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Stable isotope ratios in precipitation and their relationship with meteorological conditions in the Kumaon Himalayas, India

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SUMMARY

For the first time, environmental isotopic (δ^2H, $\delta^{18}O$, ^3H) data, predominantly based on precipitation samples in the Kumaon Himalayas, India, have been used to understand the influence of various meteorological factors governing rainout processes in the region. Further, the data are also used to understand the orographic effects in precipitation and to estimate the altitude effect in stable isotopic ratios in precipitation, etc.

The interpretation of the isotopic data revealed that the source of moisture for winter (October–February) and summer (May) precipitation in the Kumaon Himalayas is mainly from the Western Disturbances whereas for the remaining period the source is monsoonal (southwest). The δ^2H–$\delta^{18}O$ relationship in the local precipitation during the monsoon season shows a distinct seasonal effect, with a slope of 7.6. The winter and summer precipitation samples measured higher environmental ^3H compared to southwest monsoon samples, thus indicating continental evaporated moisture. There is wide range of altitude effects ($\delta^{18}O$ variation per 100 m elevation: −0.30‰ [July–August]; −0.57‰ [September]) with the mean altitude effect being −2.61‰ and −0.36‰ per 100 m elevation for δ^2H and $\delta^{18}O$ respectively. These values are different from that reported earlier for the region based on the isotopic compositions of springs/rivers samples. The 'altitude effect' in successive precipitation is basically a temperature dependent phenomenon and is explained on the basis of adiabatic cooling related rainout process (dry adiabatic lapse rate, moist adiabatic lapse rate and saturated adiabatic lapse rate for moist air mass). The altitude effect is found to be more reliable in case of δ^2H, as deuterium is least affected by secondary evaporation. The effect of secondary evaporation has been observed on the true "altitude effect". Secondary evaporation of rainfall increases the oxygen isotopic ratios and the increase is directly proportional to the vertical distance travelled by the raindrops through air.

1. Introduction

The Himalayas, the youngest mountain range on the earth, gives rise to three of the world's major river-systems viz. the Indus, the Ganges and the Brahmaputra. In spite of the hydrological importance of the region, very few studies have been reported on stable isotopic (δ^2H and $\delta^{18}O$) characteristics in precipitation in the region. Evidently, none of the studies on Himalayas (e.g., Bahadur, 1976; Ramesh and Sarin, 1992; Bartarya et al., 1995) has presented the actual observed altitude effect in precipitation. Thus the complexity in the analysis of the relationship between isotopic composition of precipitation and elevation in parts of Himalayas has been reported by Poage and Chamberlain (2001).

For the first time, environmental isotopic data predominantly based on precipitation samples, and some water bodies in the lake Naini Catchment, situated in the Kumaon Himalayas, India, have been used to understand the various meteorological factors governing rainout processes in the region and the orographic effects in precipitation and estimate the altitude effect in precipitation using actual observations (air temperature, relative humidity and rainfall etc.).

2. The study area

The study area (Fig. 1), situated in the Kumaon Himalayas (Lat. 29°24′N; Long. 79°23′E; Area: ~4.7 km^2), encompasses an altitude range between 1937 and 2600 m msl. The mean annual rainfall in the study area is 2488 mm. The mean monthly rainfall, relative humidity and air temperature recorded at lake Naini site for 1995 are shown in Table 1. The rainfall amount, in the Himalayan ranges, generally decreases westward because of the increasing

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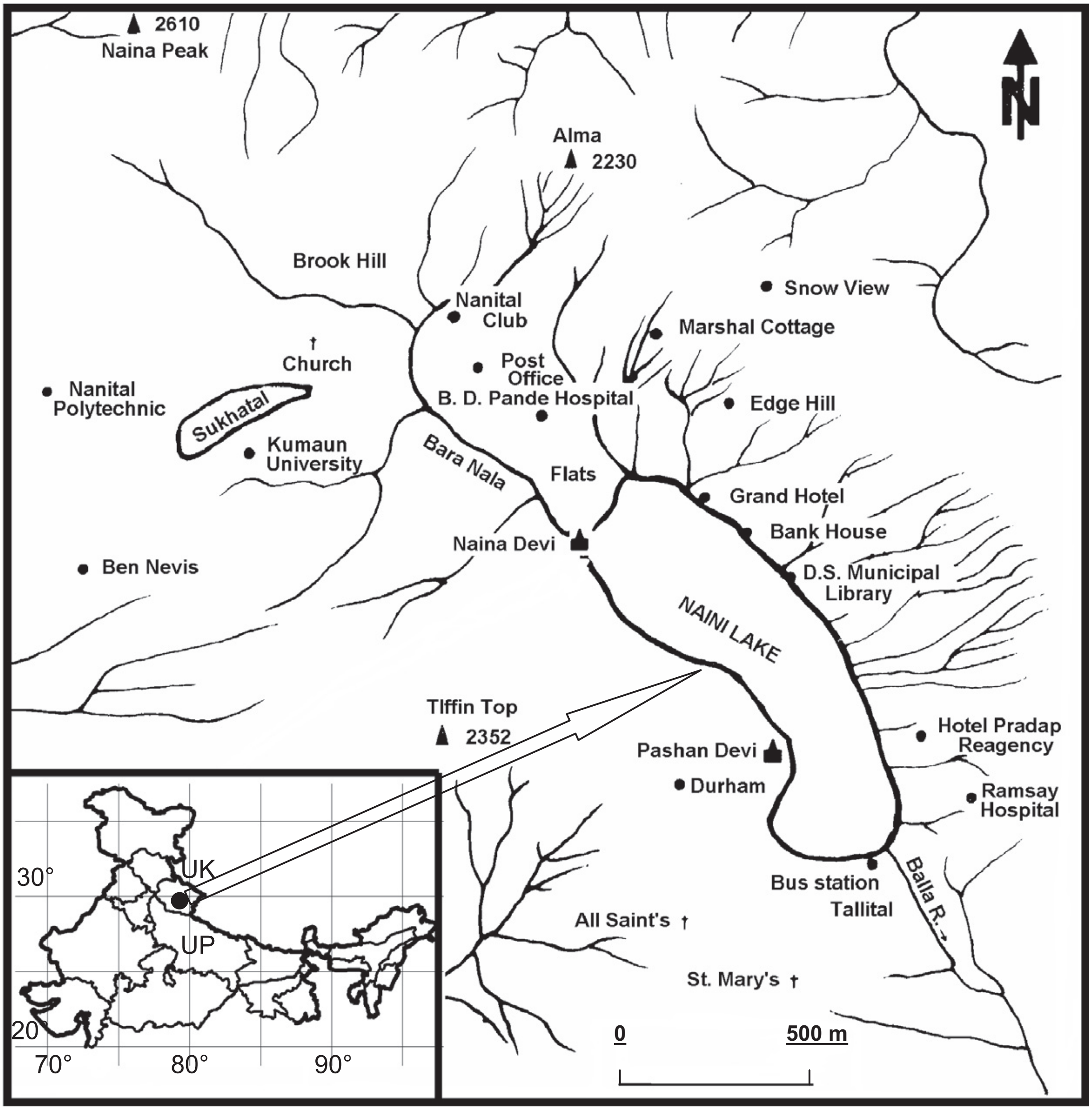

Fig. 1. The location and drainage map of the study area.

Table 1
The monthly rainfall, relative humidity, air temperature, δ^2H, $\delta^{18}O$ and deuterium excess (*d*) values of precipitation at the Lake Site in the study area in the year 1995.

Month	Rainfall (mm)	Relative humidity (%)	Air temperature (°C)	δ^2H (‰)	$\delta^{18}O$ (‰)	*d* (‰)
January	46.0	58	4	−90	−12.0	+6.3
February	59.3	59	6	−83	−11.3	+7.2
March	62.3	48	10	−77	−10.5	+6.9
April	5.8	33	15	−7	−1.6	+6.0
May	18.5	41	20	−64	−10.5	+19.9
June	89.0	69	22	−64	−10.5	+19.9
July	509.0	82	19	−79	−11.4	+12.0
August	632.0	86	18	−83	−11.3	+7.2
September	341.4	78	17	−77	−10.5	+6.9
October	0.0	73	15	–	–	–
November	0.0	51	12	–	–	–
December	10.2	54	9	−88	−12.6	+12.7

distance from the main source of moisture, i.e., Bay of Bengal. The precipitation during the monsoon season (June–September) is received as moderate to heavy. In contrast to this, during winter season (January–March) the precipitation is light to moderate (62.3–46.0 mm) with occasional snowfall, caused by extratropical weather systems of mid-latitude regions (originating over Caspian Sea). These winter weather systems are known as Western-disturbances.

The study area forms a synclinorium which is cut diagonally into two parts by the Naini Fault. The northwestern part is made up exclusively of argillaceous limestone and marlites whereas the southwestern part comprises of dolomite with limestone and black carbonaceous slates (Valdia, 1988). As shown in Fig. 1, there are a number of streams and springs in the study area. Most of the streams in the region are ephemeral while the perennial ones are mostly fed by springs.

The drainage pattern in the study area is controlled by mechanical structures. As shown in the drainage map of study area (Fig. 1),