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Research Article

Water Quality Assessment of the Central Himalayan Lake, Nainital

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The Nainital Lake, situated in the central Himalayas of India, is an important water body and a major tourist spot. This study aims to identify factors or processes that determine the water quality of the lake. For this purpose, water samples from two different points were collected—highly polluted (Mallital) and least polluted (Tallital)—to represent the actual level of pollution in the lake in four different seasons (January, April, July, and October). The collected samples were analyzed for different physical and chemical parameters. In order to assess the state of the lake's water quality, the samples were compared with the standard water quality values. Turbidity, electrical conductivity, total alkalinity, and heavy metal (lead, iron, and copper) concentration were found to be above the desirable limit of the prescribed national and international standards in all four seasons at both Mallital and Tallital. Reasons affecting the water quality were found to be natural (thermal stratification and lead-bearing rocks) and anthropogenic (domestic sewage, runoff, and illegal construction activities in the vicinity of lake). Various lake restoration alternatives/interventions have been suggested that can lead to an improvement in the lake's water quality, such as afforestation, phytoremediation, and sediment basin.

1. Introduction

Nainital city is one of the major tourist attractions in the northern part of India. The lake provides water to 40,000 local inhabitants [1] and thousands of tourists visiting it every year [2] who use the water for different purposes like drinking and for recreational activities [3, 4]. Increasing local population, logarithmic increase in the tourist flux in Nainital, and the concomitant mushrooming of a large number of hotels in the catchment area have severely affected the water resources and biodiversity of this watershed [5, 6].

According to Singh et al. [7], open sewers disposing large quantities of sewage in the lake are definitely causing a detrimental effect on the lake water quality. Other anthropogenic activities such as illegal construction, litter, domestic discharge, and recreational use of lake water are major concerns for sedimentation and eutrophication of the lake water [1].

Thus, considering it as imperative, this comprehensive primary water quality monitoring study of the Nainital Lake has been undertaken. The main objective of this paper is to assess the state of water quality of the Nainital Lake by carrying out a comprehensive monitoring exercise to identify the contributing factors for the existing water quality. For this purpose, water samples were collected from a highly polluted and a least polluted site of the lake; 18 physicochemical parameters were analyzed to understand the limnology of the Nainital Lake. Various possible measures that can be put in place to maintain the desired water quality have also been discussed.

2. Materials and Methods

2.1. Study Area. The Nainital Lake is a natural kidney-shaped, tectonic, warm monomictic-type lake, situated at 29° 24′ N latitude and 79° 28′ E longitude [5]. It covers a surface area of 48 hectares. The maximum and mean depths of the lake are 27.3 m and 16.2 m, respectively [2]. It is divided into two subbasins (Mallital and Tallital) by a 100 m wide transverse underwater ridge, 7 m below surface [5]. Mallital (north basin) is a highly polluted site due to intense boating activity and Naina Devi Mandir drain emptying into it. Tallital (south

Table 1: Drinking water quality standards, units, analytical method, and recommending agencies (source: [8–10]).

Water quality	Unit	Analytical method	Indian standards (desirable) and recommended agencies
pH	pH unit	pH meter	6.5–8.5 (BIS/ICMR)
Turbidity	NTU	Turbidity meter	5 (BIS)
Dissolved oxygen	mg/L	DO meter	5 (ICMR)
Electrical conductivity	μs/cm	Conductivity meter	300 (ICMR)
Total dissolved solid	mg/L	TDS meter	500 (BIS)
Total suspended solid	mg/L	Gravimetric	500 (WHO)
Temperature	Degree Celsius	Portable thermometer	—
Biochemical oxygen demand	mg/L	Winkler azide method	5 (ICMR)
Total hardness	$CaCO_3$ mg/L	Titrimetric	300 (BIS/ICMR)
Total alkalinity	$CaCO_3$ mg/L	Titrimetric	120 (ICMR)
Chloride	mg/L	Argentometric	250 (BIS/ICMR)
Sodium	mg/L	Flame photometer	<20 (WHO)
Potassium	mg/L	Flame photometer	10 (WHO)
Phosphate	Microgram/L	UV spectrophotometer	—
Lead	mg/L	Atomic absorption	0.05 (BIS)
Copper	mg/L	Atomic absorption	0.05 (BIS)
Iron	mg/L	Atomic absorption	0.3 (BIS)
Zinc	mg/L	Atomic absorption	5 (BIS)

BIS: Bureau of Indian Standard, WHO: World Health Organization, and ICMR: Indian Council of Medical Research.

basin) on the other hand is relatively less polluted. Geology of both basins is one of the key interests for this study. The lake's basin is formed of folded and faulted rocks of Krol and Tal formation attributed to the Cambrian Age [11]. The lake receives water from springs (Pardadhara and Chunadhara), rainwater, and 22 inlet nullahs (9 are permanent, which act as a major conduit of polluted sludge and silt draining off into the lake) [1]. The lake supports around 40,000 local inhabitants present in its catchment area; hence, anthropogenic activities like surface runoff, domestic sewage, construction activities, and agricultural activities have significantly changed the water quality of the Nainital Lake.

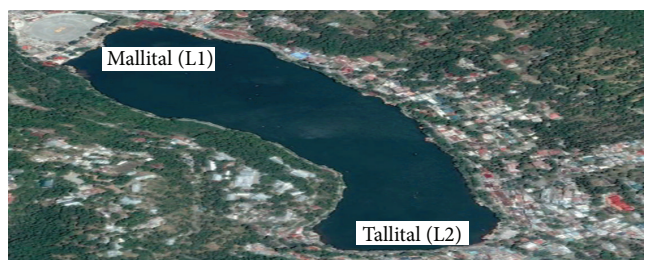

Figure 1: Map showing the study area and surface water quality sampling stations of Nainital Lake (source: Google map).

2.2. Sample Collection and Analysis. Water samples were collected from two sites of Nainital—Mallital (L1) and Tallital (L2) (Figure 1). Fourteen grab samples were collected for each month (January, April, July, and October) from both the sites. In order to collect representative samples, a sampling station network was designed in such a way so as to cover wide range of factors such as drains and springs that influence the water quality of the lake. Water samples were collected in 2,000 mL polyethylene sterilized bottles (cleaned with metal-free soap, washed with distilled water, soaked in 10% nitric acid for 24 hours, and finally rinsed with ultrapure water). Water samples were stored in an insulated, ice-cooled container and delivered to the laboratory on the same day. All the samples were kept at 4°C to avoid physicochemical changes and interference. The sampling, preservation, transportation, and analysis of water samples were carried out according to the methods described in APHA-AWWA-WEF (1998) [12]. The polyethylene bottles used for storing samples were sealed with tape to make the sample free from air contact. Surface runoff, domestic sewage, and weathering of rocks were found to be responsible for influencing the physical and chemical parameters of the Nainital Lake water. A total of 18 physicochemical parameters were analyzed in laboratory using standard protocol APHA-AWWA-WEF (1998) including total dissolved solids (TDS), total suspended solid (TSS), turbidity, electrical conductivity (EC), phosphate, total hardness, pH, alkalinity, temperature, BOD, DO, Cl, Na+, Pb, K, Cu, Fe, and Zn. Water quality parameters, unit, methods of analysis, Indian standards, and recommended agencies are all summarized in Table 1.

Table 2: Descriptive statistics of water quality parameters for Nainital Lake for all 4 seasons (January, April, July, and October).

Parameter	Nainital Lake (Mallital)			Nainital Lake (Tallital)		
	For all 4 seasons		Mean ± Std. deviation	For all 4 seasons		Mean ± Std. deviation
	Maximum	Minimum		Maximum	Minimum	
PO_4^{-3}	0.18	0.09	0.143 ± 0.046	0.16	0.09	0.123 ± 0.036
Temp.	22.00	17.00	19.50 ± 2.08	22.00	18.00	20.50 ± 1.73
DO	8.60	7.90	8.20 ± 0.29	7.20	4.00	5.77 ± 1.39
pH	8.20	7.20	7.55 ± 0.47	8.20	7.40	7.75 ± 0.34
BOD	3.50	2.80	3.25 ± 0.33	4.80	3.80	4.25 ± 0.41
Turbidity	16.00	6.00	10.25 ± 4.64	18.00	6.00	10.50 ± 5.25
TH	290.00	192.00	250.00 ± 41.53	392.00	112.00	241.50 ± 125.9
TA	278.00	230.00	253.50 ± 21.56	154.00	120.00	142.00 ± 15.05
TDS	422.00	375.00	400.00 ± 23.05	582.00	359.00	443.25 ± 98.29
TSS	390.00	286.00	338.00 ± 44.92	412.00	258.00	341.25 ± 68.62
Cl	18.00	11.00	14.50 ± 2.88	19.00	14.00	16.750 ± 2.62
EC	580.00	500.00	536.00 ± 33.62	550.00	500.00	525.00 ± 28.86
Na	3.20	2.42	2.79 ± 0.40	3.30	2.89	3.14 ± 0.18
K	14.57	11.80	12.82 ± 1.20	11.24	10.27	10.57 ± 0.45
Pb	.34	.24	0.28 ± 0.04	.27	.21	0.23 ± 0.02
Cu	.24	.14	0.19 ± 0.04	.22	.18	0.20 ± 0.01
Fe	.73	.62	0.68 ± 0.04	.79	.64	0.70 ± 0.06
Zn	.08	.03	0.06 ± 0.02	.07	.02	0.04 ± 0.02

3. Result and Discussion

The different physicochemical parameters of the lake water are discussed below and compared with WHO/BIS/ICMR standards. The descriptive statistics for both sites (Mallital and Tallital) are presented in Table 2.

The lake water appears to be alkaline in nature in all four seasons with the pH value ranging between 6.5 and 8.2. Maximum pH was recorded at Mallital in July and October and at Tallital in April. Purohit and Singh [4] too reported high pH in the lake for the said period (July–November). Increase in photosynthetic activity of submerged and suspended algal population in aquatic ecosystem may be the reason for this increase in pH value.

Total alkalinity recorded in the Nainital Lake water ranges between 230 mg/L to 278 mg/L at Mallital and between 120 mg/L to 154 mg/L at Tallital. The maximum concentration of alkalinity was recorded during July season at both the sites. During monsoon, surface runoff brings organic matter and, with decomposition of this organic matter, carbon dioxide is released resulting in the addition of carbonate and bicarbonate, which also increases the alkalinity value.

Dissolved oxygen (DO) is the indication of general health of a water body. DO recorded in the water of the Nainital Lake ranges between 7.9 mg/L to 8.6 mg/L at Mallital and between 4 mg/L to 7.2 mg/L at Tallital. The maximum amount of DO in the water of the lake was recorded during April at Mallital and in October season at Tallital. This can be explained by the fact that during active photosynthesis more oxygen gets dissolved in the lake [13, 14].

Biochemical oxygen demand (BOD) is a key parameter and it indicates the organic load in aquatic ecosystem. BOD value in the Nainital Lake ranges between 2.8 mg/L to 3.5 mg/L at Mallital and between 3.8 mg/L to 4.8 mg/L at Tallital, which was within the desirable limit of drinking water quality standards for all four seasons.

The minimum concentration of phosphate (93.12 micrograms/l to 88.65 micrograms/l) was recorded during January at both the sites (Mallital and Tallital) of the lake. Maximum concentration of phosphate (162.76 micrograms/l) was recorded during April at Tallital and in October (184.68 micrograms/l) at Mallital.

Electrical conductivity (EC) varies between 500 mg/L to 580 mg/L at Mallital and between 500 mg/L to 550 mg/L at Tallital. Maximum EC (580 mg/L) was reported at Mallital in the month of April and (550 mg/L) in April and October at Tallital. EC in the lake is controlled by surface runoff in summer and subsurface runoff during monsoon and early spring. Concentration of total suspended solids (TSS) varies from 286 mg/L to 390 mg/L at Mallital and from 258 mg/L to 412 mg/L at Tallital for different seasons. Maximum concentration was recorded at Mallital in April (390 mg/L) and in July (412 mg/L) at Tallital. Total dissolved solid (TDS) in Nainital Lake ranges between 375 mg/L and 422 mg/L for Mallital and between 359 mg/L and 582 mg/L for Tallital. The maximum amount of TDS was recorded during July at both sites. This increased concentration of TDS in the Nainital Lake was attributed to surface runoff. Results for EC and TDS show conformance with the previous study [15].

Presence of clay, silt, organic matter, phytoplankton, and other microscopic organisms causes turbidity in lake water. Presence of high turbidity indicates the presence of large amount of suspended solids. Turbidity in Nainital Lake was recorded in ranges between 6 NTU to 16 NTU for Mallital

and between 6 NTU to 18 NTU for Tallital. The maximum turbidity (16 NTU and 18 NTU) in water was recorded during the month of July at both the sites. Again this high turbidity during July can be attributed to particulate addition through surface runoff from the surrounding hills. Also, an increase in population and cultural activities leading to massive deforestation and waste generation in the catchment of Nainital Lake in turn leading to an increased concentration of suspended solids can also affect the turbidity in the Nainital Lake. The mean turbidity values obtained for Nainital Lake were in conformance with the values as reported in literature [4].

Total hardness recorded in the water of Nainital Lake for present investigation ranges between 192 mg/L to 290 mg/L and between 112 mg/L to 392 mg/L for both sites, respectively. The maximum concentration of total hardness in the water of Nainital Lake was recorded during April at Tallital (392 mg/L). High temperature, evaporation of water, weathering of rocks, and addition of calcium and magnesium salts by means of plants and living organism were found to be contributing factors for the hardness of the lake water.

Concentration of potassium (K) varied from 11.8 mg/L to 14.57 mg/L for Mallital and from 10.27 mg/L to 11.24 mg/L for Tallital. Maximum potassium concentration was observed at both the sampling sites during July. It was found that, during rains, wastewater drains (*Nallahs*) in the catchment area were responsible for the increased potassium concentration as the runoff consisted of decomposed organic waste and plant material which increases the concentration of potassium in the lake water. Similar finding has been projected by Trivedy et al. [16]. Seasonally, concentration of sodium (Na) in Nainital Lake varied from 2.42 mg/L to 3.2 mg/L and from 2.8 mg/L to 3.3 mg/L for both sites, respectively. Chloride recorded in the water ranged between 7 mg/L to 11 mg/L (Mallital) and between 14 mg/L to 19 mg/L (Tallital). The concentration of sodium and chloride in Nainital Lake did not exceed the WHO and BIS recommended values.

3.1. Distribution of Heavy Metals in Lake Water. It was found that seasonally the concentration of lead (Pb) in the Nainital Lake ranged between 0.21 mg/L to 0.34 mg/L for both the sites (Mallital and Tallital) and maximum lead was reported in October at both sites. The reasons for increased lead concentration were found to be anthropogenic activities (boat repairing, painting), presence of automobile workshop on the banks of the lake, and lead-bearing minerals present in the catchment rock formation [15]. During winter, as the top layers become cooler in comparison to the deeper layers, the sinking process starts which shows greater mixing during winter in comparison to summer (April) when it is thermally stratified. In this study, the concentration of lead obtained was higher than the permissible limit of BIS, hence, making the lake water unsuitable for drinking and domestic use. The unsuitability of such water is corroborated by Schwartz et al. [17], who reported that high concentration of lead leads to growth retardation in children.

Copper (Cu) concentration varied between 0.14 mg/L and 0.24 mg/L throughout the study period. It was reported to be highest in July at both sites; Mallital recorded 0.24 mg/L and Tallital recorded 0.22 mg/L, respectively. Leaching of metals from the catchment soil and from market waste/effluent into rainwater [2] and then transporting into the lake water increased the concentration of copper in the Nainital Lake water.

Table 3: Suitable interventions for the remediation of the Nainital Lake water.

Sr. number	Techniques	Discussion
1	Afforestation	Control soil erosion from nearby hills, which further helps in controlling turbidity of the lake water.
2	Phytoremediation	Growing common aquatic plants like bulrush, water hyacinth, duckweed, *hydrilla*, and lotus in the catchment area and inside the Nainital Lake will help in the removal of heavy metals from the surface runoff and lake water.
3	Sediment basin	Basin is rectangular in shape, formed by excavation or by constructing embankment. It reduces water flow by trapping maximum amount of sediments having efficiency of settling particle of size up to 0.005 mm, thereby making downstream water free from debris.

Concentration of iron (Fe) ranged between 0.62 mg/L and 0.79 mg/L. It was found to be highest in April at Mallital (0.73 mg/L) and in January at Tallital (0.79 mg/L). Increased concentration of iron in itself is not a pollutant but it provides a favorable condition for many pathogenic organisms to grow as they require iron to thrive.

The concentration of zinc (Zn) varied between 0.02 mg/L and 0.08 mg/L for both sites and was reported to be within the desirable level as per BIS standards.

Based on this study, it was found that at both the sites of Nainital Lake (Mallital and Tallital), surface runoff and heavy metals (lead, copper, and iron) were the main contributors of water pollution. In order to control the surface runoff and for the rejuvenation of the Nainital Lake water, suitable interventions have been discussed in Table 3.

4. Conclusion

The study reveals that turbidity, total alkalinity, electrical conductivity, and heavy metal (lead, copper, and iron) were found to be above the desirable limit of BIS/ICMR/WHO standard in all four seasons at Mallital and Tallital. The lake water quality deterioration is caused by domestic sewage, surface runoff from nearby hills, deforestation, and natural activities (thermal stratification, lead-bearing rocks). Suitable lake restoration measures/interventions as mentioned above should be adopted to reduce anthropogenic discharges into

the lake basin; otherwise, high levels of pollutants will bring about a negative effect on the lives of the surrounding population and their socioeconomic conditions.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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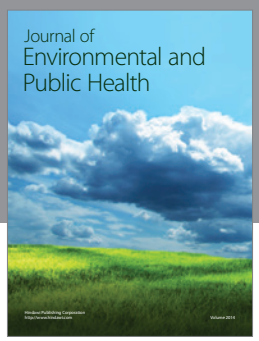

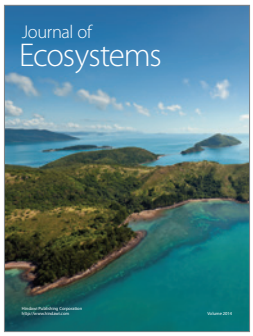

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