

Major ion chemistry and control of weathering of Bhimtal Lake, Humaun Himalaya, India

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Abstract— The water chemistry of Bhimtal Lake revealed the dominance of Ca^{2+} and HCO_3^- ions. The lake water chemistry is controlled by the dominance of Ca-Mg silicate weathering (mainly pumpellyite and epidote-bearing rocks) supported by anthropogenic activity involving extensive road cutting and house holding activities, increased industrialization in the catchment area of the lake. On the basis of phosphate values, a transitional mesotrophic-eutrophic conditions exist in this lake. The observed chemical data of the Bhimtal Lake was used to predict the mineral assemblages in the carbonate and alumino-silicate system. It demonstrates that the calcite and dolomite are the possible minerals which are in equilibrium with the lake water system and that the lake water is in the range of stability of kaolinite.

Keywords, Bhimtal; anthropogenic; carbon dioxide pressure; photosynthesis; silicate weathering.

1 Introduction

The geochemical study of Bhimtal Lake (latitude $20^{\circ}20'19''$ N— $29^{\circ}21' 00''$ N and longitude $79^{\circ}33'30''$ E— $79^{\circ}34'25''$ E) was conducted during the onset spring season, 1991 to estimate the pollution levels and source of pollution in and around the lake. The Bhimtal Lake along with other famous lakes of the region viz. , Naintital, Naukuchiyayal, Sattal and so on, occupies an important position on the tourist map of India because of its scenic beauty, recreational features, healthy climate and most importantly as the source of drinking water supply to the local population. The area harboring the Bhimtal Lake is being developed and expanded as tourist complexes which necessarily involves a certain amount of interference with the lake ecosystem. In recent times, extensive road and house building activities on the slopes in the catchment along with increased industrialization have occurred causing large scale landslips from the slopes resulting in higher rate of sedimentation in the lake (Das, 1994).

However, no systematic study has been carried out so far to record the pollution levels and to discuss the ion chemistry and its relation to weathering processes which controls the water chemistry of the lake. Hence, in the present study an attempt has been made to discuss the source of various ions present, their relation to various weathering processes and to know the trophic condition of this lake.

2 Area of study

The Bhimtal Lake falls in the Lesser Himalayan zone of Kumaun which is situated between the River Satluj in the west and Kali River at the western border of Nepal in the east. It is located at 1356m above m. s. l. The lake is 1.8 km in length, 0.454km in width a mean depth of 26.5 m and a catchment area of 4.5 sq. km (Mathur, 1955). The shape of the lake is roughly triangular, the western limb being the largest and curves inwards (Fig. 1). The lake is being seasonally fed by a small stream known as the Nauli Godna flowing from the north west through treppe rocks. According to Thomas (1952), the Bhimtal Lake was formed by choking of river through landslips. The main geomorphological features around Bhimtal Lake are landslide deposits, debris flow type fans, alluvial fans, valley scarps and so on. The average annual rainfall around Bhimtal area is about 2000 mm. The lithology around the lake mainly belongs to Bhimtal formation consisting mainly of metabasites in association with metasedimentary formations. These predominantly consists of quartzites with subordinate grits, conglomerate and phyllites and are associated with prehnite-pumpellyite-metagreywacke facies and zeolite facies rocks grading into greenschist facies at places (Varadhrajan, 1974; Fig. 2).

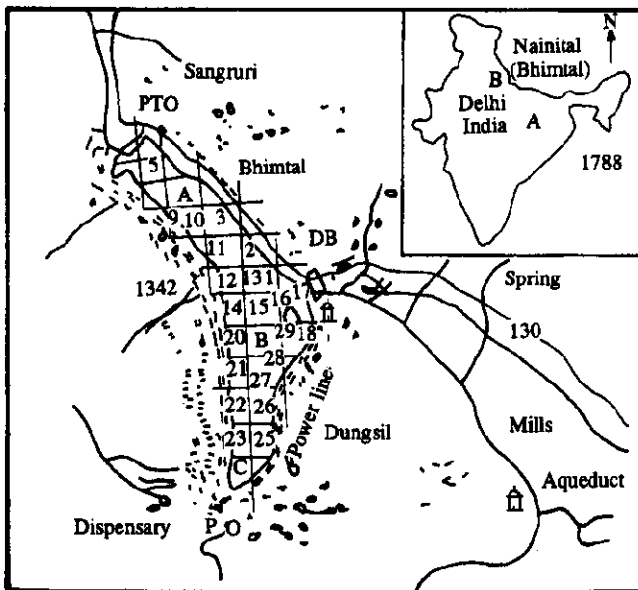


Fig. 1 Map showing the sampling points in Bhimtal Lake; Inset shows location of Bhimtal in India

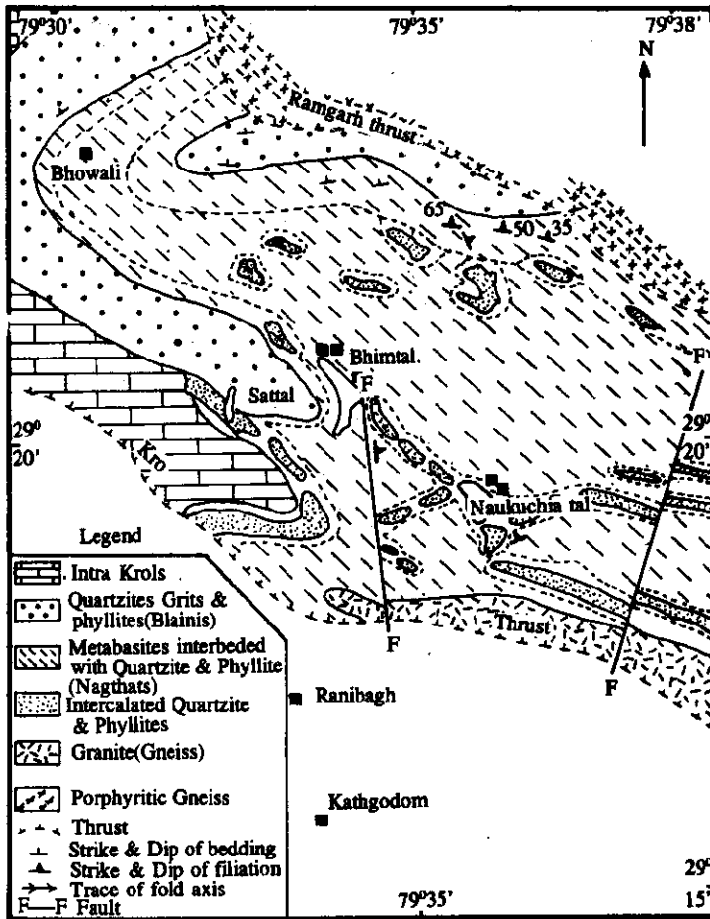


Fig. 2 Map showing lithological formations around Bhimtal Lake

3 Materials and methods

The water samples were collected from surface as well as from a depth of 5m in a frid pattern (Fig. 1), filtered using 0.45 micron filter paper and stored in polyethylene bottles. The determination of temperature, pH, electrical conductivity (E. C.), dissolved oxygen (DO) and total dissolved solids (TDS) were carried out at the site using portable field kit. The carbonate and bicarbonate were determined by acid titration; chloride by AgNO_3 titration; sulphate by titrimetric method using barium perchlorate after passing the samples through cation exchange resin; phosphate by ascorbic acid method using spectrophotometer; calcium and magnesium by EDTA titration; and sodium and potassium by flame photometry in the laboratory.

4 Results and discussion

The major ion chemistry data of the Bhimtal Lake are given in Table 1. The percentage of equivalent per million of the constituents in Bhimtal Lake is given in Table 2. The measured temperature of the lake was around 20°C. The Bhimtal Lake water is alkaline in nature (pH 8.54–9.10) and pH 7.87–8.96 in surface and depth water, respectively similar to most other Indian and world lakes (Table 3). The higher pH values reflects the ongoing photosynthetic activity which utilise CO₂ thereby shifting the equilibrium towards the alkaline side. The EC values recorded in surface and depth water of Bhimtal Lake are 181 and 182 µs/cm, respectively. These values are quite low as compared to Nainital (eutrophic) Lake (Singh, 1995) which is due to more resistant lithology around Bhimtal as compared to carbonate lithology around Nainital Lake and lesser precipitation and lesser influence of human activity in this area.

Table 1 Chemical characteristics of Bhimtal Lake, Kumaun Himalayas

Location																
No.	pH	EC	DO	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	PO ₄ ³⁻	SO ₄ ²⁻	SiO ₂ ⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	TH	TDS	TSM
Surface water																
1	8.84	180.2	7.3	6	122.5	6.39	0.0057	50	3.62	4.23	2.07	19.23	6.33	74.52	120	0.7
2	8.85	182.0	7.4	6	87.5	9.94	0.0060	36	3.51	4.23	2.07	17.63	8.27	78.61	110	1.6
4	9.10	177.4	8.2	12	87.5	5.68	0.0055	24	3.44	4.23	1.72	20.04	5.84	74.50	110	0.3
6	8.54	190.3	8.7	nil	87.5	7.81	0.0060	50	3.69	4.50	2.90	20.04	6.57	77.55	110	1.0
9	8.82	179.3	8.4	18	90	5.68	0.0060	63	3.50	4.23	2.07	20.44	5.60	73.50	100	1.2
10	8.94	183.8	8.4	24	88.5	5.68	0.0045	43	3.85	4.76	2.07	20.44	5.60	73.51	110	2.5
12	8.87	179.4	8.6	12	86.5	7.10	0.0080	30	3.86	4.23	1.74	17.63	10.22	86.74	110	1.3
13	8.92	182.0	9.6	nil	90	6.39	0.0110	76	3.92	4.50	2.07	22.44	7.30	87.40	110	6.5
14	9.04	191.1	8.3	nil	86.5	6.39	0.0078	24	3.88	4.50	2.07	22.44	7.30	87.40	110	6.5
16	8.97	182.2	8.6	24	102	7.10	0.0068	16.5	3.72	4.50	2.07	20.04	6.57	78.15	110	1.2
17	8.93	182.7	8.4	24	95	5.68	0.0055	39	3.65	4.50	2.07	19.23	7.30	79.29	110	6.1
18	8.81	182.6	8.1	nil	86.5	6.39	0.0055	43	4.00	4.23	2.07	21.04	5.84	77.69	110	3.9
19	8.85	179.1	10.1	nil	86.5	4.97	0.0068	43	3.69	4.50	2.07	19.63	6.08	75.14	110	1.1
20	8.90	177.5	9.6	12	87.5	6.39	0.0070	39	3.64	4.23	2.07	18.43	7.30	77.25	110	0.4
21	8.95	175.4	10.0	39	80	7.10	0.0115	30	3.88	4.50	2.07	19.23	5.84	73.12	100	1.2
22	8.86	182.5	8.6	6	95	6.39	0.0057	33	3.68	4.50	2.07	22.84	6.08	83.25	110	5.3
23	9.00	179.5	9.9	12	90	6.39	0.0060	36	3.59	4.23	2.07	18.03	7.30	76.74	110	1.2
24	9.00	174.6	8.1	30	91.5	5.68	0.0057	27	3.84	4.23	2.07	23.24	3.89	75.04	100	0.8
26	8.96	181.3	11.2	24	95	4.97	0.0080	19	5.90	4.50	2.07	18.43	8.27	81.33	110	4.0
27	8.92	175.2	11.0	nil	86.5	5.68	0.0060	19	3.69	4.23	2.07	19.63	6.33	76.20	100	0.8

Table 1 (continued)

Location																
No.	pH	EC	DO	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	PO ₄ ³⁻	SO ₄ ²⁻	SiO ₂ ⁻	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	TH	TDS	TSM
Depth water																
3a	7.87	199	8.0	24	82	7.10	0.0122	43	5.26	4.50	2.07	22.44	6.81	84.43	120	0.7
5a	8.65	190.7	8.9	nil	107.5	7.10	0.0057	42	3.62	4.76	2.29	22.44	6.81	84.43	120	1625.8
7a	8.78	198.1	9.0	18	90	6.39	0.0080	33	3.60	4.76	2.29	22.44	4.87	84.43	120	492.8
8a	8.72	181.6	9.2	12	87.5	7.10	0.0057	36	3.28	4.50	2.09	22.44	4.87	76.07	110	121.6
11a	8.68	180.3	9.0	nil	107.5	6.39	0.0070	27	3.84	4.76	2.07	19.23	6.81	76.52	110	124
14a	8.83	187.8	9.2	18	95	6.39	0.0068	36	3.59	4.50	2.07	20.04	6.81	78.58	110	7.3
15a	8.94	178.4	9.0	12	90	5.68	0.0060	43	3.59	4.50	2.07	17.63	7.79	76.57	110	2.4
16a	8.88	178.7	9.6	nil	86.5	6.39	0.0068	43	3.82	4.50	2.07	20.04	5.84	74.57	110	2.4
17a	8.93	177.3	9.8	nil	90	7.10	0.1960	43	3.53	4.76	2.07	20.84	7.06	81.58	110	2.2
21a	8.96	177.5	10.3	12	86.5	7.10	0.0390	27	3.64	4.76	2.07	20.04	6.08	75.07	110	1.6
23a	8.82	173.5	10.2	nil	87.5	6.39	0.0110	30	3.64	4.76	2.07	23.24	4.13	75.07	100	1.2
25a	8.90	173.6	11.8	nil	102	7.81	0.0120	33	3.74	4.50	2.07	20.04	6.33	76.57	100	1.8
28a	8.85	173.9	10.3	18	86.5	7.10	0.0078	13	3.48	4.50	2.07	19.23	6.33	74.42	100	2.4

Notes: Location number are illustrated on the map of Lake Bhimtal EC= electrical conductivity; DO = Dissolved oxygen; TH = Total hardness; TDS = Total dissolved solids; TSM= Total suspended matter.

Table 2 Percentage of equivalent per million of the constituents in Bhimtal Lake

Location No.	Cations			Anions		
	Ca ²⁺	Mg ²⁺	(Na ⁺ +K ⁺)	(CO ₃ ²⁻ +HCO ₃ ⁻)	SO ₄ ²⁻	Cl ⁻
1	55.72	30.56	13.72	62.19	32.25	5.56
2	48.76	38.12	13.12	58.21	30.43	11.36
4	58.37	28.36	13.28	68.48	23.87	7.65
6	55.08	30.09	14.83	53.19	38.65	8.16
9	59.22	27.04	13.74	50.13	44.45	5.42
10	58.48	26.66	14.86	57.86	35.76	6.38
12	44.93	43.43	11.64	63.21	27.88	8.91
13	51.83	34.20	13.97	45.55	48.88	5.57
14	56.69	30.73	12.58	67.58	23.85	8.57
16	55.74	30.44	13.82	75.48	15.50	9.02
17	52.87	33.45	13.68	61.55	32.12	6.33
18	59.26	27.40	13.34	56.86	35.92	7.22
19	56.51	29.17	14.32	57.78	36.52	5.70
20	52.15	34.43	13.42	59.09	33.48	7.43
21	56.68	28.67	14.65	61.38	29.26	9.36
22	60.19	26.70	13.11	64.23	28.35	7.42

Table 2 (continued)

Location No.	Cations			Anions		
	Ca ²⁺	Mg ²⁺	(Na ⁺ +K ⁺)	(CO ₃ ²⁻ +HCO ₃ ⁻)	SO ₄ ²⁻	Cl ⁻
23	51.62	34.82	13.56	66.96	22.62	6.42
24	67.44	18.82	13.74	67.49	25.32	7.19
26	49.56	37.06	13.38	74.39	18.93	6.68
27	56.21	30.21	13.58	71.84	20.05	8.11
3a	57.87	29.27	12.86	66.05	27.78	6.17
5a	57.38	29.02	13.60	62.63	30.26	7.11
7a	56.80	28.73	14.47	70.40	23.48	6.12
8a	63.14	22.83	14.03	65.82	26.98	7.20
11a	53.74	31.72	14.54	70.40	22.40	7.20
14a	55.16	31.17	13.67	69.80	24.36	5.84
15a	49.54	36.48	13.98	64.04	30.48	5.48
16a	57.72	27.97	14.31	57.42	35.76	7.22
17a	55.12	31.12	13.76	57.20	34.99	7.81
21a	56.65	28.64	14.71	70.54	21.71	7.75
23a	65.79	19.48	14.73	64.12	27.81	8.07
25a	56.40	29.63	13.97	64.98	26.46	8.56
28a	55.33	30.35	14.32	81.91	9.98	8.11

a=depth water

Table 3 Average chemical composition of Bhimtal Lake composed with other fresh water lakes

Lake	pH	EC, μs/cm	TDS	Na ⁺ , mg/L	K ⁺ , mg/L	Ca ²⁺ , mg/L	Mg ²⁺ , mg/L	Cl ⁻ , mg/L	HNO ₃ ⁻ , mg/L	SO ₄ ²⁻ , mg/L	SiO ₂ ⁻ , mg/L	PO ₄ ³⁻ , mg/L
Bhimtal ¹												
a	8.90	181	108	4.38	2	20	6	6.39	91	37	3.82	0.006
b	8.75	182	110	4.62	2	21	6	6.38	92	35	3.74	0.025
Nainital ²												
a	8.66	706	440	13	3.63	33	55	15	350	98	3.44	0.125
b	8.20	680	437	13	3.86	27	63	15	369	103	3.10	0.174
Pichola ³												
a	9.01	678	430	73	4	22	21	73	235	35	5	0.103
b	8.90	667	424	76	4	22	20	73	239	27	4	0.107
Naukuchiyatal ⁴												
a	9.40	125	81	4	1	15	5	6.77	74	16	6.34	0.006
b	8.54	155	88	4	1	18	5	6.67	78	16	7.92	0.011
Sattal ⁴												
a	9.66	119	62	3	0.72	11	5	7.33	54	19	5.59	0.007

Table 3 (continued)

Lake	pH	EC, µs/cm	TDS	Na ⁺ , mg/L	K ⁺ , mg/L	Ca ²⁺ , mg/L	Mg ²⁺ , mg/L	Cl ⁻ , mg/L	HNO ₃ ⁻ , mg/L	SO ₄ ²⁻ , mg/L	SiO ₂ ⁻ , mg/L	PO ₄ ³⁻ , mg/L
	b 8.01	116	63	3	0.83	11	5	7.20	61	13	5.79	0.009
Nilnag ⁵	nd	230— 370	nd	2.7— 4.6	0.4— 1.0	27— 39	5— 7.1	5—7	nd	6.5— 8.5	nd	nd
Victoria ⁶	7.8	97	nd	9	4.1	3.9	2.7	3	nd	2.5	6.7	nd
Ontario ⁷	nd	nd	nd	12.2	1.44	42.9	6.4	26.7	115	27.1	nd	nd

Notes: a = surface water; b = depth water; 1 = present work; 2 = Singh and Das, 1995; 3 = Das and Singh, 1995; 4 = Singh, 1994; 5 = Khan and Zutshi, 1980; 6 = Visser and Villeneuve, 1975; 7 = Burgis and Morris, 1987.

Bicarbonate is the major anion in the lake water with an average contribution of 62% and 63% to the total anions in surface and depth water, respectively. The soil zones beneath the lakewater body contains elevated CO₂ pressure formed as a result of decay of organic matter and root respiration (Black, 1957) which combines with rain water to form bicarbonate by the following reactions:



Sulphate is next in abundance followed by chloride. The low chloride values are due to the fact that the Bhimtal Lake lie far away from the sea and as such precipitation or dry fall-out does not have significant effect on lake water. Among the cations, calcium is the most dominant followed by magnesium, sodium and potassium which is consistent with the general trend in most of the world fresh water body. The dominance of calcium in the lake water is mainly due to the leaching of pumpellyite and epidote rich rocks present in the surrounding areas.

Phosphate is the most limiting factor for primary production in most fresh water environments. The eutrophication of lakes caused by phosphorus influx to the land-locked aquatic system has also been the subject of extensive studies (Vollenweider, 1968; Ahl, 1980). The average phosphate values in the surface and depth water of Bhimtal Lake are about 7 and 25 µg/L. However, the phosphate content at location point 17a is 196 µg/L which is due to the sewage discharge from the restaurant situated on the island near this location point (Fig. 1) in the lake water. This lake is therefore in the transitional phase of mesotrophic to eutrophic condition and may result in growth of aquatic plants like algae, photoplankton etc. reducing the dissolved oxygen content and consequent release of toxic elements to the water body (Dillon, 1975). The dissolved silica in surface (3.44–5.90 mg/L) as well as in depth (3.28–5.26 mg/L) water of Bhimtal Lake is higher than the Nainital Lake (Singh, 1995). Thus, in Bhimtal Lake the higher dissolved silica values are due to lower phosphate loading which controls the silica consuming diatom population as reported in a number of other lakes

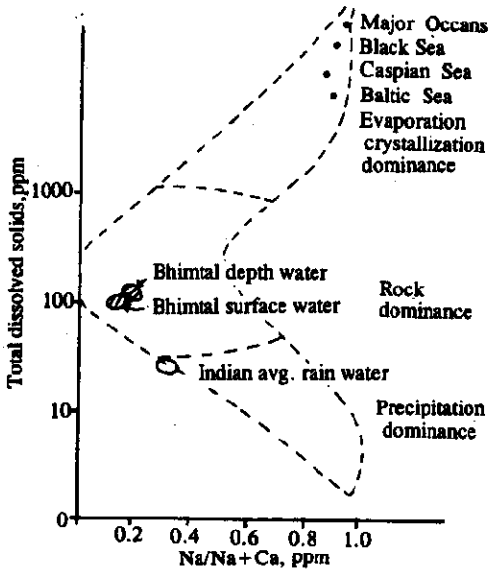


Fig. 3 Plot of $\text{Na}/(\text{Na} + \text{Ca})$ vs. TDS of Bhimtal Lake water on Gibb's (1970) diagram

(Schelske, 1988; Stumm, 1981).

The dominance of bicarbonate and calcium among anions and cations suggest that the Bhimtal Lake is of Ca-HCO_3 type. Further, the water chemistry of the Bhimtal Lake is controlled by rock weathering which is evident by placing it within the envelope of world water chemistry diagram developed by Gibb's (1970; Fig. 3). The average $\text{Ca} + \text{Mg}/\text{Tz} +$ ratio of 0.86 for both surface and depth water indicates a strong influence of alkaline earth silicates (mainly pumpellyite and epidote-bearing rocks) in controlling the distribution of cations in lake water system.

The partial carbon dioxide pressure was computed in the lake water body to study its effect on the mineral saturation, mainly calcite and dolomite. The computed PCO_2 and saturation indices

values for calcite (SIc) and dolomite (SI_d) are given in Table 4. The average PCO_2 of -3.86 and -3.70 atmosphere in surface and depth waters are lower than the average atmospheric values of -3.5 atmosphere (Wigley, 1973). The lower PCO_2 values are due to photosynthetic activity which consumes large quantities of CO_2 and since the exchange equilibrium of atmospheric CO_2 with water is a very slow process, depletion of CO_2 occurs and this could lead to supersaturation of calcite in lake water (Stumm, 1981). The SIc vs SI_d plot (Fig. 4a) shows that the lake water is supersaturated with respect to both calcite and dolomite at almost all the location points of the lake. The intense photosynthetic activity occurring in the lake and subsequent depletion of CO_2 may have resulted in supersaturation of calcite in lake. The plot of K- and Na- silicate systems (Garrels, 1965) shown in Fig. 4b and Fig. 4c demonstrates that both the surface and depth water of Bhimtal Lake are in the range of stability field of kaolinite which implies that the chemistry of water is favoring kaolinite formation. The diagram delineates the stability fields of clay minerals which co-exist in the sediment phase at a constant composition of water during the chemical reaction of the rock and water.

It is also evident that the formation of kaolinite rather than gibbsite (Fig. 4b and c) represent less rapid flushing where less silica is removed during weathering and therefore $[\text{H}_4\text{SiO}_4]$ is increased (Table 1). However, the non-conservative behavior of silica in lake water, resulting from biological removal as is the case in Bhimtal Lake may lead to inconsistency between water chemistry and clay mineral data which needs to be studied in detail. Therefore, by studying the water chemistry stable mineral assemblages can be predicted.

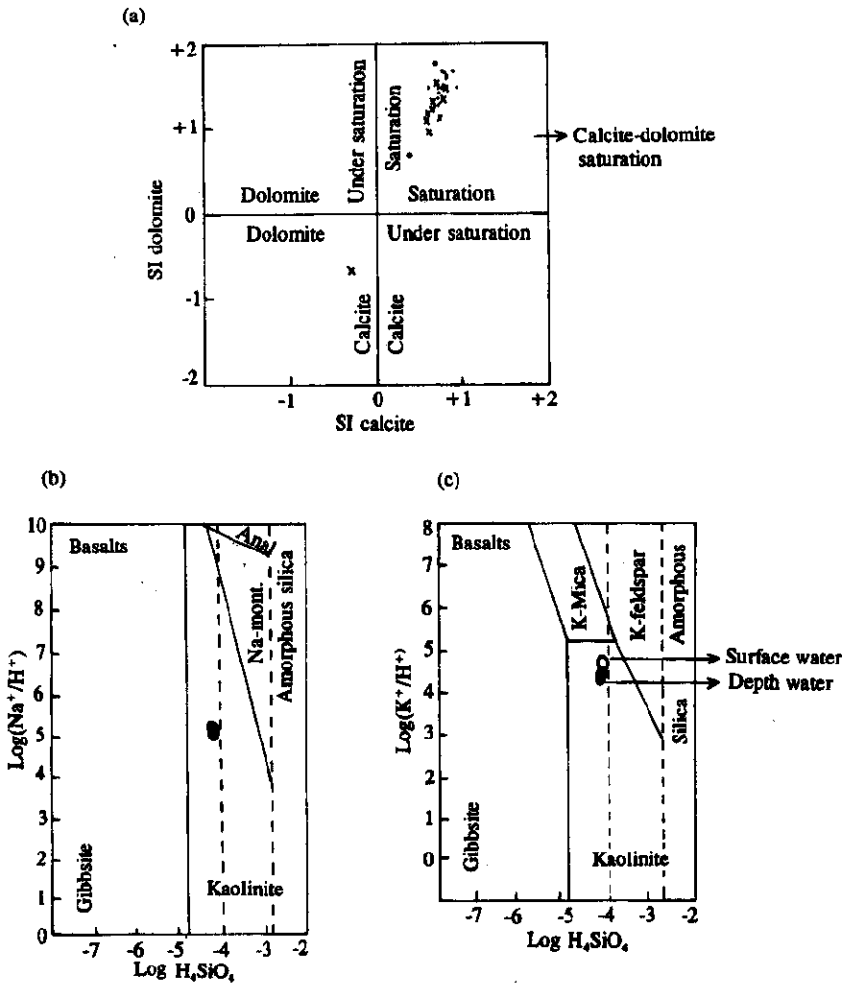


Fig. 4 Plot of surface and depth water of Bhimtal Lake on (a) carbonate equilibria diagram (solid dot surface water, cross depth water samples) and (b, c) silicate equilibria diagram

Table 4 Log PCO_2 , saturation indices values for calcite dolomite in surface and depth water of Bhimtal Lake

Location No.	Log pCO_2	SIc	SI d
Surface water			
1	-3.67	+0.78	+1.50
2	3.82	+0.62	+1.33
4	-4.12	+0.92	+1.73
6	-3.51	+0.36	+0.66
9	-3.78	+0.65	+1.16
10	-3.91	+0.77	+1.39
12	-3.84	+0.63	+1.45
13	-3.88	+0.72	+1.44

Table 4 (continued)

Location No.	Log pCO ₂	SIc	SI _d
14	-4.01	+0.71	+1.36
16	-3.87	+0.86	+1.66
17	-3.87	+0.76	+1.42
18	-3.78	+0.65	+1.17
19	-3.92	+0.67	+1.25
20	-3.87	+0.68	+1.38
21	-3.96	+0.77	+1.32
22	-3.79	+0.77	+1.39
23	-3.96	+0.79	+1.60
24	-3.95	+0.90	+1.45
26	-3.89	+0.78	+1.64
27	-3.89	+0.74	+1.41
Depthwater			
3a	-2.87	-0.30	-0.69
5a	-3.54	+0.59	+1.09
7a	-3.79	+0.66	+1.22
8a	-3.69	+0.59	+0.94
11a	-3.56	+0.58	+1.13
14a	-3.77	+0.68	+1.31
15a	-3.90	+0.71	+1.49
16a	-3.85	+0.70	+1.29
17a	-3.89	+0.78	+1.43
21a	-3.93	+0.78	+1.37
23a	-3.79	+0.72	+1.11
25a	-3.80	+0.79	+1.50
28a	-3.82	+0.66	+1.26

5 Conclusions

The chemical composition of the lake water is dominated by calcium and bicarbonate ions;

The excess of Ca, Mg to that of Na, K in lake water is due to the dominance of Ca-Mg silicate weathering in the catchment which controls the water chemistry of the lake;

The phosphate values indicates contribution from anthropogenic activity and as such transitional mesotrophic-eutrophic condition has developed in the lake;

The chemical composition of the lake water demonstrates that it is in equilibrium with calcite and dolomite and lies in the stability field of kaolinite.

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References

- Ahl T. *Proceedings Water Tech*, 1980;12:49
- Black CA. *Soil plant relationships*. New York; Pub Wiley and Sons, 1957
- Burgis MJ, P Morris. *The natural history of lakes*. Cambridge University Press, 1987
- Das MK, M Singh, MD Borkar. *Environmental Geology*, 1994; 23(2):114
- Das BK, M Singh. *Environmental Geology*, 1995(in press)
- Dillon PJ, FH Rigler. *J. Fisheries Res Board of Canada*, 1975; 32:1519
- Garrels RM, CL Christ. *Solutions, minerals and equilibria*. New York; Harper and Row, 1965
- Gibbs RJ. *Science*, 1970; 170:1088
- Khan MA, DP Zutshi. *Hydrobiologia*. 1980; 75:103
- Mathur SM. *Qurt J Geol Min Metal Soc India*. 1955; 27:175
- Schelske CL. *International Revue der Gesamten Hydrobiologie*, 1988; 73(5):559
- Singh M. *Environmental geochemical study of pollution in lakes of Nainital district, Kumaun Himalaya, India*. Ph. D. Thesis (unpublished). 1994
- Singh M, BK Das. *Indian Geol Association*, 1995; 28(1)
- Stumm W, JJ Morgan. *Aquatic Chemistry*(2nd ed.). New York; John Wiley, 1981
- Thomas AN. *Geological Magazine*, 1952; 89:385
- Varadhrajan S. *Himalayan Geology*, 1974; 4:581
- Visser SA. *JP Villeneuve, Verhandlungen internationale vereinigung fur theoretische und angewandte limnologia*, 1975;19: 1416
- Vollenweider RA. *Scientific fundamental of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication*, Paris, Organic, Econ Dev Directorate of Sci Africa, 1968
- Wigley TML. *Geochim Cosmochim Acta*, 1973; 37:1397

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