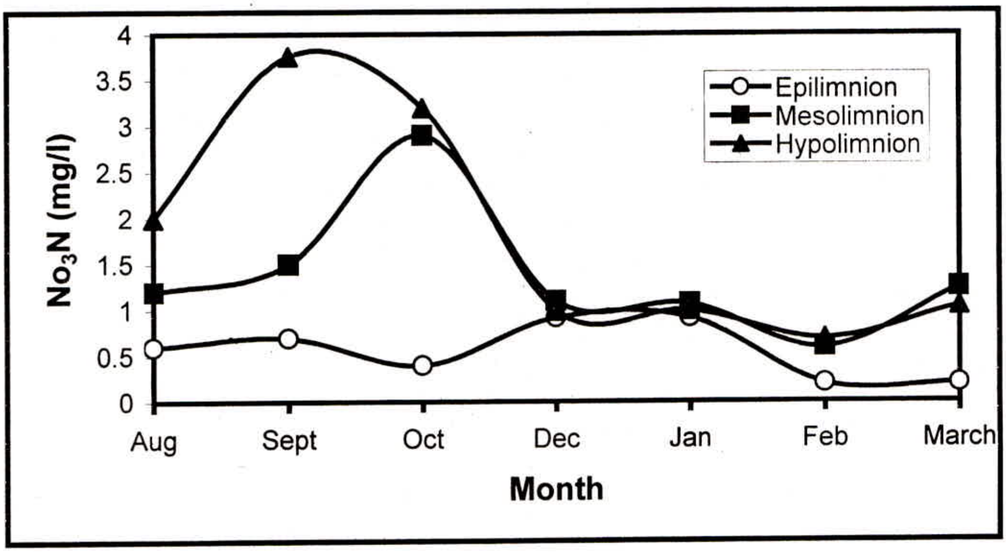


Figure 2: Variations of SRP in Lake Naini during different months and zone.

The temporal and depth-wise variations of nitrate nitrogen in the Nainital lake is shown in figure. 3. The most striking feature of nitrate-nitrogen is the it is minimum in the epilimnion zone and maximum in the hypolimnion zone of the lake. In winter months the nitrate-nitrogen is same throughout the lake due the mixing of the lake. The nitrate-nitrogen enters into the through drain vary 2mg/l to 6.75 mg/l. It shows that the drains are continuously pouring the nitrogen concentration in the lake water.



External Phosphorous Loads to the Lake

There are two main type of surface inflows to the lake. They are a) through the nalahs which is sustained by the groundwater and domestic effluents and b) the rainfall runoff. The Soluble Reactive phosphorous content of the latter is around 0.2 mg/L during non-monsoon season and 0.15 mg/L during monsoon season. The drain water PO_4-P varies from 0.2 mg/L to 1.75 mg/L. Using this information along with the inflow to the lake the total load of SRP to the lake has been computed (Kumar et al., 1999). It is clearly seen from figure. 4 that the annual areal loading to the lake in the present scenario is around 2000 mg/m^2. If the nalah waters are excluded then the annual areal loading reduces to 450 mg/m^2. That is, if the nalah waters are diverted away from the lake then the loading is reduced significantly up to 60%. This figure will further improve if the rainfall induced runoff during non-monsoon season is also considered as part of diverted water. The nalah diversion measure will not seriously affect the water availability in the lake, as the channel flow during non-monsoon season is just 1.00 m., while the total surface inflow during monsoon season is 3.89 m.

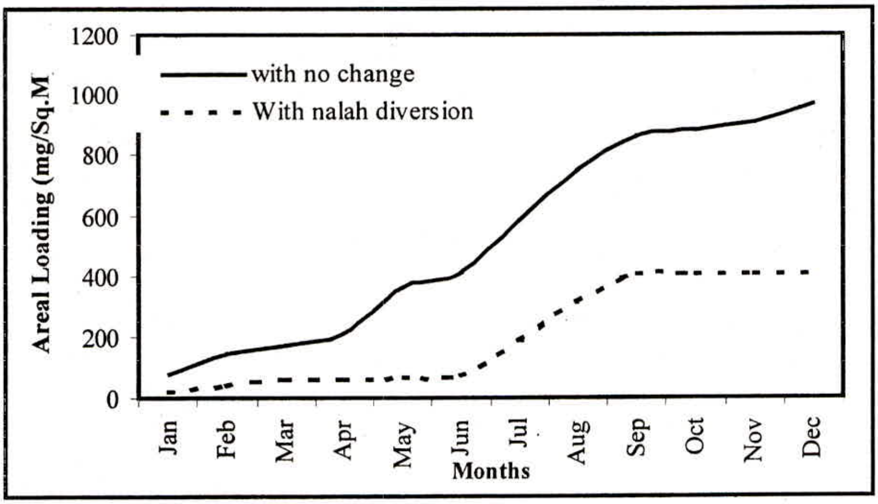


Figure 4: Cumulative annual external SRP loading in Lake Nainital.

EUTROPHIC STATUS OF LAKE

Strong relationships between chlorophyll-a and total phosphorus have been shown by Sakamoto (1966), Dillon and Rigler (1974), Jones and Bachmann (1976), Carlson (1977), Rast and Lee (1978), Bartsch and Gakstatter (1978), Smith and Shapiro (1981), Smith (1982), Lambou et.al. (1982) and Ryding (1983). Several investigators have also proposed the use of empirical relationships between secchi depth and chlorophyll-a to predict changes in transparency to be expected from changed chlorophyll-a levels. The relationship developed among the chlorophyll-a, total phosphorus and secchi depth for the Kumaun lakes (Shewa, 1998) are mentioned below:

log Chlor	=	-0.259 + 0.844 log TP	[r = 0.93]
log SD	=	0.822 - 0.444 log Chlor	[r = 0.83]
log SD	=	1.072 - 0.450 log TP	[r = -0.95]

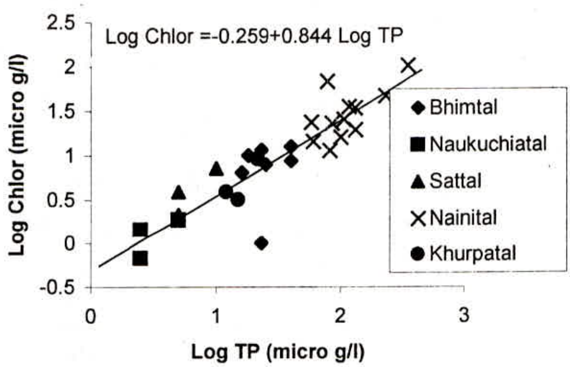


Fig 5. Relationship between Chlorophyll-a and total Phosphorus of the Nainital and surrounding lakes.

In the present study the trophic status of the 5 lakes has been determined based on the boundary values of total phosphorus given by Wetzel (1975), which were modified from Vollenweider (1968) (Table 2). The lakes in Kumaun region has been classified in the trophic states (Table 3)

Table 2. General relationships of lake productivity to average concentrations of eplimnetic total phosphorus (after Wetzel, 1975).

General level of productivity	Total phosphorus (μg/l)
Ultra - oligotrophic	< 5
Oligo - mesotrophic	5 - 10
Meso - eutrophic	10 - 30
Eutrophic	30 – 100
Hypereutrophic	> 100

Table 3. Trophic status of lakes of Kumaun region.

Lake	Average total phosphorus (μg/l)	Trophic state
Nainital	127.25	Hypereutrophic
Bhimtal	26.43	Meso-eutrophic
Khurpatal	16.17	Meso-eutrophic
Sattal	6.67	Oligo-mesotrophic
Naukuchatal	3.00	Ultra-oligotrophic

Several investigators have also developed a numerical trophic state index in an attempt to remove the subjectivity inherent in the terms oligotrophic, mesotrophic and eutrophic. Total phosphorus, chlorophyll - a and Secchi depth relationships were used by Carlson (1977) to develop a numerical Trophic State Index (TSI) which is the probably most commonly used (Cooke et.al. 1993).

Carlson used transformations of log to interrelate these indices with in a scale of 0 to 100 (applicable to any lake). The trophic state index range between 40 to 50 is most often associated with mesotrophy. The Carlson TPTSI is used for determining trophic state index of the Kumaun lakes (Table 4).

Table 4. Trophic state index of Kumaun lakes

Lake	Average total phosphorus (μg/l)	Trophic state Index (TSI)
Nainital	127.25	74
Bhimtal	26.43	51
Khurpatal	16.17	44
Sattal	6.67	32
Naukuchiatal	3.00	20

RESULTS AND DISCUSSION

The continuous increase of nutrient element nitrogen and phosphorus has been observed for lake Nainital (Table 5). NO_3^-N concentration in Nainital lake is significant, however there is no use of fertiliser in lack of agricultural land in the lake catchment. Rainwater analysis shows no NO_3-N hence domestic effluents are the major sources of nitrate nitrogen in the Nainital. Likewise, PO_4-P is mainly fed by the drains, which are carrying the domestic and other effluents. The data reveals that if the two major darins water namely, Nainadevi and Rikshaw Stand drains is excluded then the annual areal loading reduces to 450 mg/m^2. Thus, diversion of drain water away from the lake catchment reduces loading significantly (60%). It clearly indicates that the increasing population in the Nainital lake catchment has accelerated the nutrient loading in the lake and lake has reached in hypereutrophic stage in past few decades. The Carlson TPTSI used for determining trophic state index of the four lakes revealed that lake Nainital is the most eutrophic lake in the Kumaun region (74) followed by Bhimtal lake (51), Khurpatal (44), Sattal (32) and Naukchiatal (20). It clearly indicates that the anthropogenic activities have greatly affected the lake chemical characteristics.

Table 5. Long-term quality changes in Nainital Lake (source DPR, AHEC, IIT, Roorkee)

Parameter	1954	1975	1978-79	1999-2000	2002
Secchis (m)	1.9	1.12	0.90	0.90	0.88
DO mg/l	15.5	14.2	9.95	7.3	9.4
Alkalinity mg/l	-	400.0	-	221	222
NO_3^-N μg/l	Traces	338	345	370	569
NH_3^-N μg/l	19.0	165	191	445	771
PO_4^-P μg/l	Traces	6.5	14.7	53	93

REFERENCES

American Public Health Association (192), Standard methods for the examination of water and waste water, 18th edition, American Public Health Association, Washington, D.C., USA.

Appelo, C. A. J. (1988), Hydrochemistry for hydrogeologists - Application of chemical theory, Instt. for Earth Sciences, Free University, Amsterdam, The Netherlands.

Bartsch, A.F. and Gakstatter, J.H. (1978), Management decisions for lake systems on a survey of trophic status, limiting nutrients, and nutrient loadings, American-Soviet Symposium on Use of Mathematical Models to Optimize Water Quality Management, 1975, ERL, ORD, USEPA Gulf Breeze, FL, pp. 371-394.

Carlson, R.E. (1977), A trophic state index for lakes, Limnol., Oceanogr., 22, 361-369.

Chakrapani, G.J.(2002), Water and sediment geochemistry of major Kumaun Himalayan lakes, India, Environ. Geol., 43, 99-107.

Cooke et. al. (1993), Restoration and management of lakes and reservoirs, Lewis Publishers, Boca Raton, Florida.

Das, B.K., Singh, M. and Borkar, M.D. (1994), Sediment accumulation rate in the lakes of Kumaun Himalaya, India using 210Pb and 226Rn, Env. Geol., Vol. 23, 114-118.

Dillon, P.J. and Rigler, F.H. (1974), The phosphorous-chlorophyll relationships in lakes, Limnol. Oceanogr., Vol. 19(4), 767-773.

Ishaq, M. and Kaul, V.(1988), Distribution of minerals in Himalayan lakes, Trop. Ecol., Vol. 29, 41-49.

Jones, P.J. and Bachmann, R.W. (1976), Prediction of phosphorous and chlorophyll levels in lakes, Jour. Water Pollut. Control Fed., Vol. 48 (9), 2176-2182.

Khulbe, R.D. and Durgapal, A. (1994), Sweage mycoflora in relation to pollutants in Nainital lake, Kumaun Himalaya, Poll. Res., Vol. 13, 53-58.

Kumar, B., Jain, S, Nachiappan, Rm. P., Rai, S.P.(1999), Hydrological Studies of Lake Nainital, Kumaun Himalayas, Uttar Pradesh, Final Project Report, NIH, Roorkee.

Lambou, V.W. et al. (1982), Chlorophyll, phosphorous, secchi disk and trophic state, Water Resources Bull., American Water Resources Assoc., Vol. 18(5), 807-813.

Nachiappan, Rm.P., Kumar, Bhishm, Manickavasagam, Rm. and Balakrishnan ,S. (2004), Hydrochemical Characteristics of Groundwater in the Nainital Lake Basin: Implication on the Landslide Hazards, Vol. 64, No. 2, 139-145.

Pant, M.C., A.P. Saharma and P.C. Sharma (1980), Evidence for the increased eutrophication of lake Nainital as a result of human interference, Environ. pollut. (Series B), Vol. 1, 149-161.

Pant, M.C., P.K. Gupta, J. Pande, P.C. Sharma and A.P. Sharma (1981), Aspects of water pollution in lake Nainital, U.P., India, Environ. Conservn., Vol. 8(2), 113-117.

Pant, M.C., P.C. Sharma, A.P. Sharma and P.K. Gupta (1985), Species composition, temporal abundance and community structure of zooplankton in lake Sattal, U.P.,India., Arch. Hydrobiol., Vol. 102, 519-535.

Purohit, R. and Singh, S.P. (1985), Submerged macrophytic Vegetation in relation to eutrophication level in Kumaun Himalaya, Environmental Pollution (Series A), Vol. 39, 161-173.

Rai, S.P., Vijay Kumar, Singh, Omkar, Kumar Bhishm and Jain S.K. (1999), Limnological study of the Mansar Lake, District Udhampur, J&K, Final Project Report, NIH, Roorkee,

Rast, W. and Lee, G.F. (1978), Summary analysis of the North American (US portion) OECD eutrophication project: nutrient loading lake response relationships and trophic state indices, USEPA, Corvallis Environmental Research Laboratory, Corvallis, OR 454, EPA-600/3-78-008.

Ryding, S.O. (1983), Mass-balance studies to, within and from drainage basins: A new approach for water monitoring programmes (in Swedish), Nordic Co-operative Organization for Applied Research (NORD FORSK), Helsinki, Finland, 149-162.

Sakamoto, M. (1966), Primary production by phytoplankton community in some Japanese lakes and its dependence on lake depth, Arch. Hydrobiol., Vol. 62, 1-28.

Sharma, A. P., Jaiswal, S., Negi, N. and Pant, M.C (1982), Phytoplankton community analysis in lakes of Kumaun Himalaya, Arch. Hydrobiol., Vol. 93, 173-193.

Shewa, W.A. (1988), Eutrophication Analysis Of Lakes Of Kumaun Region, M.E. Dissertation, University of Roorkee, Roorkee.

Smith, V.H. and Shapiro, J. (1981), Chlorophyll-phosphorous relations in individual lakes, their importance to lake restoration strategies, Environ. Sci. Tech., Vol. 15, 444-451.

Smith, V.H. (1982), The nitrogen and phosphorous dependence of algal biomass in lakes: Empirical and theoretical analysis, Limnol. Oceanogr., Vol. 27, 1101-1112.

Valdiya, K. S. (1988), Geology and Natural Environment of Nainital Hills. Kumaun Himalaya, Gyanodaya Prakashan, Nainital, India.

Vollenweider, R.A. (1968), Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to the phosphorous as factor in eutrophication, Organ. Econ. Coop. Dev., Paris, Tech. Report No. DAS/CSI/68.27, pp. 159.

Wetzel, R. (1975), Limnology, Saunders Publishing Co., Philadelphia, pa.,.