Hydrological Status of Western Himalayas Lakes using Stable Isotopes

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ABSTRACT

In the present paper, results of isotopic investigations of two Western Himalayas lakes i.e., Nainital (located in Uttarakhand) and Mansar lake (located in Jammu and Kashmir) are discussed. The $d^{18}O$ and dD composition of the local precipitation, springs, hand pumps and lakes are used to study the hydrological behaviour of lakes. The slope of Local Meteoric Water Lines (LMWL) in both the study area is found very close to that of the Global Meteoric Water Line. In case of Nainital Lake, isotopic signatures of all the samples fall on the LMWL while Mansar Lakes' samples fall below the LMWL. Therefore, Mansar Lake isotopic signatures show considerable evaporative enrichment of lake water. However, samples from epilimnion zone of Nainital Lake show the evaporation trend but evaporative enrichment is insignificant because all the samples from Mesolimnion and hypolimnion fall on LMWL. This is due to substantial subsurface inflow and shorter retention time of the lake. In contrast, Mansar Lake bears isotopic signatures of evaporated water from epilimnion to hypolimnion which clearly indicate that subsurface inflow to lake is very poor and water retention period is comparatively higher. The change of composition of oxygen and hydrogen isotope from epilimnion to hypolimnion region in a lake reveals the status of interaction of lake water with groundwater regime in the lake catchment and water retention period, which is very useful to know the status of hydrological conditions of the lake.

INTRODUCTION

A large number of natural lakes in Himalayas are famous for their picturesque view and most of them are utilised for drinking and irrigation purposes. For example, Nainital, Dal, and Mansar Lakes are used to meet out the drinking water supply to the respective cities. Lakes are important in maintaining hydrological, ecological and environmental balance of the region. However, the increasing anthropogenic activities in recent years have greatly affected the hydrological regime of the lakes in the country and inflow of eroded material and other contaminant from the lake catchment have accelerated eutrophication process and rate of sedimentation (Ishaq and Kaul, 1988: Zutshi, 1985). This higher rate of sedimentation has diminished the useful life of several small lakes within the country and others are shrinking at alarming rate due to accelerated sedimentation. Hence, knowledge of hydrological conditions of these lakes become utmost importance for appropriate management of lakes and future planning. Physicochemical and biological characteristics of various lakes in the Himalayas have been studied (Zutshi *et al.*, 1972, 1980; Kaul, 1977; Zutshi and Khan, 1977; Pant *et al.*, 1985; Trisal, 1987; Gopal and Zutshi, 1998; Kumar *et al.*, 1999a; Rai et al. 1998, 2002, 2006 and 2007) in detail. However, complete water balance studies of any Himalayan lakes are not reported using conventional techniques only some parameters of lake water balance have studied. In Indian Himalayas, Nainital Lake is first example where all the parameters of lake water balance have been estimated using isotopic techniques (Kumar et al., 1999; Nachiappan, 2002). The complete water balance of any lake reveals the hydrological status of the lakes. In the present study, isotopic composition of Mansar lake has been compared with the Nainital lake isotopic composition to understand the hydrological status of Mansar lake.

STUDY AREA

The Nainital Lake is located in the southern fringe of the Lesser Himalayas in Kumaun region of Uttaranchal (Fig. 1). The Lake is surrounded by in hills which encompass a rock succession that includes 1,800-2,000 million years old granites and the sediments, which range in age from 1,600 to 500-600 million years and have thrusted over the very young 2-20 million yr – old Siwaliks along the Main Boundary Thrust (MBT). The MBT is tectonically very active and is manifested in large scale hillside instability in the region (Valdiya, 1988). The lithology around Nainital consists of carbonate rocks, calcareous slates, argillaceous limestones, ferrugious shales, algal dolomites, black shales with marlite, greywacke, siltstones etc. of the Krol Formation (Permo-Triassic). Among all the Kumaun lakes, the Nainital is one of the major tourist places of Uttaranchal. Since the 1980s, increased local population pressure and tourist traffic resulted in a sudden spurt in construction activity and unplanned development of infrastructure facilities at Nainital to cater to the demands of the tourist as well as the local population. This has resulted in rapid degradation of the lake environment.

The Mansar Lake is located in outer Himalayas of Western Himalayan region. It is situated 60 km east of Jammu city at elevation of 666 m a.m.s.l in Siwalik Himalayas of Jammu region. Mansar has been developed as tourist spot in the Jammu region due to its natural beauty. Geologically, the Mansar Lake catchment is composed of fine-grained sandstone alternating with siltstone, mudstone and clay of the Lower Siwalik (Fig 1). Mansar Lake is located at the crestal part of the WNW-NW to ESE-SE trending sub-horizontal anticlinorium. Associated with upright fold plunging 5° towards S52°E, the NNE-SSW trending faults have displaced the anticlinorial axes at several places (Singh and Sharma, 1999) and are responsible for the fragile nature of the Lower Siwalik. The detailed morphometric features of Nainital and Mansar Lakes are presented in table 1.

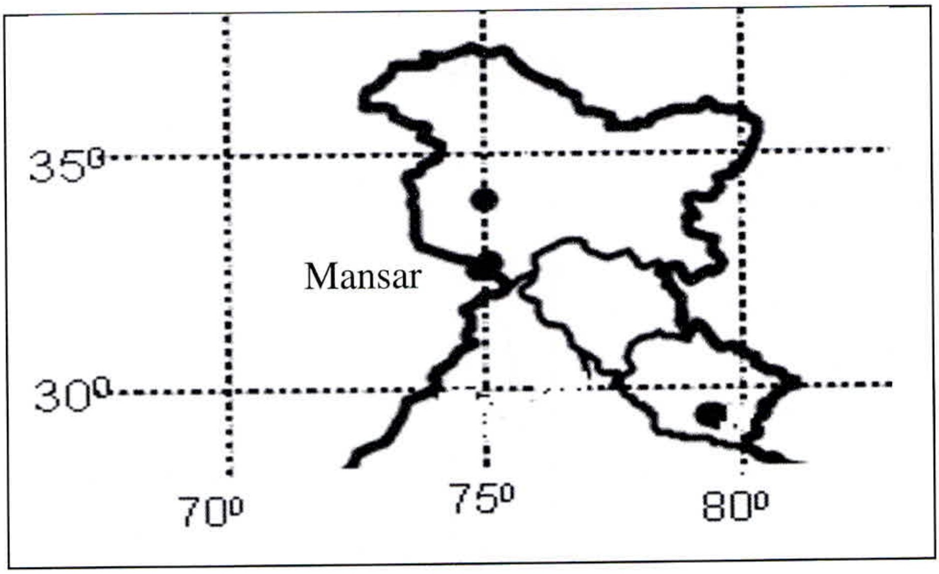

Fig. 1: Location of Mansar and Nainital lakes in Western Himalayas.

Table 1: Morphometric features Nainital and Mansar lakes.

Features	Mansar	Nainital
Height amsl. (m)	666	1937
Latitude	$32^0$40' N	$29^0$24' N
Longitude	75^0 5' E	79^0 28'E
Surface Area (km^2)	0.59	0.46
Max. Length (m)	1204	1400
Max. Width (m)	645	450
Mean Depth (m)	21	16.2
Max Depth (m)	38.25	27.3
Total Vol. (Mm^3)	12.37	8.58
Catchment Area (km^2)	1.67	4.7
Av. Rainfall (mm)	1500	2488
Av. Temp (^{0}C)	32	20
Winter Av. Temp. (^{0}C)	11	5
Shape of Lake	'C' Type	Crescent shape

METHODOLOGY

In order to assess the lake water isotopic composition, samples were collected from different locations in the lakes at different depth intervals. To characterise groundwater, samples were collected on seasonal and monthly basis from various handpumps and springs located nearby the lake, within the lake catchment or outside the lake catchment. Water samples were collected in pre-cleaned 60 ml Polypropylene bottles (Tarsons make). These were rinsed profusely at site with sample water and filled with water samples, tightly capped (to prevent evaporation and exchange with the atmospheric moisture) and brought to the laboratory for isotopic analysis. The oxygen and hydrogen isotope measurements were carried out using a Dual Inlet Isotope Ratio Mass Spectrometer (GV instruments, U.K) with automatic sample preparation units. For oxygen and hydrogen isotopes, 400mL water samples were taken and hokobeads were used as catalyst. Along with each batch of samples, secondary standards developed with reference to primary standards (i.e., V-SMOW, SLAP, GISP) were also measured and the final ä-values were calculated using a triple point calibration equation. The overall precision, based on 10 points repeated measurements of each sample, was with the error limits of ±0.1‰ for ä^{18}O and ±1‰ for äD.

RESULTS AND DISCUSSIONS

Variations of d^{18}O with Time

Both lakes are stratified for 8 to 9 months in a year (i.e., from March to November). The stratification builds up quickly in March and is very strong in summer months. During the stratified periods, the metalimnion (i.e. the region of relatively rapid change of temperature) is seen at a depth of 3 m to 9 m during the stratified months. In Nainital Lake winter overturn starts in November and since then the lake is well mixed for 3-4 months (i.e. from November/December to February/March) (Kumar et al, 1999) while in Mansar Lake mixing period is for 2-3 months (December to January/February) .(Rai et al. 2006). This is due to location of lakes at different altitude which results in variation of temperature. The uniform tritium content of the lake Nainital during the reconnaissance survey in May 1994 (i.e. about 11.2 ± 0.5 TU) gave a clear indication, in advance, that the stratification seen during summer months could be seasonal and the lake is expected to be well-mixed during winter (Sarvana Kumar et al., 2001).

The depth profile of d^{18}O with time reveals the hydrological status of lake water occurring at different depths i.e., epilimnion, mesolimnion and hypolimnion. The d^{18}O of surface water in Nainital Lake (i.e., 0 m depth) varies from -7.7‰ (minimum) during the month of Feburary to -5.6‰ (maximum) in the month of March and from -7.9‰ during the month of May to -7.1‰ during the month of November in bottom part the lake (i.e., 25 m depth) (Fig. 2). While, d^{18}O in surface water of Mansar lake varies between +1.0‰ (minimum) during the month of August and +4.2‰ (maximum) during the month of June and in lake bottom part between +1.6‰ during the month of June and +2.2‰ during the month of August (Fig 2). The d^{18}O data clearly show that Mansar Lake water is isotopically enriched in comparison to Nainital Lake from top to bottom (Fig 2). The d^{18}O value of surface water observed minimum during month of August in Mansar Lake is due to the direct rainfall on the lake surface and runoff generated in the lake catchment with depleted d^{18}O values (Av. -6.8‰) join the lake water and dilute isotopic composition of surface water from +4.2‰ to +1.1‰. The temporal variation in the isotopic composition of the epilimnion zone is significant than in the hypolimnion zone, due to the effect of evaporative enrichment and depletion due to addition of runoff water in Monsoon period. Similarly in Nainital Lake significant variation is found between epilimnion and hypolimnion. However, minimum isotopic composition of hypolimnion does not remain same during the period of stratification in Nainital Lake and it goes minimum during the period of mixing. The significant isotopic variation has also been recorded in hypolimnion part of lake Nainital which shows that lake receives significant subsurface inflow while Mansar lake hypolimnion show negligible variation in isotopic composition, thus it has negligible subsurface inflow (Fig 2).

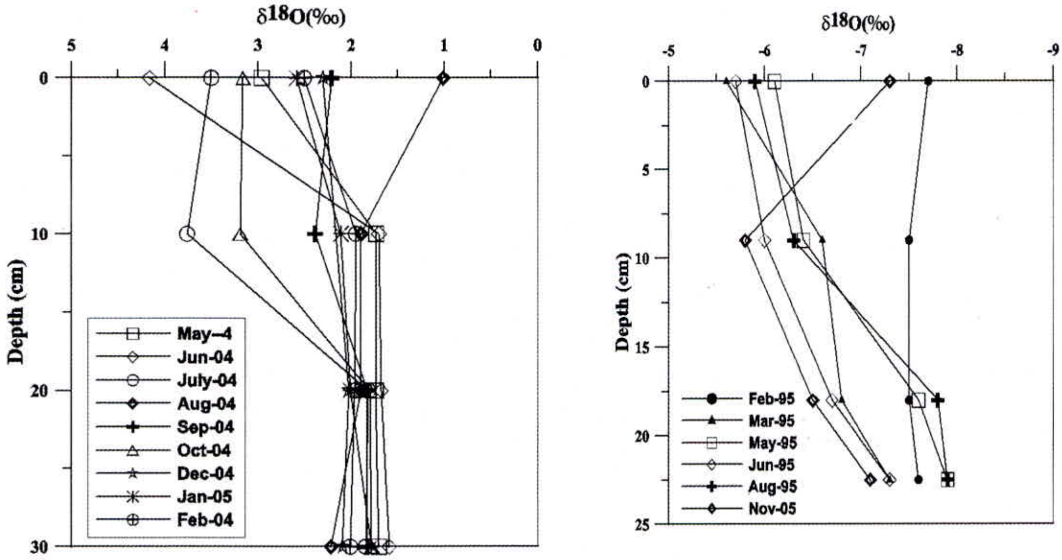

Figure 2: Depth profile of d^{18}**O in various month of Mansar and Nainital Lake.**

d^{18}O - dD Relationship

The d^{18}O - dD plots (Fig. 3) show the isotopic composition of both the lakes from epilimnion to hypolimnion. Both lakes have distinct isotopic composition. The Local Meteoric Water Line (LMWL) for Naintal and Mansar Lakes' catchment are as follows. $dD = 7.4*d^{18}O + 3.9$ (n= 20, r=0.97 , significant at 0.05 level) (Nainital) (i) $dD = 8.1*d^{18}O + 9.3$ (n= 24, r=0.99, significant at 0.05 level) (Mansar) (ii) The slope of LMWL for both the lake catchments are very close to GMWL (dD=8.2±0.1 d^{18}O + 10.6±0.6, Rozanski 1993) which shows condensation process is in equilibrium conditions. In case of Nainital lake, d^{18}O values of all the samples fall on the LMWL (Fig 3) while in case of Mansar Lake below the LMWL (Fig 4). If the d^{18}O - dD values fall below the LMWL, it points out that the water body is subjected to a considerable evaporation. Therefore, it reveals the evaporative enrichment of Mansar Lake. In case of Nainital lake, the epilimnion zone samples are also plotted in a separate group (Fig. 3) which shows the evaporation trend but evaporative enrichment is insignificant because all other the samples from mesolimnion and hypolimnion fall on LMWL. The water balance study of the Nainital lake shows that average evaporation loss in terms of water depth of lake surface area is about 1.2 m (Kumar et al., 1999) and 1.0 m from Mansar lake (Goyal et al., 2002). The epilimnion zone water samples show the signatures of evaporative enrichment (eq. iii) while hypolimnion zone show the signature of rain and ground water (eq. iv) which show the significant contribution of groundwater into the lake Nainital. Mansar lake isotopic signature from all part of the lake show evaporative enrichment (eq. v and vi). It clearly indicate the little contribution from groundwater in hypolimnion part.

dD = 5.6 d^{18}O - 6.4 (n= 6, r^2=0.93) (Epilimnion part of Nainital) (iii)
dD = 7.3 d^{18}O + 4.4 (n= 30, r^2=0.75, (Hypolimnion Part of Nainital) (iv)
dD = 4.7 d^{18}O -3.7 (n= 20, r^2=0.66) (Epilimnion part of Mansar) (v)
dD = 4.6 d^{18}O - 3.6 (n= 30, r^2=0.66) (Hypolimnion Part of Mansar) (vi)

Nainital lake does not show significantly affected by non-equilibrium evaporative enrichment processes because lake is receiving significant contribution from subsurface inflow during the whole year. The rates of change of isotopic composition of hypolimnion and epilimnion waters of the lake indicate that the water retention time of the lake Nainital is very short and the two have independent inflow components (Sarvana Kumar, 2001). It clearly indicates that subsurface inflow to the Mansar lake is very less which is not enough to dilute the isotopically enriched water due to evaporation. It also reveals that the residence time of the Mansar Lake is comparatively very high.

D EXCESS

The isotopic imprints of evaporation are also recorded in the form of a parameter called D excess. The D excess or d-index means the surplus deuterium relative to the Craig's Line (Dansgaard, 1964). The characteristics of the d-index are a) equilibrium processes do not change the d-index for any of the phases, b) non-equilibrium evaporation from a limited amount of water reduces the d-index of the water as long as exchange is not a dominating factor. The extent to which ^{18}O is more fractionated compared to D can be defined by Dansgaard (1964) as below:
D excess= d = dD-8 d^{18}O (‰) (vii)

The D excess (d) as defined above represents the excess dD than 8 times d^{18}O for

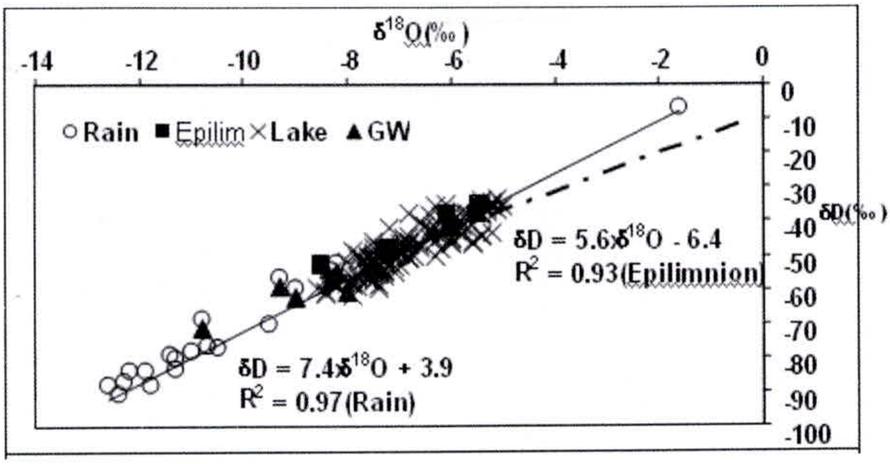

Fig. 3. Stable isotope composition of Lake Nainital with LMWL

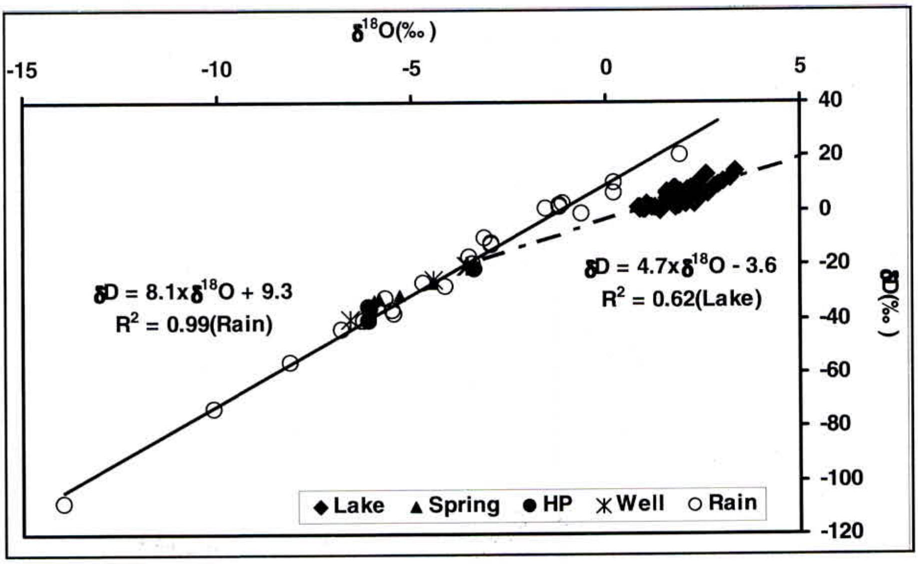

Fig. 4. Stable isotope composition of Lake Mansar with LMWL

any water body or vapour. Since magnitude of equilibrium fractionation (condensation) for D is about 8 times to that for d^{18}O. Thus due to evaporation (non equilibrium fractionation) from a water body, the D excess of the evaporating water decreases while it increases in water vapour. The D excess in the Mansar lake is varying between 0‰ and -15‰ while in case of Nainital lake it varies between 0‰ and +15‰ (Fig 5) .The more negative D excess of Mansar lake shows significant effect of non equilibrium fractionation of lake water. On the other hand, 2/3rd samples from Nainital Lake have D excess in the range of -10‰ to -15‰, which shows the nonequilibrium fractionation process, or in other term most of the sample represents D excess near to the rainfall. The isotopic signatures of lake Nainital are very much in agreement with water balance components of the lake in which groundwater contributes about 50% of total annual inflow to Nainital Lake and sub-surface outflow is about 55% of the total annual outflow from the lake. It shows that the lake is a 'flow - through' type, with substantial groundwater inflow and lake seepage. Thus it clearly shows that the lake Nainital groundwater system appears to be a flow-through type. In comparison to lake Nainital, Mansar Lake groundwater interaction appears to be very poor. The enriched isotopic composition of Mansar Lake also indicates that residence time of the lake is comparatively higher than Nainital Lake. This is probably due to the higher sedimentation rate in Mansar lake (Rai et al. 2006) has clogged the sub-surface pathways by deposition of finer sediments. Therefore, subsurface outflow from Mansar is also very limited.

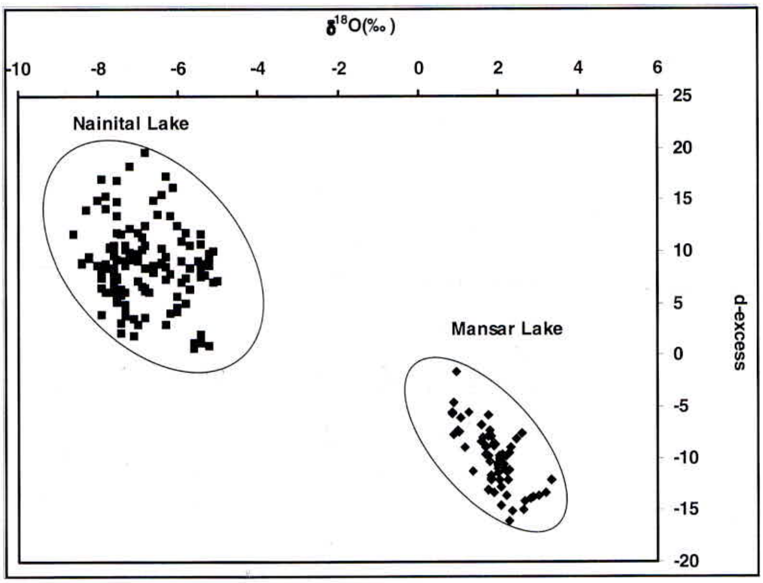

Fig. 5: Variation of D excess in Nainital and Mansar Lakes.

CONCLUSIONS

The variation of $d^{18}O$ and dD results clearly show that Mansar Lake is subjected to more evaporative enrichment. The D excess in the Mansar lake is varying between 0‰ and -15‰ while in case of Nainital lake it varies between 0‰ and +15‰. It shows that the lake is a 'flow - through' type, with substantial groundwater inflow and lake seepage. In comparison to lake Nainital, Mansar Lake groundwater interaction appears to be very poor. The enriched isotopic composition of Mansar Lake also indicates that residence time of the lake is comparatively higher than Nainital Lake.

The rates of change of isotopic composition from epilimnion to hypolimnion indicates the dynamic nature of a lake as well as it also reveals the status of groundwater contribution to lake and water retention time. The results point out that higher rate of sedimentation does not only reduce the volume of the lake but also reduces the lake subsurface inflow and reduces outflow from the lake due to clogging the sub-surface pathways by deposition of finer sediments. Thus stable isotopes will be useful tool to understand the status of groundwater inflow and outflow from the lake and water retention time.

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