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Assessment of Water Quality of Nainital Lake and surrounding Springs, using Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI)

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ABSTRACT

In the last few decades, the health of Nainital Lake in the Nainital town (Uttarakhand) has degraded severely due to anthropogenic activity and there is no regular monitoring of the lake in terms of the quality index. We made an attempt to understand the hydrochemical facies and Water Quality Index (WQI) of the lake and nearby springs. The water quality parameters, selected for computation of the WQI were mainly pH, Total Dissolved Solids (TDS), Electrical conductivity (EC), major cations, *e.g.,* Na^+, K^+, Mg^{2+}, Ca^{2+}, major anions, *e.g.,* F^-, Cl^-, Br, SO_4^{2-}, NO_3, PO_4, alkalinity and heavy metals (Pb, Ni, Mn, Fe, Cu, Cr, Co, Cd, Zn) from eight different locations, four of them from Nainital Lake water and remaining four from nearby springs. This is the first ever study carried out using WQI and HPI indices water and surrounding springs. Additionally, we have also measured Pb, Ni, Mn, Fe, Cu, Cr, Co, Cd and Zn using the Atomic Absorption Spectrometer (AAS) to compute Heavy Metal Pollution Index (HPI). Here, we present two frequently used water quality indices rating scales, *i.e.,* Ramkrishnaiah *et al.* (2009) and Yadav *et al.* (2010). The calculated index of the water samples was compared with the standard values of the World Health Organization (2011) and BIS (Bureau of Indian Standard, 1999). Our results indicate that the lake water is highly polluted and is not suitable for drinking without proper purification. This is an upsetting state of affair and the main concern is whether the lake water is properly purified before it is used by about 50,000 residents living around the lake.

Keywords: Nainital Lake; Physical and chemical parameters; Water Quality Index(WQI); Heavy Metal Pollution Index (HPI)

INTRODUCTION

India has various number of natural water resources distributed unequally all over the country, but their presence in the Himalayan region has a great importance as these resources are the important source of freshwater for the locals, tourists, trekkers, sages

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and wildlife. The ancient lakes in the Uttarakhand Himalaya are great natural phenomena that have attracted the attention of researchers (*e.g.,* Valdiya *et al*., 1996; Kotlia and Joshi, 2013; Joshi and Kotlia, 2015; Demske *et al.*, 2016). In addition, this region is blessed with several enchanting freshwater modern lakes which are a potential source of drinking water. Besides forming as aesthetic beauty of the region, these lakes contribute a considerable amount of the total water reserve of the state which is an important source of drinking, irrigation, recreation or other development activities for a major population (Khati, 2016). The inhabitants residing around the lakes entirely depend on the lake water for their daily needs. Freshwater lakes situated at the higher elevations are more vulnerable to atmospheric inputs than lowland lakes due to factors like climate, shallow soils, small watersheds and rapid flushing rates. Generally, the hydrochemistry of a lake depends on the surface inflows or/and precipitation and rock weathering of its catchment, climatic changes and human activities.

To ascertain both ecological environment and public health, water quality measurement of the lakes are important (Boyd, 2015; Lu *et al*., 2015). Given the diffuse sources of pollutants, it is hard to control non-point sources. As stated by the WHO, drinking water causes almost 80% of all diseases in human population (CPCB, 2006; Sharma *et al.,* 2014). The causes of water quality declination are several pollutants that come from the discharges of industry wastes, sewage and agricultural production. Difficulties to maintain water quality increases when natural factors (*i.e.,* rainfall intensity, vegetation type, landscape, topography, soil types and river discharge) affect any area. Due to abnormal increase in population and deforestation, rapid change in ecological system is observed around the Nainital Lake which has resulted in soil erosion on the hill slopes and enhanced flow of sewage directly into the lake basin (Das, 2005). Increasing anthropogenic pressure in the catchment and even increasing tourist influx is also a great contribution to the pollution of the lake (Joshi *et al.,* 2006). According to National Institute of Hydrology (2000), the water quality of Nainital Lake is majorly governed by the sub-surface inflow and flow takes place through drainage system present around the area. A previous study by Joshi *et al*. (2006) has confirmed that cleaning operation has reduced the contents of toxic elements and now Nainital Lake is quite safe for tourists as well as local people since it is the sole source of water for drinking, household, agriculture and other anthropogenic activities. In effort to conserve these resources, the rationale of present study is measurement and analysis of some of the selected parameters that may collectively yield a good indication for the overall water quality of the lake and nearby springs. By such effort, we can promote better living condition around the lake to save it from eutrophication.

STUDY AREA

Nainital Lake, a tectonically formed and warm monomictic type water body (29° 24´ N: 79° 28´ E) in the Nainital town is situated at an altitude of 1937m (Fig.1) and is the only source of drinking water for over 50,000 residents in addition to a huge number of tourists (Ali *et al*., 1999). With a surface area of 0.48 km^2, it has maximum and mean depths as 27.3m and 16.2m respectively. It is divided into two sub-basins as Tallital (Talli=lower) and Mallital (Malli=upper) by a 100m wide transverse underwater ridge, located 7m below surface (Jain *et al*., 2007). The lake receives water from springs, rainwater and several inlet nullahs, some of which act as a major conduit of polluted sludge and silt draining off into the lake (Purushothaman *et al*., 2012). To regulate the water level in the lake particularly during the rainy season, a dam has been constructed at the lower end of the lake. Excess water is discharged from the dam through five sluices, which join the Balia river. However, because of the intense activities in the lake catchment as a result of tourist influx and an increase in sedentary human population, there has been a rapid deterioration of the water quality through increased nutrient input. Geologically, the area falls in the Lesser Himalaya zone, mainly comprised of carbonate rocks, massive limestones, ferruginous slates, algal dolomites, black shales with marlite, siltstones etc. of the Krol Formation (Precambrian in age; Valdiya, 1995) including a few intrusions (see Fig. 1).

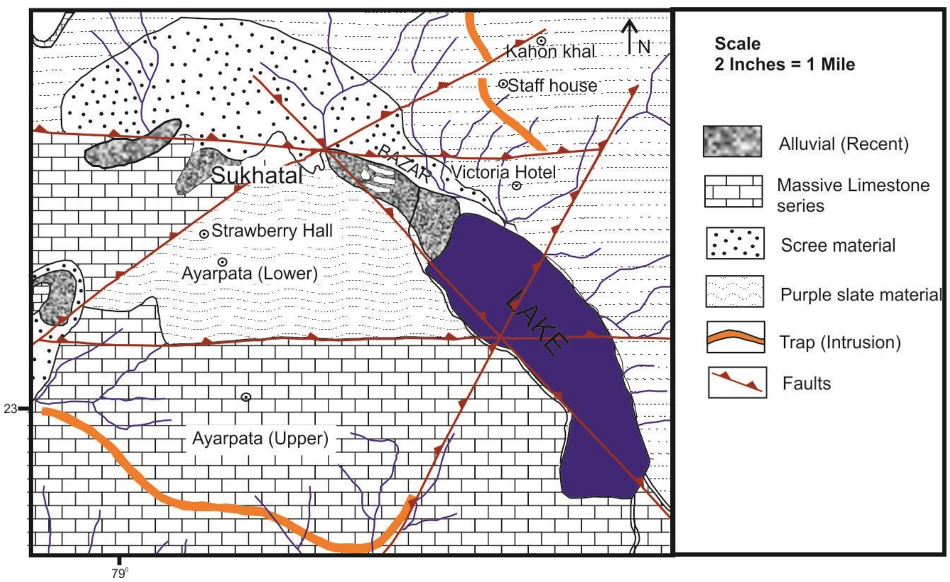

Fig.1: Geological map of Nainital town (modified after Ball, 1887).

The physico-chemical characteristics of Nainital Lake vary due to their ecological variations and primarily due to different lithology in the catchment area and magnitude of anthropogenic inputs. In Nainital Lake, Ca^{2+} and Mg^{2+} are the major cations mainly because of dolomitic limestone are the dominant lithology in the catchment, while SO_4 is dominant anion which is mainly derived from the dissolution of gypsum outcropping in pockets at places with limestone in the basin. Earlier preliminary studies on the water chemistry of the Nainital Lake reveal that the lake sulfidization, sulphide oxidation and degradation of organic matter play a significant role in the remobilization of the metals from the lake sediments (Purushothaman and Chakrapani, 2012; Purushothaman *et al*., 2012).

METHODOLOGY

The samples were collected in May, 2017 (for sample spots; sample code as LW=lake water, DW=drainage water, SW= spring water). Samples were collected from following spots (see Fig. 2), NTL-BS (LW), NTL-C (LW), NTL-TMP (LW), NTL-BN (DW), SP-SLD (SW), SP-ZP (SW), SP-SD (SW) and SP-HGD (SW). All the samples were collected in the polypropylene bottles, the bottles were washed with 15% HNO_3 solution and were rinsed three times with the de-ionized water *i.e.,* ultrapure water and again rinsed two times with the water which was to be sampled to avoid any contamination.

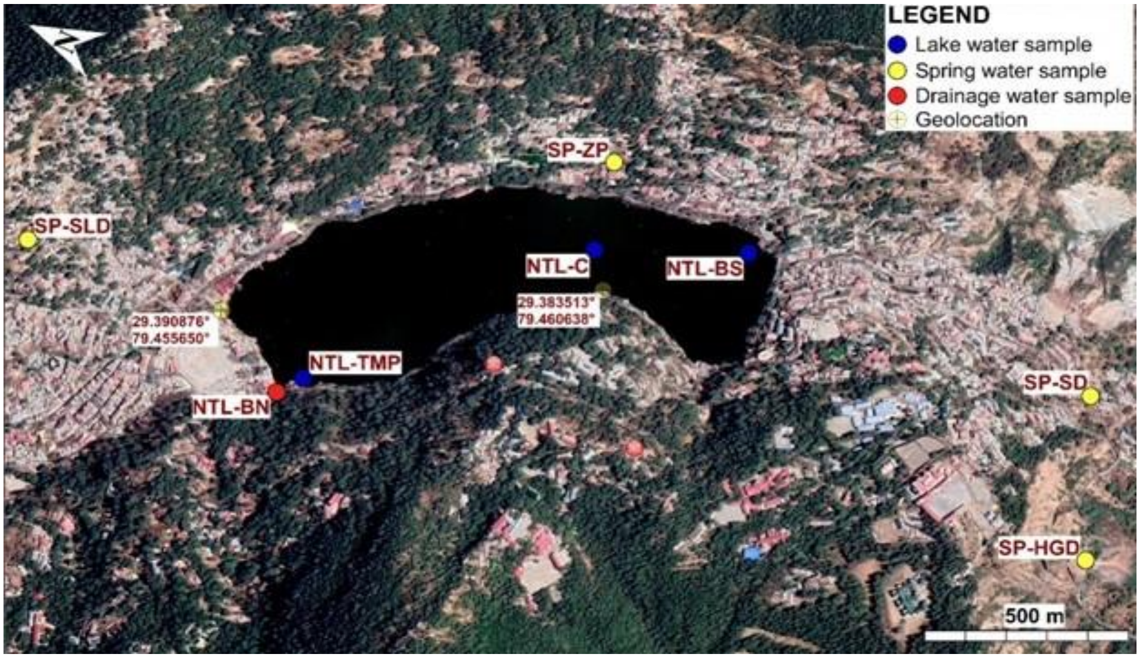

Fig. 2: Satellite image of Nainital Lake in Nainital town (Uttarakhand) and sample points.

The water was acid treated to slow down the precipitation of cations to obtain accurate values of cations as much as possible. Two representatives of each water samples were collected, one filtered another non-filtered. The filtered water sample was used for chemical analysis of cations and anions. The non-filtered sample was measured for turbidity and Total Suspended Sediment (TSS). Before chemical analysis, all the samples were kept at 4^0C. Physical parameters, *e.g.,* Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature and pH were measured at the time of sampling using coway-Tri Meter Probe. Major ions were measured through Ion-Chromatograph at French Cell, IISc Bangalore. Heavy metals were measured using Atomic Absorption Spectrometer (AAS) in the Department of Geology, Kumaun University.

Water Quality Index (WQI) determination

To calculate WQI, we followed Hameed *et al.* (2010) and Sharma *et al.* (2014). A total of 11 parameters were considered and each parameter was given a definite "Assigned Weightage" *(Wa)* according to its relative importance from 1 to 5 on overall quality of water (Table-1). The weightage 5 is assigned to the parameter which is most influential on water quality and 1 is assigned to one contributing the least. Relative weight (W_r) is calculated as;

$$W_r = \frac{W_{ai}}{\sum_{i=1}^{n} W_{ai}} \quad \text{.. (1)}$$

Table-1: Weightage and relative weightage of each parameter

A S.no	B parameter	C weight (W_{ai})	D = C/33 relative weight (W_r)
1	pH	4	0.1212121212
2	TDS	4	0.1212121212
3	Alkalinity	2	0.0606060606
4	EC	5	0.1515151515
5	Na^+	1	0.0303030303
6	Ca^{++}	2	0.0606060606
7	Mg^{++}	2	0.0606060606
8	F^-	2	0.0606060606
9	Cl^-	3	0.0909090909
10	NO_3^{--}	4	0.1212121212
11	SO_4^{--}	4	0.1212121212
		$\sum_{i=1}^{n} W_{ai} = 33$	

Here, "Assigned weightage" for each parameter is represented by W_a,n is number of parameters considered and $W_r$is "Relative weight" for each parameter which is calculated as per equation (1). The calculated relative weights are given in Table-1. After assigning relative weightage, the "Quality Rating Scale" (Q) is calculated by dividing the concentration of considered parameter (C_i) by its respective "Standard value" (S_i) as mentioned in the guidelines of WHO and BIS.

$$Q_i = \frac{C_i}{S_i} * 100 \qquad (2)$$

The Q value of the two parameters, *i.e.,* dissolved oxygen (DO) and pH is calculated differently by using their "Ideal value" (V_i) from Hameed *et al*. (2010) and Sharma *et al.* (2014). The Ideal value (V_i) for pH is 7 and DO is 14 and the calculation for Q from their ideal values is given below.

$$Q_{i(pH,DO)} = \frac{c_i - v_i}{s_i - v_i} * 100 \qquad (3)$$

After computing Q values for the desired parameters, the "Sub-Indices" (SI) is calculated as a product of relative weight (W_r) and Quality rating scale (Q_i). Finally, the Water Quality Index (WQI) is the sum of all Sub-Indices (*e.g.,* Ramakrishnaiah *et al.,* 2009; Yadav *et al.,* 2010; Sharma *et al.,* 2014). The calculation of WQI is given by equation (5).

$$SI = W_r * Q_i \qquad (4)$$

$$WQI = \sum SI_i \qquad (5)$$

Heavy metal pollution index (HPI)

It is a method that rates the total influence of a heavy metal and a composite influence of all metals on the nature of water and contamination (House and Ellis, 1987; Bisht *et al.,* 2020). The metal weighted factor is equal to the inverse of standard value and the weighted factors summation is less than one. Higher values of HPI indicate decayed water quality as for metals utilizing both the ideal and standard values (Prasanna *et al.,* 2012). In this study, Cr, Ni, Pb, Zn, Mn, Cu, Co, Cd and Fe were measured for the index utilizing (Mohan *et al*. 1996) by the following two equations:

$$Qi = \sum_{1=1}^{n} \frac{(Mi-Ii)}{(Si-Ii)} \times 100 \quad (1)$$

$$HPI = \frac{\sum_{1=1}^{n} WiQi}{\sum_{1=1}^{n} Wi} \quad (2)$$

where Qi is the sub-index of the ith metal, Wi is the unit weightage of ith metal, n is the number of metals included and Mi is the monitored value of the heavy metal. Ii is the ideal value and Si is the standard value of the ith metal ignoring the sign (-) which indicates the difference between the two values, and the maximum HPI threshold value is 100 for drinking water (Mohan *et al.,* 1996; Prasad and Bose, 2001).

RESULTS

Physical parameters

pH: The pH of water samples ranges from 7.29 to 8.05. The maximum pH was recorded form the sample collected from the centre of the lake and minimum pH of 7.48 was observed in spring water sample SP-SLD. The pH values between 6.5 and 8.5 are acceptable for outdoor bathing and such waters are considered safe for the skin and delicate organs like eyes, nose and ears (CPCB, 2009). As per the WHO guidelines, the pH of normal waters should be in the range of 7.0-8.5 and all the collected samples fall in the same range.

TDS: As per WHO guidelines, the TDS is permissible as <600 mg/L, while it is less than 500 mg/L for BIS. Our water samples show TDS ranging from 290 to 590, the later values were obtained from the spring sample SP-ZP, collected from near the Catholic Church. Most lake waters have TDS values between 350 and 550 while the spring waters (SP-SLD and SP-ZP) have TDS of 570 and 590 respectively. However, the drainage water sample shows a maximum TDS of 550 ppm which does not qualify the standards of BIS.

EC: The WHO guidelines promote water with EC<750 μS for drinking purposes while the BIS suggests water with EC less than 250 which can be extended to a maximum of 750μS if alternate source is not available. In general, the EC of the water samples varies from 420 to 840 μS. The conductivity of the lake samples at Tallital bus stand is 500 μS which is the least among the collected samples. The Ec was measured as 510 and 580μS at the center of the lake and near the temple. The drainage joining the lake has an EC of 790 μS and maximum conductivity of about 840 was observed in the spring water in SP-ZP (Catholic Church) and 810 in SP-SLD spring. High EC values in spring waters (SP-SLD and SP-ZP) and drainage sample (NTL-BN) suggest that the spring water has high dissolved ions in it.

Turbidity: The turbidity values of the lake samples vary from 11.82 at Tallital Bus stand to 11.66 at the lake centre to a 12.05 at Naina Devi Temple. The spring waters are less turbid compared to the lake water. The spring SP-SP has a turbidity of 5.54 and the SP-ZP spring (Near Catholic church) is least turbid of all with a turbidity of 0.05. High turbidity affects the drinking quality of the water.

TSS: The TSS is usually un-dissolved sediments, mainly comprises fine sand, silt, clay, dust and colloidal particles. More suspended sediments in the water, more turbid is the water. A value of 500.571ppm is set as a secondary standard for drinking purpose by U.S. Environmental Protection Agency. NTL-BS has a maximum of 0.010ppm and the minimum as 0.00 ppm in sample SP-ZP.

Alkalinity: The alkalinity of the collected water sample varies from 245 to 331 ppm. The highest alkalinity is observed at NTL-BN point and the least alkalinity is observed at SP-HGD spot. All the water samples are above the desirable limits of BIS and WHO (200 ppm). Table-2 depicts the results of physical parameters.

Table-2: Physical parameters of studied samples. Rows A and B show permissible limit of various parameters according to the WHO and BIS

A	**WHO**	**-**	**7-8.5**	**750**	**600**	**-**	**-**	**-**
B	**BIS**	**-**	**6.5-8.5**	**250-750**	**500**	**200**	**-**	**-**
Sample No.	Type	Temp(^{0}C)	pH ±SD	>EC(μS)	>TDS(ppm))	>Alk (ppm)	Turbidity	TSS
NTL-BS	LW	21.8	8.03	500	350	259.87	11.82	0.01
NTL-C	LW	20.5	8.05	510	351	258.45	11.66	0.008
NTL-TMP	LW	21.8	8.03	580	350	276.83	12.05	0.009
NTL-BN	DW	16.6	7.82	790	550	331.38	-	-
SP-SLD	SW	17.43	7.48	810	570	251.35	5.54	0.004
SP-ZP	SW	19.4	7.79	840	590	260.96	0.05	0
SP-SD	SW	17.1	7.29	630	440	271.7	-	-
SP-HGD	SW	20.1	7.83	420	290	245.28	-	-

Chemical parameters

Cations: Decreasing abundance of cations in the Nainital Lake water is Mg^{++}>Ca^{++}>Na^{++}>K^{++}.The sodium concentration ranges from 10.4 (NTL-TMP) to 11.4 ppm (NTL-BS) and calcium concentration varies from 37.31 (NTL-BS) to 38.84 (NTL-BS), a relatively higher Ca^{++} concentration is observed towards the temple side because of extra input of calcium from the big drainage (NTL-BN) which terminates near the temple with Ca^{++} concentration of 75.75 ppm. The Mg^{+} concentration varies from 46.25 to 48.29 ppm and K^{+} concentration varies from 3.76 to 4.03 ppm. The magnesium and potassium concentrations are found to be maximum towards the temple side resulting from an extra input of Mg^{++} and K^{++} from big drainage (NTL-BN) with Mg^{+} and K^{+} concentration 63.39 and 6.37 ppm respectively. The decreasing abundance of cations in spring water is similar to the lake water Mg^{++}>Ca^{++}>Na^{++}>K^{++}.SP-SD and SP-HGD are spring water originating from dolomitic horizons, whereas SP-ZP and SP-SLD are the spring water collected from marl horizons. The K^{+} in the spring water sample varies from 0.90 to 2.97 ppm and the Ca^{++} varies from

11.77 (SP-SLD) to 18.6 (SP-HGD) ppm, whereas, Mg^{++} varies from 41.42 (SP-HGD) to 127.03 ppm (SP-ZP). The Na^{+} and K^{+} concentration varies from 2.34 (SP-HGD) to 9.59 (SP-SD) and 0.9 (SP-HGD) to 2.97 ppm (SP-SD) respectively. The drainage water has the highest concentration of K^{+}, Ca^{++} and Na^{+} with corresponding values of 6.37, 75.75 and 24.42 ppm, while the concentration of magnesium is higher in the springs originating from marl horizons. All the water samples have higher concentration of Mg^{++} than the permissible limit of WHO and BIS.

Anions: The concentration of major anions in the water samples is significantly lower than the permissible limit of WHO and BIS suggesting that the waters quality in terms of anion concentration is acceptable. The decreasing anion concentration of the water sample is as follows SO_4^{-2}> NO_3^{-2}> Cl^{-1}>F^{-1}. The sulphate SO_4^{-2} ion is the most abundant anion in the samples; the lake water has SO_4^{-2} around ~104.23 ppm. The fluorine varies from 0.038 to 0.114 ppm. The nitrate NO_3^{-2} concentration in the lake water is around 5.89 ppm and the spring water shows nitrate concentration of ~5.25 ppm. The spring waters, SP-SLD and SP-ZP have somewhat higher sulphate concentration of 15.42 and 13.36 ppm. The spring water has nearly twice the chlorine content of that of the lake water, *i.e.,*2.48 ppm. Potential sources of NO_3 for the lake could be precipitation, surface runoff, sewage discharge, drain inputs, leaf litter etc. Table-3 shows the results of the chemical parameters and the Table-4 depicts WQI values and water quality.

Table-3: Chemical parameters of the water samples (measured values of cations and anions (in ppm) and their permissible limits as of WHO and BIS

WHO **BIS**	**75** **75**	**30** **30**	**200** **200**	**-** **-**	**-** **200**	**200** **250**	**250** **250**	**0.1** **-**	**1.5** **1.5**	**45** **50**
Sample No.	Ca	Mg	Na	K	Alk	SO_4	Cl	PO_4	F	NO3
NTL-BS	37.31	46.25	11.4	3.87	259.87	102.78	9.1	1.14	0.057	5.89
NTL-C	37.59	47.55	10.99	3.76	258.45	102.78	8.99	0.993	0.04	6.03
NTL-TMP	38.84	48.29	10.44	4.03	276.83	104.23	9.44	0.855	0.038	7.5
NTL-BN	75.75	63.39	24.42	6.37	331.38	139.38	18.78	0.475	0.209	18.42
SP-SLD	11.77	92.87	9.5	1.15	251.35	15.42	4.26	0.82	0.091	5.25
SP-ZP	11.77	127	2.15	1.66	260.96	13.36	4.26	0.79	0.084	7.25
SP-SD	16.67	54.73	9.59	2.97	271.7	94.04	9.41	0.95	0.076	8.25
SP-HGD	18.6	41.42	2.34	0.9	245.28	39.77	3.2	1.045	0.114	5.77

Pearson's Correlation

Pearson correlation coefficient (Table-5) was measured to understand the potency of a linear relationship between the measured water quality parameters and WQI. The positive and negative values denote positive and negative linear correlation respectively. The values close to 1 and -1 denote that the linear relationship is stronger.

Heavy metal determination

One sample from Tallital area (NTL-LKW) was also analyzed for heavy metal contamination using AAS to obtain heavy metal concentration in the lake water. Table-6 shows the parameters measured in this study. Except Pb, all other elements were found within the admissible limit as per the WHO and BIS.

Table-4: WQI values of Nainital Lake and spring water samples. Two popularly used water quality scales (Ramakrishnaiah *et al.,* 2009; Yadav *et al.,* 2010) are followed

	Water quality scale	Excellent	Good	Poor	Very poor	Unsuitable
WQI (values)	**Yadav *et al.* (2010)**	**0-25**	**26-50**	**51-75**	**76-100**	**>100**
	Ramakrishnaiah *et al.* (2009)	**< 50**	**50-100**	**100-200**	**200-300**	**>300**

Sample no.	Water type	WQI	Yadav *et al.* (2010)	Ramakrishnaiah *et al.* (2009)
NTL-BS	LW	91.72	Very poor	Good
NTL-C	LW	103.92	Unsuitable	Poor
NTL-TMP	LW	97.998	Very poor	Good
NTL-BN	DW	113.358	Unsuitable	Poor
SP-SLD	SW	104.633	Unsuitable	Poor
SP-ZP	SW	121.915	Unsuitable	Poor
SP-SD	SW	84.428	Very poor	Good
SP-HGD	SW	74.006	Poor	Good

Table-5: Pearson's correlation matrix of different parameters and WQI (the correlation is strongly positive if it is close to +1 and negative if it is close to -1)

	Ca	Mg	Na	Alk	SO_4	Cl	F	NO_3	pH	EC	TDS	WQI
Ca	1.000											
Mg	-0.384	1.000										
Na	0.892	-0.272	1.000									
Alk	0.855	-0.060	0.871	1.000								
SO_4	0.841	-0.657	0.787	0.690	1.000							
Cl	0.924	-0.307	0.945	0.935	0.882	1.000						
F	0.527	0.122	0.553	0.699	0.168	0.529	1.000					
NO_3	0.811	-0.009	0.815	0.975	0.588	0.877	0.829	1.000				
pH	0.459	-0.305	0.089	0.038	0.335	0.152	-0.209	-0.023	1.000			
EC	0.011	0.840	0.240	0.401	-0.274	0.166	0.418	0.417	-0.433	1.000		
TDS	-0.026	0.852	0.218	0.358	-0.313	0.135	0.455	0.398	-0.479	0.987	1.000	
WQI	0.253	**0.731**	0.290	0.401	-0.062	0.266	0.206	0.375	0.143	0.793	0.765	1.000

Table-6: Heavy metal parameters of the lake water (values of cations and permissible limits as per the WHO and BIS (in ppm)

WHO **BIS**	**1.5** **0.05**	**0.006** **0.02**	**-** **0.1**	**-** **0.03**	**0.05** **0.05**	**0.05** **0.05**	**-** **-**	**0.003** **0.01**	**-** **5**
Sample no.	Pb	Ni	Mn	Fe	Cu	Cr	Co	Cd	Zn
NTL-LKW	0.0695	0.0053	-0.0165	0.1187	-0.0005	-0.0249	0.0176	0.0071	0.0321

For calculating the HPI, Pb, Ni, Mn, Cr, Cu, Co, Fe, Ze, and Cd were analyzed. The weightage (Wi) was taken as the inverse of Si which is the WHO standard for drinking water (Prasad and Bose, 2001), Ii is the Iraqi standard (Edet and Offiong, 2002), and M is the measured value of metal concentration in µg/l. In Nainital Lake water, the HPI shows negative value which is less than the low threshold value of 50 as proposed by Dede *et al.* (2013). Our results indicate that the influence of the studied metals on the water quality is normal but individual level of lead is high.

Sample no.	HPI value
NTL-LKW	-7262.84

CONCLUSION AND RECOMMENDATIONS

As mentioned in the text, we used two widely used water quality rating, e.g., Ramakrishnaiah *et al.* (2009) and Yadav *et al.* (2010). Based on the physico-chemical parameters, water from location NTL-BN is found unsuitable (see Yadav *et al.,* 2010) for drinking purpose. The spring water at SP-SD has a poor water quality (*e.g.,* Yadav *et al.,* 2010). The water quality measured at location NTL-BN was unsuitable (see Sharma *et al*., 2005) for drinking use. Comparison of data with the WHO standards for drinking water indicates that most of the lake water is unsuitable for drinking purpose. Out of 8 water samples, 5 samples were found to show lower values of maximum permissible limit. All samples analyzed for nitrate concentration were found to have lower values than suggested by the WHO. The phosphate values are 10 folds larger in concentration than the suggested values by BIS or WHO, the phosphate in the lake water near bus stand and the SP-HGD spot are fairly high because of the fact that the algal dolomitic limestone contain higher phosphorous content upto~19% and the drain waters have high concentration of phosphate probably because of the anthropogenic influence.

In the study area, dominant hydrochemical facies is $MgHCO_3$ type which is probably because of the presence of limestone, dolomite and marl stone dominating rocks in the region. Most analyzed waters are highly alkaline in nature. This is most likely reason for the stable pH in the lake water. The spring waters are more turbid with more TDS and EC as compared to the lake water which is because of drainages and channels carrying suspended solid particles during rainfall. The WQI obtained from each location around the lake is mostly unsuitable as per the rating of Yadav *et al.* (2010) but is good and poor as suggested by Ramakrishnaiah *et al.* (2009).

Concentration of lead (Pb) in the Nainital Lake is higher than the permissible limit. The reasons for high lead content seem to be a result of the anthropogenic activity (boat repairing, painting etc.), open automobile workshops near the lake shore and lead-bearing minerals present in rocks of the catchment area. Most population burden in catchment area of Nainital Lake together with the non-scientific approaches to lake management is responsible for water quality degradation (Ali *et al.,* 1999). Steps should be taken to treat the flow through the Naina Devi drain to decrease the external pollutant loading. Such measures will stabilize the lake quality and decrease the rate of eutrophication (*e.g.,* Sumant *et al*., 2018). The lake is of paramount importance and precious to locals and tourists, and its conservation is invaluable. Due to rapid urbanization, it has now come under pollution and is on the way to losing its original characteristics. Therefore, continuous monitoring of the lake water is required particularly near the temples. To safeguard this water body, a judicious water management is required. The lake should be treated as an independent watershed of management and conservation. Several springs which existed on the surrounding hills of the lake until a few decades ago, are dying up fast, therefore, spring inventory around the town and recharge of groundwater must be taken into consideration by researchers and administrative authorities. The shore areas of the lake should be maintained in the natural state except for removal of dead and decaying vegetation. Initiation by citizens can revolutionize lake conservation as the lake has already suffered the urbanization. The Nainital town authorities should also ensure to keep boats in good repair to reduce the paint spill into the lake. Also, it is the liability of every inhabitant to keep the lake dirt free as it is the only source of our water consumption. Once the lake is polluted, there is hardly a way out.

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