551.324 (235.24)

Altitudinal variation in deuterium concentration of water samples of central Himalayas

JAGDISH BAHADUR

Nuclear Research Laboratory

Indian Agricultural Research Institute, New Delhi

ABSTRACT. During 1971-glaciohydrological expedition to Gangotri glacier, a few meltwater samples were collected from the Central Himalayan region. The deuterium concentration and the hydrochemical d ta of these samples are presented and discussed.

With the help of data from global surveys for deuterium and oxygen-18 distribution, it has been possible to estimate the likely altitude where the precipitation might have taken place. Calculated altitudes based on Mussorie—a neighbouring meteorological station for which long term data was available—show that the origin of these waters is due to summer precipitations over the glaciated region.

An altitudinal variation of $3\cdot36\%_0$ has been obtained assuming a lapse rate of $0\cdot6°C$ for each 100 m altitude variation.

1. Introduction

The principal stable molecular species present in water are in the following proportion:

$^1H_2^{16}O$	99,7680
$^1H^2H^{16}O$	320
$^1H_2^{18}O$	2000

The physical properties of these three forms of water vary slightly and in particular, their vapour pressures are different, the vapour pressure decreasing with increasing molecular weight. This results in slight fractionation when phase changes occur in water, *i.e.*, vapour to liquid and *vice versa*. This fractionation effect becomes more marked with decreasing temperature and is independent of the relative composition. The fractionation factors for D/H and $^{18}O/^{16}O$ ratios between ice and liquid water at 0°C are $1\cdot020$ and $1\cdot003$ respectively. Thus, the D/H and $^{18}O/^{16}O$ for glacier ice are higher by $20°/_{00}$ and $3\%_0$ respectively as compared to those of their meltwater.

As the source of water vapour in the atmosphere is oceanic, standard mean ocean water (SMOW) is accepted as a convenient reference level for reporting stable isotope ratios. Deviations from this standard are known as δ-values and are expressed :

$$\delta D = \left\{ \frac{(D/H) \text{ Sample}}{(D/H) \text{ Standard}} - 1 \right\} \times 1000°/_{00}$$

Positive δ-values denote enrichment and negative values depletion within any one phase. Dansgaard (1964) has reviewed the research work on the fractionation of these isotopes.

Since 1961 worldwide survey of these isotopes in precipitation is organised by IAEA—WMO with an aim to provide information for tritium input function for hydrological investigations and on some characteristics of the circulation patterns and mechanisms of the global and local movement of water.

In the present studies, Thomson-Houston's mass spectrometer (model THN 202B) at Bhabha Atomic Research Centre (BARC), Bombay, was used for analysis of water samples. The equipment was suitable for D/H-ratio measurement between 0 to 10,000 ppm with an accuracy better than $\pm0\cdot1$ ppm or $\pm0\cdot1\%$ whichever is greater. It could accept both gaseous and liquid samples. Water samples were directly introduced in the system. Complete analysis took about 30 minutes for each sample. Standards were run before and after each sample.

2. Sample description

A set of snow and ice meltwater samples from emerging streams were collected during the interdepartmental glaciohydrological expedition, October 71. The description of locations wherefrom samples were collected is given in Table 1 with the respective dates of collection and approximate altitudes above mean sea level.

TABLE 1

Details of samples from Gangotri region

Sample No.	Date of collection	Approx. altitude (m)	Origin
1	11 Oct 1971	4290	Melt water from perennial mountain snow
2	19 Oct 1971	3920	Stream at the snout of the glacier
3	,,	3860	Spring water from glacial moraine
4	,,	3840	,,
5	,,	3760	,,
6	,,	3640	,,
7	,.	3630	,,
8	,,	3540	,,
9	20 Oct 1971	3560	,,
10	22 Oct 1971	2800	Glacial river (Gangotri water
11	,,	2800	Glacial river (Kedar Ganga)
12	24 Oct 1971	2625	Glacial river (Jad Ganga)
13	,,	2625	Glacial river (Bhagirathi at Bhaironghati)
14	27 Oct 1971	1115	Glacial river (Bhagirathi at Uttar Kashi)

3. Results and discussion

The hydrochemical data (Table 2) shows that the chloride content is fairly high. This has to be airborne as it is impossible to get so much chloride from the leaching of the rocks. The Cl/Na ratio for these waters ranged from 0.5 to 3.1. The higher values are due to oceanic winds while the lower values could be related to continental precipitation.

The deuterium concentration δD of these melt water samples varied from -103 to $-175‰$ (Bahadur 1973) as compared to -74 to $-126‰$ obtained by Mushiki and Matsuo (1973) for eastern Himalayas. A value of $-194.5‰$ was obtained for newly fallen snow for Nepal region as compared to values of -106 to $-229‰$ and -158 to $-182‰$ obtained for new snow and snowpack in the Rocky Mountains (Judy et al. 1970).

A worldwide survey shows that there exists a linear relationship over the entire range of δD and $\delta^{18}O$. This established relationship for the meteoric waters of the earth is given by

$$\delta D = 8\,\delta^{18}O + 10$$

This relationship normally called as Graig-plot has been found to be valid for eastern Himalayan

region (Bahadur 1973). While dealing with a very wide air temperature range form North Atlantic coastal stations to Greenland ice cap, Dansgaard (1964) gave the empirical relation betwen the mean annual air temperature (t_a) and the mean $\delta^{18}O$ or δD

$$\delta^{18}O = .695\ t_a - 13.6 \qquad (1)$$
$$\delta D = 5.6\ t_a - 100 \qquad (2)$$

Eriksson (1965) has shown the complexity of the transport of these isotopes in relation to that of water vapour. He found that the fractionation of these water isotopes is considerably less when the atmospheric transport is due to eddy motion than when the transport is advective. In a subsequent paper (Eriksson 1967), he concluded that these atmospheric models have given a fairly consistent picture for the circulation of stable isotopes of water in nature and Deuterium is probably the most suitable isotope for studying water balance problems of lakes as the kinetic effect on the fractionation during evaporation is relatively small.

In the present case it is known that the moisture is lifted with the air due to advection and hence the δD and t_a relationship can be used. Taking Mussorie (30° 27' N, 78° 05' E) located at 2040 m as the neighbouring meteorological station, and its mean summer and winter temperatures as $17.3°C$ and $9.4°C$ and assuming a mean lapse rate* of $0.6°C$ per 100 m height variation, the altitude (expressed in 100 m) where the precipitation might have taken place during summer (H_s) and winter (H_w) the following equation are derived from equation (2):

$$H_s = -\frac{\delta D}{3.36} + 19.47 \qquad (3)$$
$$H_w = -\frac{\delta D}{3.36} + 6.30 \qquad (4)$$

H_s and H_w values vary from $5020-6390$ m (neglecting the H_s value for sample No. 3) and 3700 to 5850 m respectively. The winter values are not acceptable as it is not possible to get water from lower altitudes of precipitation than the altitude of the ampling location. Further the glacier snouts are located between altitudes ranging from 4000 to 5200 m and melt water has to come from higher location in the ablation zone. During October months, the snow line recedes to about 6000 m on the avalanche fed glaciers lying in the altitude range 4000–6200 m with mountain peaks going upto 6860 m (Bhagirathi group—I-6856 m, II-6512 m, III-6454 m, Shivling 6543 m).

*At Gaumukh (altitude 3920 m), the air temperature during October 1971 was 8°C while it was around 30°C at Calcutta giving a mean lapse rate of $.56°C/100$ m.

TABLE 2

Deuterium concentration and hydrochemical data of selected samples in Gangotri region

Sample No.	Deuterium concentration (% SMOW)	Conductivity in micromhos ×cm	pH	Total Iron (ppm)	ppm of cations				ppm of anions		
					Na	K	Ca	Mg	CO_3 + HCO_3	SO_4	Cl
1	—120·3	55	6·6	·10—·15	2·1	1·95	5·6	1·4	10	17	4
2	—129·1	120	7·0	,,	2·6	2·50	16·8	2·9	20	35	8
3	—175·3	70	7·0	Between ·05—·10	2·2	0·65	11·2	1·0	24	9	5
4	—149·4	80	7·1	Between ·10—·15	2·7	0·40	10·4	2·4	24	7	6
5	—115·8	60	6·6	Trace	2·6	1·85	7·2	1·4	15	10	6
6	—129·1	90	7·4	Trace	1·6	0·45	11·2	3·8	27	21	2
7	—112·7	50	7·3	Trace	1·4	0·40	6·4	1·9	20	10	2
8	—116·5	50	7·4	Trace	4·0	0·75	9·6	1·0	34	6	2
9	—122·2	125	7·4	10	3·3	3·10	14·4	3·8	15	45	6
10	—122·2	105	7·0	·05	2·8	2·25	12·3	3·4	15	35	3
11	—118·4	140	6·8	·10	2·3	2·85	19·2	3·4	12	56	5
12	—108·9	175	7·5	·05	2·4	0·60	22·4	8·2	66	39	2
13	—110·1	170	7·4	·05	2·5	0·60	22·4	9·1	68	42	2
14	—103·2	110	7·4	·05	3·4	1·50	16·0	2·9	44	17	4

It may be relevant to mention here that the tritium content of adjacent snow profile of Khumbu glacier in Everest region shows that the strata represents bi-annual accumulation (Miller 1965). Further rainfall studies in Ganga basin show that the annual precipitation is 75 to 150 cm with a few pockets of 250 cm in the mountaineous regions, as compared to 40 to 150 cm in the plains of this region. Most of the precipitation in the high altitude mountaineous region is concentrated during hot weather season (March to May), when the westerly disturbances release moisture during their passage eastwards across northern India. They give rise to thunderstorms which are occasionally severe and are sometimes accompanied by hail and are more frequent in the glaciated Gangotri region.

Deuterium has been used as a tracer for studying the snow hydrology in Sierra Nevada (Friedman and Smith 1971). An altitude variation of $\triangle \delta D \simeq 4\%_{oo}$ has been observed in Alps (Amback et al. 1968, Moser and Sticher 1970 Dincer et al. 1970). A similar situation was found in Sierra Nevada area by Friedman and Smith (1972) for altitudinal variations in snows. The

winter of 1968-69 produced two or three time the amount of precipitation in the area as the winter of 1969-70. The deuterium of 1968-69 snow showed a depletion of about $20\%_{oo}$ relative to that of 1969-70. The authors claim that the winter of 1968-69 may have resembled the Pleistocene in both isotope character and increased precipitation.

The source of water which precipitates and deposits as glacier ice in central Himalayas is predominantly summer precipitation. The altitudinal variation in deuterium of $3·36\%_{oo}$ per 100 m is comparable to that observed in other parts of the world.

The large variations in δD-values can be extremely useful to study the origin of waters from Himalyas. These differences in deuterium concentration could be applied for studying several local and regional hydrological problems in the sparcely explored Himalayan region. This assumes a greater significance as we receive water from this source at a time when we need it most for our agriculture and industry in addition to its perennial character.

REFERENCES

Amback, W., Denagaard, W., Eisner, H. and Moller, J.	1968	*Tellus*, **20**, 4, pp. 595-600.
Bahadur, J.	1973	IHD News letter No. 20-21, pp.5-6 April-July 1973.
Dansgaard, W.	1964	*Tellus*, **16**, 4, pp. 436-468.
Dincer, T., Martinec, J., Payne, B. R. and Yen, C. K.	1970	Variation of the Tritium and Oxygen-18 content in precipitation and snowpack in a representative basin in Czechoslovakia, Proc. IAEA Symp. 'Isotopic Hydrology', pp. 23-42.
Eriksson E.	1965	*Tellus*, **17**, 4, pp. 498-512.
	1967	'Isotopes in Hydrometeorology' Proc. IAEA Symp. Isotopes in Hydrology, pp. 21-33.
Friedman, I. and Smith, G. I.	1971	'Deuterium as a Tracer in snow Hydrology' Proc. Internat. Symp. on Role of snow and Ice Hydrology, UNESCO, Moscow.
	1972	*Science*, **176**, pp. 790-793.
Judy, C., Meiman, J. and Friedman, I.	1970	*Water Resources Res.*, **6**.
Miller, M. M., Leventhal, J. S. and Libby, W F.	1965	*J. geophys. Res.*, **70**, 16, pp. 3885-3888.
Moser, H. and Stichler, W.	1970	'Deuterium Measurements on snow samples from Alps Proc. IAEA Symp. 'Isotopic Hydrology', pp. 43-57.
Wushiky, H. and Matsuo, S	1973	'Oxygen-18 and Deuterium content of Himalayan waters— A preliminary report (Preprint).