Altitudinal variation in deuterium concentration of water samples of central Himalayas

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ABSTRACT. During 1971-glaciological and hydrological expedition to Gangetic glacial, a few meltwater samples were collected from the Central Himalayan region. The deuterium concentration and the hydrochemical data 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 Mussoorie—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 alitudinal variation of 3-36‰ has been obtained assuming a lapse rate of 0.6°C for each 100 m altitude variation.

1. Introduction

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

\[ \text{H}_2^{16} \text{O} \quad 99,7680 \]
\[ \text{H}_2^{18} \text{O} \quad 320 \]
\[ \text{H}_2^{16} \text{O} \quad 2000 \]

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 \(^{18}\text{O}/^{16}\text{O}\) ratios between ice and liquid water at 0°C are 1.020 and 1.003 respectively. Thus, the D/H and \(^{18}\text{O}/^{16}\text{O}\) for glacier ice are higher by 20‰ and 3‰ 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 as:

\[ \delta \text{D} = \left\{ \frac{(D/H) \text{ Sample}}{(D/H) \text{ Standard}} - 1 \right\} \times 1000/oo \]

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 Bhagath 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 ±0.1 ppm or ±0.1% 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 glaciological expedition, October 71. The description of locations where-from samples were collected is given in Table 1 with the respective dates of collection and approximate altitudes above mean sea level.
TABLE 1

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Date of collection</th>
<th>Approx. altitude (m)</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11 Oct 1971</td>
<td>4290</td>
<td>Melt water from perennial mountain snow</td>
</tr>
<tr>
<td>2</td>
<td>19 Oct 1971</td>
<td>3020</td>
<td>Stream at the snout of the glacier</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>3860</td>
<td>Spring water from glacial moraine</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>3840</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>3760</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>3860</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>3830</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>3540</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>20 Oct 1971</td>
<td>3540</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>22 Oct 1971</td>
<td>2800</td>
<td>Glacial river (Gangotri water</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>2800</td>
<td>Glacial river (Kedar Ganga</td>
</tr>
<tr>
<td>12</td>
<td>24 Oct 1971</td>
<td>2625</td>
<td>Glacial river (Jad Ganga</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>2625</td>
<td>Glacial river (Bhagirathi at Bhaironghati)</td>
</tr>
<tr>
<td>14</td>
<td>27 Oct 1971</td>
<td>1115</td>
<td>Glacial river (Bhagirathi at Uttar Kashi)</td>
</tr>
</tbody>
</table>

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 CI/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 $\delta D$ of these melt water samples varied from $-103$ to $-175/00$ (Bahadur 1973) as compared to $-74$ to $-126/00$ obtained by Mushiki and Matsuo (1973) for eastern Himalayas. A value of $-191/500$ was obtained for newly fallen snow for Nepal region as compared to values of $-106$ to $-229/00$ and $-158$ to $-182/00$ 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 $\delta D$ and $\delta^{18}O$. This established relationship for the meteoric waters of the earth is given by

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

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 between the mean annual air temperature ($t_a$) and the mean $\delta^{18}O$ or $\delta D$

$$\delta^{18}O = 695 t_a - 13.6 \quad (1)$$

$$\delta D = 5.6 t_a - 100 \quad (2)$$

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 $\delta D$ and $t_a$ relationship can be used. Taking Mussoorie (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 8·4°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):

$$H_s = -\frac{\delta D}{3.36} + 19.47 \quad (3)$$

$$H_w = -\frac{\delta D}{3.36} + 6.30 \quad (4)$$

$H_s$ and $H_w$ values vary from 5020-6380 m (neglecting the $H_s$ value for sample No. 3) and 3700 to 5550 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 sampling 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, Shiviling 6543 m).
### TABLE 2

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Deuterium concentration (%) at 3300 m</th>
<th>Conductivity (in micromhos/cm)</th>
<th>pH</th>
<th>Total Iron (ppm)</th>
<th>ppm of cations</th>
<th>ppm of anions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Na</td>
<td>K</td>
</tr>
<tr>
<td>1</td>
<td>-120-3</td>
<td>55</td>
<td>6-6</td>
<td>10-15</td>
<td>2-1</td>
<td>1-95</td>
</tr>
<tr>
<td>2</td>
<td>-129-1</td>
<td>120</td>
<td>7-0</td>
<td></td>
<td>2-8</td>
<td>2-50</td>
</tr>
<tr>
<td>3</td>
<td>-155-3</td>
<td>70</td>
<td>7-0</td>
<td>Between -05-10</td>
<td>2-2</td>
<td>0-65</td>
</tr>
<tr>
<td>4</td>
<td>-149-4</td>
<td>80</td>
<td>7-1</td>
<td>Between -10-15</td>
<td>2-7</td>
<td>0-40</td>
</tr>
<tr>
<td>5</td>
<td>-115-8</td>
<td>60</td>
<td>6-6</td>
<td>Trace</td>
<td>2-6</td>
<td>1-85</td>
</tr>
<tr>
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<td>-129-1</td>
<td>90</td>
<td>7-4</td>
<td>Trace</td>
<td>1-6</td>
<td>0-45</td>
</tr>
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<td>-112-7</td>
<td>50</td>
<td>7-3</td>
<td>Trace</td>
<td>1-4</td>
<td>0-40</td>
</tr>
<tr>
<td>8</td>
<td>-116-5</td>
<td>50</td>
<td>7-4</td>
<td>Trace</td>
<td>4-0</td>
<td>0-75</td>
</tr>
<tr>
<td>9</td>
<td>-122-2</td>
<td>125</td>
<td>7-4</td>
<td>10</td>
<td>3-3</td>
<td>3-10</td>
</tr>
<tr>
<td>10</td>
<td>-122-2</td>
<td>105</td>
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<td>2-25</td>
</tr>
<tr>
<td>11</td>
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<td>140</td>
<td>6-8</td>
<td>-10</td>
<td>2-3</td>
<td>2-85</td>
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<tr>
<td>12</td>
<td>-108-9</td>
<td>175</td>
<td>7-5</td>
<td>-05</td>
<td>2-4</td>
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<tr>
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<td>-110-1</td>
<td>170</td>
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<td>-05</td>
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<td>0-60</td>
</tr>
<tr>
<td>14</td>
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<td>110</td>
<td>7-4</td>
<td>-05</td>
<td>3-4</td>
<td>1-50</td>
</tr>
</tbody>
</table>

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 mountainous regions, as compared to 30 to 150 cm in the plains of this region. Most of the precipitation in the high altitude mountainous 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 $\Delta^6D \approx 4\%_0$ has been observed in Alps (Ambach 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$\%_0$ relative to that of 1969-70. The authors claim that the winter of 1968-69 may have resembled the Piemonte 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 3-35$\%_0$ per 100 m is comparable to that observed in other parts of the world.

The large variations in $\delta^D$-values can be extremely useful to study the origin of waters from Himalayas. These differences in deuterium concentration could be applied for studying several local and regional hydrological problems in the sparsely 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.
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REFERENCES