

Water Quality Assessment of Sacred Lake Nachiketa Tal, Garhwal Himalaya, India

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ABSTRACT

The present study on monthly variations in physico-chemical parameters of water was undertaken at four sampling stations during the period from May 2014 to April 2015, for assessing the water quality of the sacred lake Nachiketa Tal of Garhwal Himalaya. Monitoring of monthly variation in physico-chemical variables of the water for one annual cycle of the Nachiketa Tal revealed that the water temperature ranged from 6.5°C to 22.6°C. The pH fluctuated between 6.57 and 7.36. Electrical conductivity ranged from 32.0 μScm^{-1} to 71.6 μScm^{-1} . Turbidity and TDS fluctuated from 2.15 NTU to 8.65 NTU and 15.20 mg l^{-1} to 38.0 mg l^{-1} respectively. Dissolved oxygen ranged from 6.0 mg l^{-1} to 9.2 mg l^{-1} , while BOD ranged from 0.5 mg l^{-1} to 1.6 mg l^{-1} . Free CO_2 fluctuated between 0.88 mg l^{-1} and 2.82 mg l^{-1} , Total hardness and alkalinity ranged from 20.00 mg l^{-1} to 40.00 mg l^{-1} and 40.2 mg l^{-1} to 85.20 mg l^{-1} respectively. Nitrates fluctuated from 0.246 mg l^{-1} to 0.392 mg l^{-1} . While, phosphates fluctuated from 0.053 mg l^{-1} to 0.090 mg l^{-1} . Sulphates ranged from 5.12 mg l^{-1} to 8.23 mg l^{-1} . Chlorides fluctuated between 2.27 mg l^{-1} and 6.25 mg l^{-1} . Calcium and Magnesium ranged from 3.21 mg l^{-1} to 10.42 mg l^{-1} and 1.94 mg l^{-1} to 4.37 mg l^{-1} respectively. The water quality index (WQI) was computed using the Weighted Arithmetic Index Method (WAIM) based on these physico-chemical parameters. The concentrations of the nitrates and phosphates and the values of turbidity, electrical conductivity, TDS were found to be maximum during the monsoon months and minimum during rest of the seasons. Statistical correlation calculated between different physico-chemical parameters revealed that the turbidity has positive correlation with water temperature ($r=0.807$, $p<0.01$) and electrical conductivity ($r=0.887$, $p<0.01$). Dissolved oxygen of water of Nachiketa Tal has a significant negative correlation with water temperature ($r=-0.869$ $p<0.01$). Water quality index based on the mean of all the stations of Nachiketa Tal was 43.83, which indicated the 'good' water quality of Nachiketa Tal. Thus, the water is suitable for consumption only after the proper disinfection and treatment. However, keeping in view its location in the depression of the midst of dense forest and continuous deposition of sediments in the lake, remedial measures for maintaining the water quality of the lakes have been suggested.

Keywords: *Garhwal Himalaya, Nachiketa Tal, Water quality, Water quality index*

INTRODUCTION

Lakes represent one of the most resourceful ecosystems on the Earth. Surface water of lakes and rivers are the major source of water in most of the countries all over the world. Environmentally, lakes are of great value

due to various reasons, like sources of water for surface and groundwater recharge and discharge, recreational value, habitat for wildlife and pisciculture. In lakes, input and output of materials are taken place, and therefore represent a

continual chemical process like any other aquatic ecosystem. The condition of the lake depends on its nature and exposure to the various environmental factors. Therefore, not only the natural processes but also the anthropogenic pressures influence the surface water quality (Papatheodorou *et al.*, 2006). Lakes are dynamic lentic ecosystems which are significant inland water resources for meeting increasing water demand. However, all these functions depend on the quality of water, which is based on a well-balanced environment in terms of its physical, chemical, and biological variables (Yu *et al.*, 2010). A water quality index (WQI) is an important tool for assessing the water quality of a water source. It is used for both the surface and ground water quality assessment (Bora and Goswami, 2017). Enrichment of nutrients deteriorates the water quality of the lakes by triggering the growth of the algae and other higher plants (Oczkowski and Nixon 2008; Yu *et al.*, 2010). Water quality index is determined to provide a single value to assess the health of the aquatic ecosystem. Complex data of physico-chemical parameters of water are converted into the understandable and informative data under water quality index calculation, So that it can be used easily by a layman (Yogendra and Puttaiah, 2008). A considerable work

STUDY AREA

Nachiketa Tal is one of the most important and sacred lakes of the Garhwal Himalaya. It is located at latitude N 30° 38.666" N and longitude E 078° 28.362" E at an altitude of 2,453 m asl. in Uttarakashi district of Uttarakhand state. It is elliptical in shape, measuring about 132 m in length, 58 m width and 413 m periphery. Total

has been done on the assessment of water quality on the different parts of the world including India. Gupta and El-hamid (2003) on lake Qarun (Egypt) and Mihaiescu *et al.* (2013) have done work on glacial lakes of Romania. While, Inaotombi and Gupta (2014) have studied the water quality of lake Sattal, India. Ghimire *et al.* (2013) studied the water quality of high-altitude lakes in the Sagarmatha, Nepal. Singh and Jain (2013) have made assessment of water quality and eutrophication of five Himalayan lakes of India. Sharma and Kumar (2017) have recently studied the water quality of Satopanth lake in Garhwal Himalaya. But no sincere attempt has been made to assess the water quality of the very important and sacred lake of Nachiketa Tal of Garhwal Himalaya. Therefore, an attempt has been made to collect physico-chemical environmental variables of the water for assessing the water quality of Nachiketa Tal. Nachiketa Tal is named after the famous Saint Nachiketa. Therefore, a good number of pilgrims and tourists visit this lake round the year. A big festival is celebrated at the bank of lake and the people take holy dip in the lake on the day of *Baisakhi*, an auspicious day in Hindu calendar. This creates a lot of anthropogenic pressure on the lake

area of lake is 0.49 ha (Fig.1). The lake remains covered with thin sheet of ice during the winter months of January and February. The lake depth varies from season to season and attains its maximum depth 3.14 m during rainy season. The mean depth of Nachiketa Tal is 2.0 m. It has no noticeable inlet as well as outlet.

The surface runoff from the surrounding forest during the monsoon season deposit sediments in the lake. Four sampling stations (S₁, S₂, S₃, S₄) were identified for collecting data on the physico-chemical variables for assessing water quality. Micro-ecological setting of these sampling stations are slightly different. Anthropogenic activities were common at S₁ and S₄ while, the sedimentation was common at S₂. The station S₂ has dense canopy of forests, which receives maximum litter and sediments. The limnetic zone has submerged macrophytes (*Chara* sp. and *Ceratophyllum* sp.) and littoral zone has maximum number of rooted vegetation (*Diplazium melanochlamys*, *Diplazium caudatum*,

Agrimonia pilosa, *Euphorbia* sp. and *Rumex nepalensis*). Sampling station S₃ was least disturbed site in Nachiketa Tal.

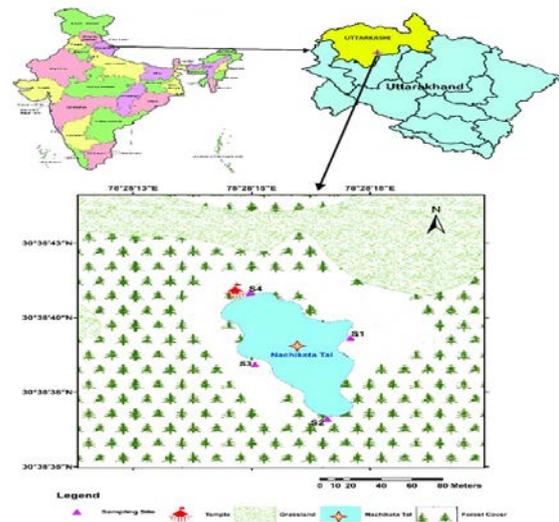


Fig. 1. Location map of Nachiketa Tal with sampling stations (S₁-S₄)

MATERIALS AND METHODS

Monthly sampling at all the four sampling sites (S₁- S₄) was undertaken at 08:00 to 10:00 hrs for one annual cycle (May 2014 to April 2015). Water temperature was recorded with the help of the centigrade (0-110°C) thermometer; pH was recorded with the help of potable pH meter. Electrical conductivity of the sample was measured with the help of the Toshcon Multiparameter Analyser. Nitrates (Phenol disulphonic acid method), phosphates (Stannous chloride method) and sulphates (Turbidimetric method) were determined by using the spectrophotometer (Model-UV-VIS Systronics 117 series). Dissolved Oxygen, total hardness, BOD, alkalinity, calcium and magnesium were measured following the methods outlined in Wetzel and Likens (1993) and APHA (1998). The Pearson's correlation coefficient was calculated to know the relationship among

the various physico-chemical parameters. The correlation coefficient was performed using SPSS version 16.0. Water quality Index (WQI) of the lake was made using Weighted Arithmetic Index method (Brown *et al.*, 1972). WQI of the lake was calculated by taking mean of the monthly data of all the 13 physico-chemical variables of all the four stations separately and to calculate the overall water quality index of the lake taking into consideration of mean of all the four stations (Table 2, 3). The environmental parameters which were considered for calculating the water quality index were pH, electrical conductivity, total dissolved solids, dissolved oxygen, BOD, free CO₂, alkalinity, total hardness, nitrates, sulphates, chlorides, calcium and magnesium. The following expression was used to calculate the Water quality index (WQI):

$$q_n = 100[V_n - V_{io}] / [S_n - V_{io}]$$

where, q_n = Quality rating for the n^{th} water quality parameter,

V_n = Estimated value of the n^{th} water quality parameter of collected sample,

S_n = Standard permissible value of the n^{th} water quality parameter,

V_{io} = Ideal value of the n^{th} water quality parameter in pure water,

V_{io} is 0 for all the parameters except pH and dissolved oxygen in which case, it was 7 and 14.6 mg l⁻¹ respectively. If there is n water quality parameters and quality rating (q_n) corresponding to n^{th} parameter is a number reflecting the relative value of this parameter in sample water with respect to its permissible value. The standard

permissible value for the drinking water, recommended by the Central Pollution Control Board (CPCB), World Health Organization (WHO) and Bureau of Indian Standards (BIS) were used to calculate the WQI.

Unit weight (W_n) was calculated by the following expression:

$$W_n = k / S_n$$

It is calculated by value inversely proportional to the standard permissible value. k is constant of proportionality. The overall WQI was calculated by summation of product of quality rating and unit weight divided by sum of unit weight of n^{th} parameters.

$$WQI = \sum q_n W_n / \sum W_n$$

The suitability of water WQI for human consumption (Table 1) was based on WQI given was by Mishra and Patel (2001) on their study on the drinking water of Rairangpur of north Orissa.

RESULTS AND DISCUSSION

The variation in physico-chemical parameters of an aquatic ecosystem has profound impact on its ecological processes. Changes in temperature, precipitation and sediments can lead to changes in hydrological processes, which ultimately affect the nutrient concentration, light penetration and other significant ecological parameters in aquatic systems (Herbei *et al.*, 2016). A total of 16 physico-chemical variables of the water of Nachiketa Tal were determined for one annual cycle (May 2014-April 2015) (Table 6-9). Out of these studied 16 physico-chemical parameters, 13 potential physico-chemical parameters were considered for water quality assessment. The rate of bio-chemical

responses in the aquatic ecosystem was decided by the temperature (Simon *et al.*, 2011). In Nachiketa Tal, water temperature was found to be maximum (22.6°C) in June at S₄ and minimum (6.5°C) in February at S₂. Higher water temperature was observed in the summer months and lower in the winter months. There was little difference in water temperature among the different stations throughout the study period. In monsoon months, Nachiketa Tal showed higher value in electrical conductivity, as seasonal conditions and the spatial variations in the lake decide its electrical conductivity (Upadhyay *et al.*, 2012). Electrical conductivity was recorded highest (71.6 μScm^{-1}) in August at S₂ and lowest (32.0 μScm^{-1}) in January at S₄. EC of the lake was in the prescribed limit of WHO and

BIS. The value of electrical conductivity signifies the presence of biogenic and abiogenic impurity in the lake water (Upadhyay *et al.*, 2012). The pH of the water is essential for assessing the suitability of water for various purposes (Yogendra and Puttaiah, 2008). pH of the water of Nachiketa Tal was almost neutral (6.57 to 7.36). The values of pH in the Nachiketa Tal are within the limits of BIS and WHO for drinking water. The pH is relatively less at the sampling station S₂. This may be due to the presence of dissolved organic matter of plant litter at this site. Kangabam *et al.* (2017) stated that the high organic content in the water decreases the pH level due to its carbonate chemistry. Low pH values are often found in natural waters rich in dissolved organic matter. An appreciable portion (often > 50%) of dissolved organic matter occurs as organic acids derived from humic compounds (Wetzel, 2001). Total dissolved solids in Nachiketa Tal was found to be maximum (38.0 mg.l⁻¹) at S₄ in July and minimum (15.20 mg.l⁻¹) at S₁ in February. TDS was maximum in July (rainy season), because it receives sediments from the upper watershed due to natural process. Turbidity determines the transparency of water. Turbid water prevents the entering of light and affects the photosynthesis and aquatic life. During the daylight, total solids present in an aquatic body get heated up and increase the water temperature (Fulazzaky, 2010). Turbidity was found to be maximum (8.65 NTU) in August at S₂ and minimum in February (2.15 NTU) at S₄. Increased temperature of water decreases the oxygen solubility into the water, because dissolved oxygen is negatively co-related with the water temperature (Solanki *et al.*, 2010). The dissolved oxygen (DO) was found to

be maximum (9.2 mg l⁻¹) in December at S₃ and minimum (6.0 mg l⁻¹) at S₁ in August. The high level of DO in the Nachiketa Tal indicates good quality of water. The low concentration of DO indicates poor quality of water for drinking purpose. Higher DO level was found in the winter months at all the stations, as low temperature of water holds more dissolved oxygen (Kangabam *et al.*, 2017). The BOD was found to be maximum (1.6 mg l⁻¹) in June and July at S₂ and S₄ respectively and minimum (0.5 mg l⁻¹) at S₂, S₃ and S₄ in different months. Free CO₂ was found to be maximum (2.82 mg l⁻¹) at S₂ in July and minimum (0.88 mg l⁻¹) in January at S₁, in January- February at S₂, October and January at S₃ and in January at S₄. Total alkalinity was found to be maximum (85.20 mg l⁻¹) in May at S₁ and in June at S₄ and minimum (40.2 mg l⁻¹) in December at S₃. Calcium was found to be maximum (10.42 mg l⁻¹) in June at S₁ and minimum (3.21 mg l⁻¹) in July at S₂ and in September at S₄. Magnesium was found to be maximum (4.37 mg l⁻¹) in May and minimum (1.94 mg l⁻¹) in August-September at S₁, S₃ and in August at S₂. Total hardness was found to be maximum (40.00 mg l⁻¹) in June at S₁ and S₂ and minimum (20.00 mg l⁻¹) in August at S₁ and S₂; and in August-September at S₃ and in September at S₄. Chlorides were found to be maximum (6.25 mg l⁻¹) in August and minimum (2.27 mg l⁻¹) in December at S₂. Concentration of nitrates in water body depends on the activity of nitrifying bacteria which in turn influenced by the presence of dissolved oxygen into the water body. The water bodies which are polluted by the organic matter contain high concentration of the nitrates (Etim *et al.*, 2012). The water of Nachiketa Tal is contaminated by the organic matter like

plant litter and animal wastes received by the lake from the surface run-off of the watershed. The most oxidized form of nitrogen compounds in the natural waters is nitrate which is also an important plant nutrient. It is formed by the aerobic decomposition of organic nitrogenous matter (Sharma *et al.*, 2017). Nitrates were found to be maximum (0.392 mg l^{-1}) in September at S_2 and minimum (0.246 mg l^{-1}) in January at S_3 . Sharma *et al.*, (2017) also found the highest concentration of nitrates in August and September in lakes of Himachal Pradesh due to surface run-off. Wetzel (2001) stated that the nature of the sediment in the water body strongly influences its nutrients concentration. The concentration of phosphorus released into the aquatic system increases, when its sediments are frequently disturbed. Phosphates were found to be maximum (0.090 mg l^{-1}) in August at S_1 and minimum (0.053 mg l^{-1}) in February at S_3 . Surface run-off is very common in monsoon season in Nachiketa Tal. It brings sediments and other organic material from the watershed to the lake. Sulphates were found to be maximum (8.23 mg l^{-1}) in August and minimum (5.12 mg l^{-1}) in May at S_1 . All the physico-chemical parameters were in the permissible limit prescribed by the Bureau of Indian Standards (BIS), Central Pollution Control Board (CPCB) and World Health Organization (WHO).

Statistical Treatment of Data

Bray-Curtis similarity index was used for knowing the similarity among the four stations based on the physico-chemical variables. The station S_1 and S_4 showed maximum similarity (≤ 0.9960). However, S_2 and S_3 did not show any significant

similarity as the micro ecological setting of S_2 and S_3 are slightly different (Fig.2). Pearson's correlation coefficient was calculated between various physico-chemicals attributes of the lake (Table 5). Water temperature and EC were significantly positively correlated ($r=0.873$, $p<0.01$). TDS has significant positive correlations with the water temperature ($r=0.719$ $p<0.01$) and electrical conductivity ($r=0.771$, $p<0.01$). BOD and EC are also significantly positively correlated ($r=0.905$ $p<0.01$). Turbidity has significant positive co-relation with WT ($r=0.807$ $p<0.01$) and EC ($r=0.887$ $p<0.01$). DO has significant negative correlation with water temperature ($r=-0.869$ $p<0.01$). pH has also significant negative co-relation with water temperature ($r=-0.989$ $p<0.01$) and EC ($r=-0.886$ $p<0.01$).

Water Quality Index (WQI)

The quality of water in terms of index number is represented by Water Quality Index (WQI). It represents the overall quality of water for any further use (Etim *et al.*, 2012). The value of the Water Quality Index (WQI) of Nachiketa Tal has been given in Table 3 and 4. Water quality indices calculated for S_1 , S_2 , S_3 and S_4 were 45.89, 42.89, 41.03 and 45.52 respectively, which is in the range of 26-50 of "good" quality of water (Table 1). Thus, the quality of water at all the stations was 'good'. All the physico-chemical parameters were in permissible limit. The water quality index of S_1 was maximum, followed by S_4 , S_2 , and S_3 . There is slight difference in the water quality of various sampling stations, as water temperature, DO, BOD were found higher at S_1 and S_4 . Increased water temperature speeds up the chemical reaction which on its turns

reduces the solubility of the dissolved oxygen, imparts odour to the water (Kulkarni and Tapase, 2011). The overall water quality index of Nachiketa Tal was 43.83, which also implies the ‘good’ water quality of the lake.

Table 1. Status of water quality based on WQI (Mishra and Patel, 2001)

Level of Water quality index	Status of water quality
0-25	Excellent
26-50	Good
51-75	Bad
76-100	Very Bad
100 & above	Unfit

Table 2. Drinking water standards and their unit weight of various environmental variables (Guidelines of Bureau of Indian Standards (BIS) and World Health Organization (WHO)).

Parameters	Standard permissible value (S _n)	W _n
pH	8.5	0.128501
Electrical Conductivity (µScm ⁻¹)	250	0.004369
TDS (mg l ⁻¹)	500	0.002185
Dissolved oxygen (mg l ⁻¹)	5	0.218451
BOD (mg l ⁻¹)	2	0.546128
Free CO ₂ (mg l ⁻¹)	250	0.004369
Alkalinity (mg l ⁻¹)	200	0.005461
Total Hardness (mg l ⁻¹)	200	0.005461
Chlorides (mg l ⁻¹)	250	0.004369
Sulphates (mg l ⁻¹)	200	0.005461
Nitrates (mg l ⁻¹)	45	0.024272
Calcium (mg l ⁻¹)	75	0.014563
Magnesium (mg l ⁻¹)	30	0.036409

Table 3. Data on calculation of water quality index (WQI) at sampling stations (S₁-S₄) based on physico-chemical parameters of water of for Nachiketa Tal, Garhwal Himalaya

Parameters	V _{io}	S ₁			S ₂		S ₃		S ₄	
		1/S _n	Q _n	Q _n W _n	Q _n	Q _n W _n	Q _n	Q _n W _n	Q _n	Q _n W _n
pH	7	0.118	-3.056	-0.393	-0.167	-1.306	-6.667	-0.857	-5.722	-0.735
Electrical Conductivity (µScm ⁻¹)	0	0.004	20.860	0.091	21.357	0.093	20.757	0.091	20.770	0.091
TDS (mg l ⁻¹)	0	0.002	4.545	0.010	4.760	0.010	4.545	0.010	4.537	0.010
Dissolved oxygen (mg l ⁻¹)	14.6	0.200	74.653	16.308	74.392	16.251	74.306	16.232	73.438	16.043
BOD (mg l ⁻¹)	0	0.500	53.333	29.127	49.583	27.079	45.417	24.803	53.750	29.354
F.CO ₂ (mg l ⁻¹)	0	0.004	0.625	0.003	0.631	0.003	0.590	0.003	0.598	0.003
Alkalinity (mg l ⁻¹)	0	0.005	34.475	0.188	34.475	0.188	34.258	0.187	34.446	0.188
Total Hardness (mg l ⁻¹)	0	0.005	13.508	0.074	13.221	0.072	13.017	0.071	13.333	0.073
Chlorides (mg l ⁻¹)	0	0.004	1.543	0.007	1.562	0.007	1.496	0.007	1.486	0.006
Sulphates (mg l ⁻¹)	0	0.005	3.131	0.017	3.233	0.018	3.175	0.017	3.187	0.017
Nitrates (mg l ⁻¹)	0	0.022	0.691	0.017	0.713	0.017	0.691	0.017	0.686	0.017
Calcium (mg l ⁻¹)	0	0.013	8.780	0.128	7.834	0.114	7.943	0.116	8.229	0.120
Magnesium (mg l ⁻¹)	0	0.033	8.565	0.312	9.533	0.347	9.038	0.329	9.117	0.332
WQI				ΣQ _n W _n 45.89		Σ Q _n W _n 42.89		Σ Q _n W _n 41.03		Σ Q _n W _n 45.52

Table 4. Data on calculation of water quality index based on the mean of physico-chemical parameters of water of for Nachiketa Tal

Parameters	S _n	V _n	V _{io}	1/S _n	W _n	Q _n	Q _n W _n
pH	8.5	6.90	7	0.117647	0.128501	-6.40278	-0.82276
Electrical Conductivity (µScm ⁻¹)	250	52.34	0	0.004	0.004369	20.93583	0.091469
TDS (mg l ⁻¹)	500	22.98	0	0.002	0.002185	4.596667	0.010041
Dissolved oxygen (mg l ⁻¹)	5	7.48	14.6	0.2	0.218451	74.19705	16.20844
BOD (mg l ⁻¹)	2	1.01	0	0.5	0.546128	50.52083	27.59085
F.CO ₂ (mg l ⁻¹)	250	1.53	0	0.004	0.004369	0.610867	0.002669
Alkalinity (mg l ⁻¹)	200	68.83	0	0.005	0.005461	34.41354	0.187942
Total Hardness(mg l ⁻¹)	200	26.54	0	0.005	0.005461	13.26979	0.07247

Chlorides (mg l ⁻¹)	250	3.80	0	0.004	0.004369	1.521767	0.006649
Sulphates (mg l ⁻¹)	200	6.36	0	0.005	0.005461	3.181667	0.017376
Nitrates (mg l ⁻¹)	45	0.313	0	0.022222	0.024272	0.695093	0.016872
Calcium(mg l ⁻¹)	75	6.15	0	0.013333	0.014563	8.196667	0.119371
Magnesium (mg l ⁻¹)	30	2.72	0	0.033333	0.036409	9.063313	0.329982
Total				0.915536	1	WQI	43.83137
			K	1.092256			

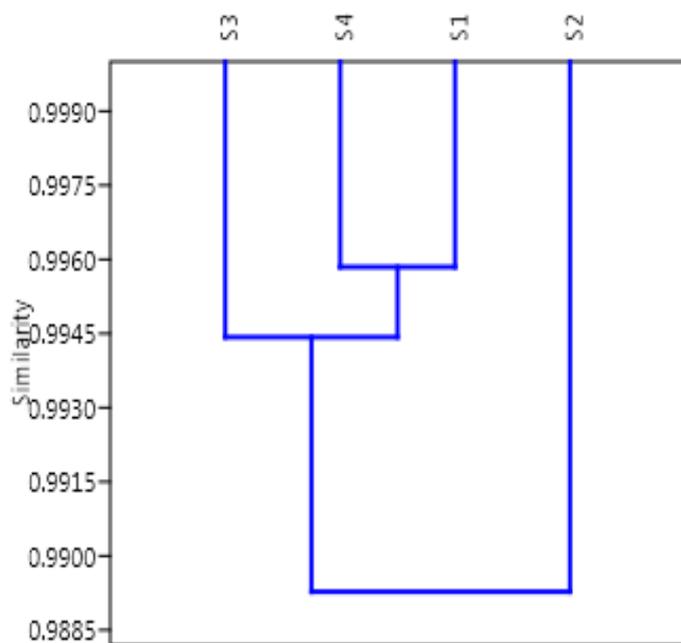


Fig. 2. Bray-Curtis similarity index between the four stations

Table 5. Correlation between the physico-chemical attributes of the Nachiketa Tal, Garhwal Himalaya during the period from May 2014 to April 2015

	WT	EC	AL K	TDS	FC O ₂	DO	BO D	pH	TU B	CL	TH	NO ₃	PO ₄	SO ₄	Ca	M g
WT	1															
EC	.873 **	1														
AL K	.830 **	.837 **	1													
TD S	.719 **	.771 **	.694 *	1												
FC O ₂	0.29 2	0.28 3	0.11 9	.626 *	1											
DO	-.869 **	-.898 **	-.844 **	-.658 *	0.10 1	1										
BO D	.903 **	.905 **	.915 **	.839 **	0.38 9	.792 **	1									
pH	-.989 **	-.886 **	-.828 **	-.718 **	-0.29	.868 **	.915 **	1								
TU B	.807 **	.887 **	.766 **	.847 **	0.47 7	.858 **	.849 **	.839 **	1							
CL	0.43 5	.586 *	0.46	0.53 8	0.19 6	0.52 4	0.47 6	0.45 1	.590 *	1						
TH	0.18 8	0.05 1	0.27 4	0.19 6	0.12 3	0.02	0.22 8	0.09 6	0.10 4	0.46 4	1					
NO ₃	.863 **	.901 **	.699 *	.661 *	0.34 3	.812 **	.835 **	.910 **	.878 **	0.50 1	0.20 1	1				
PO ₄	0.50 3	.644 *	0.29	0.56 1	0.47 7	.652 *	0.41	0.53 6	.778 **	0.52 3	0.48 6	.690 *	1			
SO ₄	0.11 5	0.23 6	0.14 1	0.54	.656 *	0.16 1	0.19 1	0.08 1	0.41 2	.617 *	-0.12	0.13 5	0.49 5	1		
Ca	-0.03	-0.22	0.08 8	0.06 7	0.09 8	0.19 4	0.01 5	0.12 7	0.22 8	0.54 6	.944 **	0.38 4	0.50 7	0.03 2	1	
Mg	0.47 9	0.22	0.49 7	0.35	0.13 3	0.25 2	0.50 3	0.41 6	0.10 9	0.23 4	.863 **	0.12 4	0.34 6	0.22 7	.64 7*	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

WT: water temp.; EC: Electrical Conductivity; ALK: Alkalinity; TDS: Total dissolve solids; FCO₂: Free Carbon dioxide; DO: Dissolve oxygen; BOD: Bio-chemical Oxygen Demand; TUB: Turbidity; Cl: Chloride; TH: Hardness; NO₃: Nitrates; PO₄: Phosphates; SO₄: Sulphates; Ca: Calcium; Mg: Magnesium

Table 6. Monthly variations in physico-chemical parameters at sampling stations S₁ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

Parameters	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	$\bar{X} \pm$ S.D.
Water temp. (°C)	20.20	22.50	19.00	20.50	16.20	17.60	11.20	8.50	7.80	6.90	16.80	18.80	15.5± 5.45
Electrical Conductivity (µScm ⁻¹)	60.20	62.40	66.50	70.40	58.20	54.60	38.00	33.20	32.50	46.50	50.50	52.80	52.15± 12.55
Alkalinity (mg l ⁻¹)	85.20	84.50	76.20	80.20	75.30	60.50	58.00	40.50	62.00	58.50	68.00	78.50	68.95± 13.4
TDS (mg l ⁻¹)	30.50	32.50	37.50	35.00	15.80	18.60	16.50	17.20	16.40	15.20	17.50	20.00	22.73± 8.48
Free CO ₂ (mg l ⁻¹)	1.06	2.46	2.73	1.76	1.14	0.97	1.76	2.64	0.88	1.06	1.06	1.23	1.56± 0.69
Dissolved oxygen (mg l ⁻¹)	6.60	7.00	7.00	6.00	6.40	7.00	7.60	9.00	8.60	8.80	7.80	7.40	7.43± 0.96
BOD (mg l ⁻¹)	1.50	1.40	1.50	1.20	1.20	0.90	0.80	0.60	0.70	0.80	1.20	1.00	1.07± 0.31
pH	6.72	6.75	6.77	6.68	6.82	6.90	7.30	7.20	7.30	7.36	6.85	6.80	6.95± 0.26
Turbidity (NTU)	5.82	6.12	7.14	8.42	6.05	4.25	3.26	3.15	3.18	2.38	3.85	4.48	4.84±1.85
Total Hardness(mg l ⁻¹)	36.00	40.00	24.00	20.00	22.00	24.00	26.00	26.20	28.00	26.00	24.00	28.00	27.02± 5.69
Chlorides (mg l ⁻¹)	3.41	2.84	5.11	5.68	3.41	3.69	4.26	2.56	2.84	3.69	4.26	4.54	3.86±0.95
Nitrates (mg l ⁻¹)	0.316	0.322	0.365	0.344	0.356	0.312	0.258	0.305	0.250	0.262	0.311	0.328	0.31± 0.04
Phosphates (mg l ⁻¹)	0.062	0.070	0.082	0.090	0.078	0.078	0.073	0.064	0.060	0.057	0.062	0.060	0.07± 0.01
Sulphates (mg l ⁻¹)	5.12	6.65	7.32	8.12	4.96	5.79	7.20	6.15	6.10	6.20	5.26	6.28	6.26± 0.95
Calcium(mg l ⁻¹)	8.02	10.42	5.61	4.81	5.61	5.61	6.41	6.41	7.69	6.41	5.61	6.41	6.59± 1.51
Magnesium (mg l ⁻¹)	3.88	3.40	2.43	1.94	1.94	2.43	2.43	2.48	2.14	2.43	2.43	2.91	2.57± 0.57

Table 7. Monthly variations in physico-chemical parameters at sampling stations S₂ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

Parameters	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	$\bar{X} \pm$ S.D.
Water temp. (°C)	20.0	20.5	19.1	20.0	16.0	17.1	10.8	8.2	7.1	6.5	16.2	18.5	15± 5.35
Electrical Conductivity (µScm ⁻¹)	62.0	63.6	68.2	71.6	60.4	55.8	39.2	34.8	33.6	47.2	51.8	52.5	53.39± 12.67
Total Alkalinity (mg l ⁻¹)	85	84.8	77.5	82.5	75.8	60.5	60.5	40.8	60.0	60.0	65.0	75.0	68.95± 13.35
TDS (mg l ⁻¹)	33.50	32.80	37.00	36.50	16.20	19.50	16.90	18.20	17.00	15.90	19.60	22.50	23.8± 8.5
Free CO ₂ (mg l ⁻¹)	1.23	2.46	2.82	1.94	1.23	1.06	1.76	2.20	0.88	0.88	1.14	1.32	1.58± 0.65
Dissolved oxygen (mg l ⁻¹)	6.5	6.8	7.0	6.3	7.0	6.8	8.5	8.8	8.0	8.6	8.0	7.2	7.46± 0.87
BOD (mg l ⁻¹)	1.4	1.6	1.5	1.2	0.9	0.7	0.5	0.6	0.8	0.7	1.0	1.0	0.99± 0.36
pH	6.60	6.57	6.60	6.58	6.85	6.75	7.10	7.10	7.20	7.32	6.80	6.70	6.85± 0.27
Turbidity (NTU)	5.98	6.46	7.28	8.65	6.20	4.28	3.55	3.30	3.19	2.55	4.12	4.62	5.02± 1.88
Total Hardness(mg l ⁻¹)	34.00	38.00	22.00	20.00	20.80	24.00	26.00	26.00	28.50	26.00	24.00	28.00	26.44± 5.25

Chlorides (mg l ⁻¹)	3.98	3.41	5.11	6.25	3.41	3.41	3.98	2.27	3.12	3.41	4.26	4.26	3.91±1.02
Nitrates (mg l ⁻¹)	0.323	0.342	0.372	0.372	0.392	0.317	0.262	0.285	0.256	0.270	0.321	0.340	0.32±0.05
Phosphates (mg l ⁻¹)	0.064	0.069	0.080	0.088	0.075	0.076	0.068	0.070	0.058	0.062	0.058	0.063	0.07±0.01
Sulphates (mg l ⁻¹)	5.52	6.82	7.52	7.95	5.45	5.92	7.32	6.42	6.25	6.48	5.42	6.52	6.47±0.83
Calcium(mg l ⁻¹)	6.41	9.62	3.21	4.81	4.01	5.61	4.80	6.41	8.01	6.41	4.80	6.41	5.88±1.75
Magnesium (mg l ⁻¹)	4.37	3.40	3.40	1.94	2.62	2.43	3.41	2.43	2.07	2.43	2.92	2.91	2.86±0.69

Table 8. Monthly variations in physico-chemical parameters at sampling stations S₃ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015

Parameters	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	$\bar{X} \pm$ S.D.
Water temp. (°C)	20.2	22.3	19.3	20.2	16.5	17.3	11.0	8.2	7.5	6.9	16.4	19.5	15.44 ± 5.54
Electrical Conductivity (µScm ⁻¹)	59.8	61.3	64.9	69.5	59.5	54.6	38.5	33.0	32.4	46.5	50.2	52.5	51.89 ± 12.23
Total Alkalinity (mg l ⁻¹)	84.2	85	76.5	80.2	75.2	60.2	58.2	40.2	62.5	60.0	68.0	72.0	68.52 ± 13.01
TDS (mg l ⁻¹)	30.20	32.00	37.50	35.20	15.90	18.20	16.60	17.50	16.50	15.40	17.20	20.50	22.73 ± 8.4
Free CO ₂ (mg l ⁻¹)	1.06	2.46	2.64	1.76	1.06	0.88	1.76	1.94	0.88	0.97	1.14	1.14	1.47±0.62
Dissolved oxygen (mg l ⁻¹)	6.8	7.0	7.2	6.2	6.7	7.0	7.5	9.2	8.4	8.2	8	7.4	7.47±0.84
BOD (mg l ⁻¹)	1.0	1.2	1.0	1.4	1.0	0.8	0.7	0.5	0.5	0.6	1.0	1.2	0.91±0.29
pH	6.71	6.60	6.65	6.72	6.80	6.90	7.00	7.30	7.20	7.30	6.80	6.82	6.9±0.25
Turbidity (NTU)	5.23	6.23	7.20	8.29	6.11	4.2	3.20	3.19	3.11	2.25	3.80	4.37	4.77±1.86
Total Hardness (mg l ⁻¹)	32.00	36.00	22.00	20.00	20.00	24.00	26.00	26.00	28.00	26.40	24.00	28.00	26.03 ± 4.67
Chlorides (mg l ⁻¹)	3.69	2.84	4.83	5.68	3.12	2.84	4.26	2.56	2.84	3.69	4.26	4.26	3.74±0.95
Nitrates (mg l ⁻¹)	0.311	0.326	0.355	0.365	0.343	0.324	0.265	0.278	0.246	0.265	0.316	0.336	0.31±0.04
Phosphates (mg l ⁻¹)	0.066	0.065	0.083	0.084	0.072	0.081	0.060	0.068	0.059	0.053	0.060	0.065	0.07±0.01
Sulphates (mg l ⁻¹)	5.21	7.02	7.65	8.05	5.10	5.65	7.15	6.21	6.18	6.31	5.32	6.36	6.35±0.96
Calcium (mg l ⁻¹)	6.41	8.02	4.81	4.81	4.81	5.61	6.41	6.41	7.21	6.73	5.13	5.13	5.96±1.06
Magnesium (mg l ⁻¹)	3.89	3.88	2.43	1.94	1.94	2.43	2.43	2.43	2.43	2.33	2.72	3.69	2.71±0.7

Table 9. Monthly variations in physico-chemical parameters at sampling stations S₄ of Nachiketa Tal, Garhwal Himalaya, Uttarakhand during the period from May 2014 to April 2015.

Parameters	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	$\bar{X} \pm$ S.D.
Water temp. (°C)	20.5	22.6	19	20.4	16.8	17.7	11.4	8.5	7.9	7.0	16.5	19.2	15.63± 5.46
Electrical Conductivity (µScm ⁻¹)	60.0	62.5	64.5	70.2	58.6	53.8	38.6	33.5	32.0	46.2	50.6	52.6	51.93± 12.31
Total Alkalinity (mg l ⁻¹)	80	85.2	76.5	80.5	75.2	60.0	60.2	40.6	62.0	62.0	68.0	76.5	68.89± 12.54
TDS (mg l ⁻¹)	30.80	30.60	38.00	35.40	16.00	18.40	16.50	17.50	16.80	15.50	17.20	19.50	22.68± 8.42
Free CO ₂ (mg l ⁻¹)	1.06	2.46	2.64	1.85	1.06	1.06	1.76	1.94	0.88	0.97	1.14	1.14	1.5± 0.61
Dissolved oxygen (mg l ⁻¹)	6.5	7.2	7.0	6.4	6.8	7.2	8.1	9	8.6	8.2	8.4	7.2	7.55± 0.87
BOD (mg l ⁻¹)	1.5	1.5	1.6	1.4	1.2	0.8	0.7	0.6	0.5	0.8	1.1	1.2	1.08± 0.38
pH	6.72	6.67	6.66	6.71	6.70	6.80	7.20	7.32	7.32	7.35	6.82	6.70	6.91± 0.29
Turbidity (NTU)	5.76	6.40	7.18	8.35	6.09	4.20	3.24	3.20	3.14	2.15	3.77	4.44	4.83± 1.9
Total Hardness(mg l ⁻¹)	34.00	40.00	22.00	22.00	20.00	24.00	26.00	26.00	28.00	26.00	24.00	28.00	26.67± 5.55
Chlorides (mg l ⁻¹)	3.41	2.84	4.26	5.96	3.41	3.41	4.26	2.84	2.84	3.69	3.41	4.26	3.72± 0.89
Nitrates (mg l ⁻¹)	0.334	0.336	0.360	0.354	0.325	0.320	0.253	0.264	0.252	0.261	0.312	0.332	0.31± 0.04
Phosphates (mg l ⁻¹)	0.060	0.072	0.085	0.086	0.080	0.079	0.070	0.066	0.061	0.059	0.062	0.060	0.07± 0.01
Sulphates (mg l ⁻¹)	5.20	7.08	7.45	8.23	5.26	5.72	7.25	6.05	6.20	6.38	5.22	6.45	6.37± 0.97
Calcium(mg l ⁻¹)	8.02	9.62	4.81	5.13	3.21	5.61	6.41	6.41	6.41	6.41	5.61	6.41	6.17± 1.59
Magnesium (mg l ⁻¹)	3.40	3.88	2.43	2.23	2.91	2.43	2.43	2.43	2.91	2.43	2.43	2.91	2.74± 0.49

CONCLUSION

The present study reveals that the water quality of Nachiketa Tal is 'good'. It is fit for drinking after proper disinfection, as it receives sediments and other plant litter from its watershed. This lake is an important aquatic ecosystem in the dense forests of the area and acts as a natural water hole for the wild animals, local inhabitants, and tourists. Therefore, a regular monitoring and remedial measures (removal of sediments and litter, embankment of the lake and

regulation of influx of tourists) are necessary for maintaining the water quality of the sacred lake of Nachiketa Tal.

ACKNOWLEDGEMENT

One of the authors (Vijayta Tiwari) is thankful to the University Grants Commission, New Delhi and H.N.B. Garhwal University (A Central University), Srinagar-Garhwal, Uttarakhand for providing Central University fellowship for undertaking the present work.

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