Study of the interconnection between a lake and surrounding springs using environmental tracers in the Kumaun Lesser Himalayas

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Abstract The interconnection between Lake Nainital, located in the Kumaun Lesser Himalayas, and the springs issuing in the vicinity of the lake, was investigated using hydrochemistry. The lake water and most of the downstream springs have a high concentration of $MgHCO_3$. Although, the downstream springs that issue in the Kailakhan area southwest of the lake are dominated more by $MgSO_4$, $\delta^{18}O$ data confirmed the interconnection between the lake and the springs. The springs in the Balia ravine located south of the lake are also dominated by $MgHCO_3$. However, the springs located in the area to the west of the lake are not hydrologically connected to the lake, as deduced from the stable isotope data. Based on the vertical profiles of the water chemistry and isotopic composition of the lake, we hypothesize that the leakage from the lake takes place from the epilimnion zone. The study highlights the usefulness of stable isotope data combined with water chemistry in identifying recharge sources.

INTRODUCTION

Seasonally stratified Lake Nainital (29°23′09″N and 79°27′35″E) has a surface area of 0.46 km^2 and mean depth of 18.5 m. It is located at an altitude of 1937 m a.m.s.l. in the Kumaun Lesser Himalayas and is surrounded by many freshwater springs (Fig. 1). The lake basin is made of folded and faulted rocks of Krol and Tal formations of Cambrian age (Valdiya, 1988). A few of the springs located south of the lake in the Balia ravine, have significantly large discharges. To date, no study has been able to investigate if these springs are connected to Lake Nainital through interconnected fractures using conventional hydrological data (e.g. such as lake level, rainfall and spring discharge (Hukku *et al.*, 1968)). In this paper we hypothesize that the springs issuing in the area west and also southeast of the lake basin, at a lower altitude than Lake Nainital, might have the lake as their source.

MATERIALS AND METHODS

The water quality of Lake Nainital was monitored during different seasons between 1994 and 1996. The samples from the lake were collected using a standard depth water sampler. The samples collected for water quality investigation were preserved following standard procedures (Appello, 1988) and were analysed using standard procedures (National Institute of Hydrology, 1987). The electro-neutrality as well as

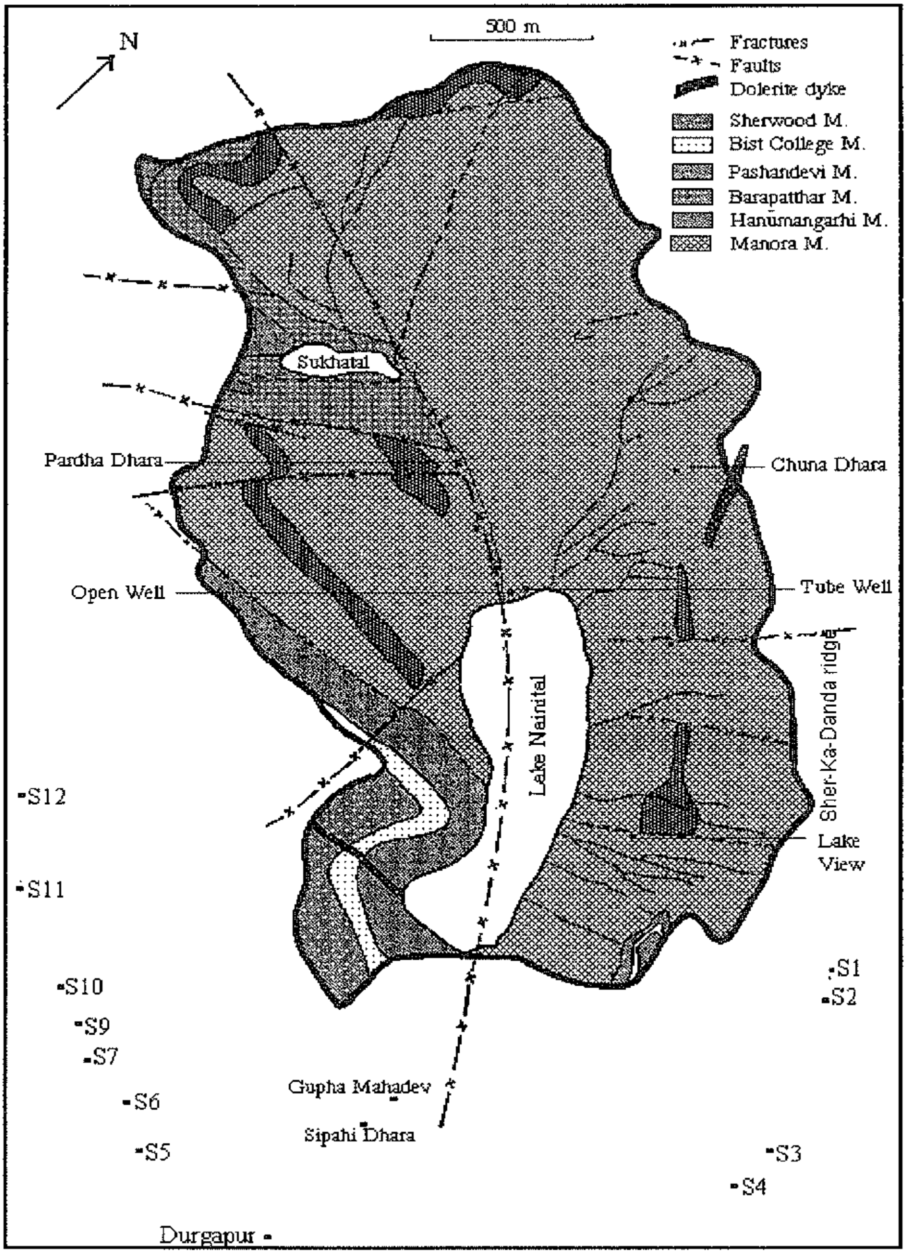

Fig. 1 Geological map of Lake Nainital basin, also showing locations of downstream springs (modified after Valdiya, 1988).

repeat analyses of samples used for ascertaining laboratory analytical efficiency indicate that the analytical errors are within 5%. The samples for stable isotope were collected in 20 ml plastic vials and tightly sealed, and were analysed at the Stable Isotope Ratio Mass Spectrometer facility at the Isotope Division, Bhabha Atomic Research Centre, Mumbai, India. The samples were analysed using the CO_2

equilibration method for $\delta^{18}O$ (Navada & Kulkarni, 1989). The measurement precision for $\delta^{18}O$ was 0.1‰. All the isotope data reported correspond to Vienna—Standard Mean Ocean Water.

DISCUSSION

The quality of water sampled from Lake Nainital and the springs is shown in Table 1. Calcium and Mg are the major cations and HCO_3 is the major anion in all the springs and the lake. This appears to be due to the geological formations that characterize the lake basin (Fig. 1). However, in certain springs (S3, S4, Durgapur etc.) sulphate is the major anion, as they are issuing from the pyritiferous shales that characterize the area west of the lake. In the case of S12, the gypsum deposit of the Nehal Nadi appears to control the chemistry. Concentrations of sodium, potassium and chlorine are low in all the natural waters in the study area. When sulphate concentrations are plotted against the more conservative chlorine (Fig. 2), the values for Lake Nainital and the downstream springs are clustered.

In order to complement the information obtained through the hydrochemical analyses, stable isotopic investigations were carried out (Table 2). During winter, when the lake is well mixed, the Gupha Mahadev spring shows an $\delta^{18}O$ value (–9.5‰) close to that of the Lake (–9.6‰). However, springs S2, S3 and S4 in the Kailakhan area show a comparatively heavier $\delta^{18}O$ (–7.0‰ to –7.5‰). Since, the lake has an $\delta^{18}O$ value of about –7‰ during July–August, the enriched values in the Kailakhan springs suggest the possibility of leakage from the lake and a travel time of 4–5 months. If the waters that issue from springs S3 and S4 are considered as leakage from Lake Nainital, then the change in water type from magnesium bicarbonate to magnesium sulphate could be ascribed to the long travel time and contact with the highly shattered pyritiferous shales. The springs S1, S6, S7, S9, S10, S11 and S12 are not connected to the lake, as their $\delta^{18}O$ values (–10.2‰ to –11.8‰) are depleted compared with lake values (–5‰ to –9.6‰).

Table 1 Physico-chemical characteristics of Lake Nainital and the springs issuing in the vicinity of the lake. Electrical conductivity (EC) in μmho cm^{-1}, temperature in °C, and all concentrations are in mg l^{-1}.

Source	Location	Type	pH	EC	Temp.	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-
Lake (May)	Epilimnion	$MgHCO_3$	7.9	571	20.8	36	49	11.3	4.6	210	97	14
Lake (May)	Mesolimnion	$MgHCO_3$	7.5	642	9.1	41	57	10.8	4.7	253	94	11
Lake (May)	Hypolimnion	$MgHCO_3$	7.4	645	8.6	42	58	10.0	4.6	249	92	13
Lake (Dec.)	Mean	$MgHCO_3$	8.1	475	9.8	54	56	7.3	4.7	283	80	13
Spring	S3	$MgSO_4$	7.6	885	nd	39	62	32.0	2.5	187	192	12
Spring	S4	$MgSO_4$	8.2	475	nd	54	41	32.0	1.8	86	140	13
Spring	S5	$CaHCO_3$	8.1	288	nd	34	20	6.4	0.7	174	25	-
Spring	S9	$MgHCO_3$	7.9	562	nd	55	52	5.2	1.7	268	61	10
Spring	S12	$CaSO_4$	8.3	1066	nd	129	66	8.4	4.8	208	267	10
Spring	Durgapur	$MgSO_4$	8.0	775	nd	52	63	5.8	6.7	164	180	12
Spring	Sariyatal	$MgHCO_3$	7.4	586	nd	74	57	2.0	1.5	249	91	10
Spring	Rais Hotel	$MgHCO_3$	nd	657	nd	45	53	14.8	5.5	250	118	26
Spring	Sipahidhara	$MgHCO_3$	8.3	434	nd	49	49	4.6	3.2	288	122	10
Spring	G. Mahadev	$MgHCO_3$	8.3	468	nd	47	57	4.3	2.9	280	75	16

nd: not determined

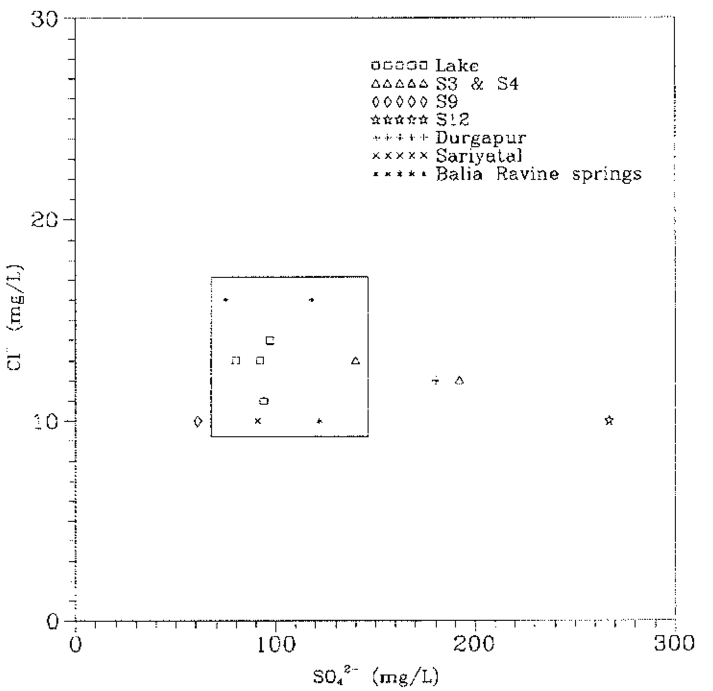

Fig. 2 Sulphate–chlorine cross plot of Lake Nainital and downstream springs.

The inference that Gupha Mahadev spring and Sipahidhara spring are connected to the lake through lineaments, is substantiated by the chemical concentrations. When total cation (TZ^+) values of different springs are normalized to that of Lake Nainital, Sipahidhara spring shows little variation with time in comparison to the upstream springs and wells located within the lake basin. This indicates that the lake is the only source for the Sipahidhara spring and the local groundwater has little influence on the chemistry of the spring. Comparison of ion concentrations of the series of springs (around Sipahidhara and Gupha Mahadev located in the Balia ravine) to the vertical concentration profile of the lake, indicates that these springs receive water from the epilimnion zone of the lake.

Table 2 Stable isotope concentration and altitude of downstream springs issuing in the area surrounding the Lake Nainital basin. Springs sampled during December 1994. The lake was sampled during all seasons, and the most depleted and most enriched values observed in the lake during 1994–1996 are presented.

Location	Altitude (m a.m.s.l.)	$\delta^{18}O$ (‰)	Location	Altitude (m a.m.s.l.)	$\delta^{18}O$ (‰)
S1	1850	−10.6	S9	1760	−10.7
S2	1790	−7.5	S10	1760	−10.2
S3	1730	−7.4	S11	1650	−10.9
S4	1720	−7.0	S12	1700	−10.7
S5	1730	−7.7	G. Mahadev	1785	−9.5
S6	1750	−11.0	Lake Nainital	1940	−5.2 to −9.6
S7	1640	−11.8			

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