Origin and Recharge Zones of Ground Water in a Himalayan Catchment: An Isotopic Approach

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Abstract: Generally ground water emerges out in the form of natural springs as an important source of drinking water in the mountainous regions. An attempt has been made to study the origin and natural recharge zones of ground water by using isotopic composition ($\delta^{18}O$ and δD) of ground waters in parts of upper Ganga catchment. The $\delta^{18}O$ in ground water varies between –12.73‰ (minimum) at Gangotri (3050 m amsl) to –4.6‰ (maximum at Rishikesh (347 m amsl). The $\delta^{18}O$ in precipitation varies –0.25‰ to –0.28‰ per 100 m with increase in altitude and in ground water, it is calculated to be -0.24‰ per 100 m with increase in altitude. The depletion of $\delta^{18}O$ in ground water and precipitation with increase in altitude is due to the altitude effect. The regression analysis of $\delta^{18}O$-δD of ground water shows that best fit line is close to Local Meteoric Water Line of Bhagirathi basin. This similarity in altitude effect and isotopic composition reveals that isotopic composition of precipitation is well preserved in the ground water and precipitation is the only source of recharge for ground water in the study area. The $\delta^{18}O$ in ground water of Devprayag and Gangotri is more depleted than precipitation of these locations. It indicates that recharge zone is about 480 and 160 m above the sampling sites of Devprayag and Gangotri.

INTRODUCTION

Studies conducted worldwide during last few decades have established that stable oxygen and hydrogen isotope ratios provide useful tools for hydrological investigations (Clark and Fritz, 1997; Mazor, 1991; Fontes, 1980). In case of groundwater, stable isotopes have been used to estimate recharge rates and to identify the recharge zones, to determine the effect of evaporation on groundwater system, to estimate diffusion rates in unsaturated zones, to study the groundwater surface water interaction and to identify source of salinity (Bhattacharya et al., 1985, Navada et al., 1986; Deshpande et al., 2003). The stable isotopic characteristics of Himalayan river namely, Ganga, Yamuna and Indus river have been studied by Ramesh and Sarin (1992), Dalai et al. (2003) and Pande et al. (2000), respectively.

Sarvana Kumar et al. (2001) and Nachiappan et al. (2002) have studied the lake dynamics and water balance of Nainital Lake using isotopic techniques. However, groundwater occurring in Himalayas have not received due attention in spite of the importance as a potential source for drinking water and also feeding the stream originating from non glacier area The isotopic composition ($\delta^{18}O$ and δD) of groundwater and precipitation has been used to understand the origin and recharge zones of groundwater in part of upper Ganga catchment.

STUDY AREA

Generally, the ground water in mountainous region emerges out in the form of springs, locally called as Dhara. These springs are the major source of drinking water and other domestic requirements in the hilly terrain. The India mark-II handpumps have been installed in the study area at various altitudes that are also serving the need of water for domestic purposes. The present study area covers from Gangotri (3050 m amsl) to Rishikesh (347 m amsl) where samples were collected mainly along Bhagirathi river up to Devprayag and along Ganga up to Rishikesh (Fig. 1).

The study area experiences a severe winter (December to March) characterized by the occurrence of severe snowfall at higher altitudes. The winter season is followed by pre-monsoon season (April to June) characterized by hailstorms and thunderstorms that get more severe towards the end of the season. The monsoon season sets on usually by July and extends up to September contributing about 75% of the annual rainfall. The post-monsoon season during October-November is generally the driest one with scanty and little amount of rainfall.

Geologically, the upper part of the study area consist Upper, Middle and Lower Crystalline rocks which is composed of sillimanite schist/gneiss, kyanite schist, starurolite-garnet schist, biotite schist/ gneiss, chlorite schist, migmatite, leucogranite, augen gneiss, schistose-quartzite and phyllite. The

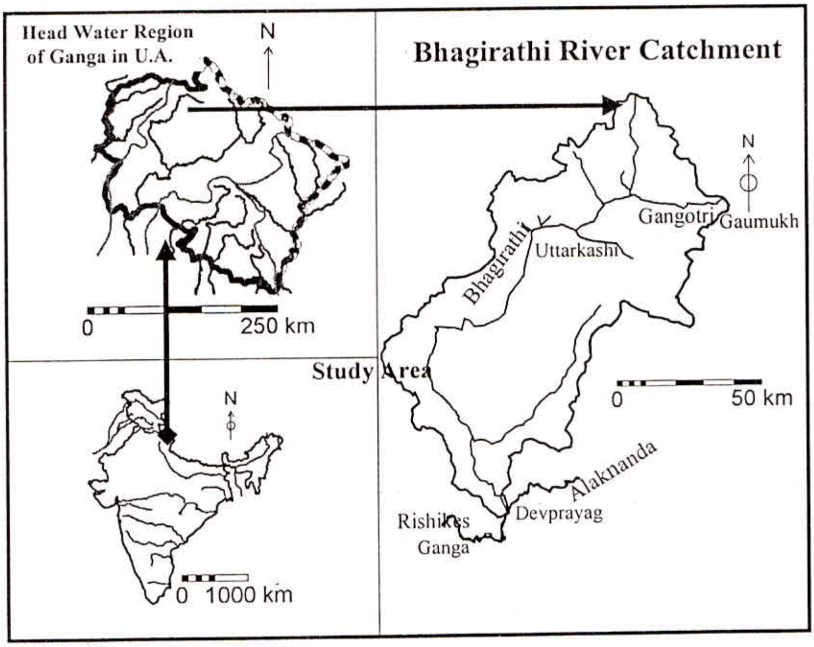

Fig. 1. Study area in Upper Ganga catchment.

middle reach is made up of Garhwal Group rocks, which is composed of thick pile of metamorphosed arenaceous and argillocalcareous sediments together with thick bands of metabasics and chlorite schist. At the lower part the Siwalik succession of sandstones and mudstones are exposed.

The study area is cut by numerous faults trending NW-SE, N-S and NE-SW. Fractures and joints are conspicuous in all rock formations. These structures not only control the drainage pattern, but also play an important role in promoting groundwater recharge and in location of springs. There is a strong relationship between the tectonic linears and high discharge of springs, as the major springs are lying directly on or within a few metres of them (Valdiya and Bartarya, 1991).

METHODOLOGY

Sampling and Analysis

To identify the isotopic signatures of ground water, samples were collected on seasonal and monthly basis from various handpumps and springs, of the study area during 2004 to 2006 and have been analysed for $\delta^{18}O$ and δD. The altitude of sampling locations were measured with an altimeter and cross-verified with GPS. For stable isotopes measurements, 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, 400 μL 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 ±0.1‰ for $\delta^{18}O$ and ±1‰ for δD.

RESULTS AND DISCUSSION

The $\delta^{18}O$ and δD values for groundwater, collected from various parts of the basin during pre-monsoon and post monsoon period, vary from –4.7‰ to –12.6‰ and –23.4‰ to –88.7‰ respectively. In general the isotopic composition of groundwater belonging to higher altitude is depleted in comparison to lower altitude groundwater.

The $\delta^{18}O$-δD Relationship

A regression line drawn in $\delta^{18}O$-δD for the global precipitation defines the Global Meteoric Water Line (GMWL) and that for the precipitation in a region and at a location is named as the Regional Meteoric Water Line (RMWL) and Local Meteoric Water Line (LMWL), respectively. The $\delta^{18}O$-δD relationship in groundwater when compared with GMWL and LMWL provides information on the preservation/alteration of stable isotopic composition of precipitation in groundwater. Figure 2 presents the $\delta^{18}O$-δD plots for groundwater and precipitation samples collected from the study area and regression analysis of the data gives the best-fit line for groundwater (BFL) as:

$$\delta D = 8.21 \times \delta^{18}O + 12.71 \ (n = 45, r = 0.98)$$

where n is the number of samples and r is the correlation coefficient. The slope of this BFL is marginally above than that of GMWL $\delta D = (8.17) \times \delta^{18}O + 10.35$ (Rozanski et al., 1993), and Local Meteoric Water Line of Bhagirathi Basin $\delta D = (8.32) \times \delta^{18}O + 13$. This similarity in the slope of groundwater with LMWL suggests that isotopic composition of precipitation is well preserved in groundwater of the Bhagirathi basin and evaporation during infiltration, if any, is negligible. These results show that in absence of Local Meteoric Line of Himalayan basin, the $\delta^{18}O$-δD relationship of groundwater can represents rainfall $\delta^{18}O$-δD relationship in the mountainous region where groundwater recharge takes place at higher rate. It also indicates that isotopic composition of groundwater can be treated as the yearly average of the precipitation.

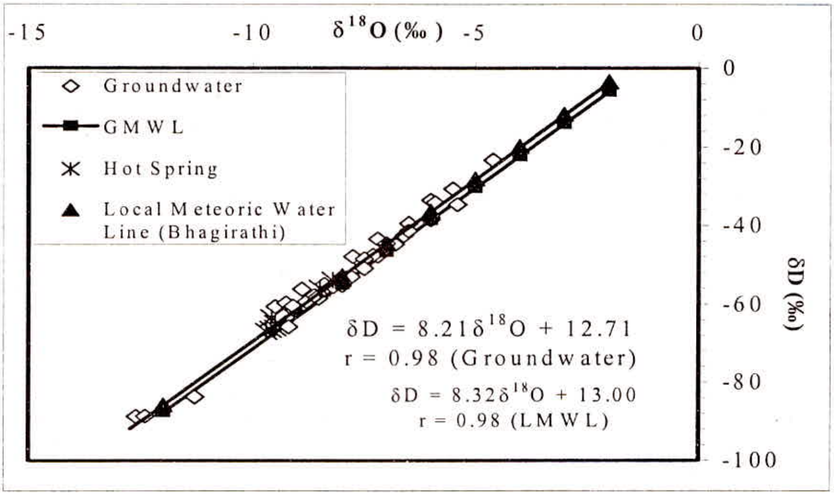

Fig. 2. The $\delta^{18}O$-δD regression line for groundwater and Local Meteoric Water Line of Bhagirathi river basin.

All the groundwater samples were cold water (temperature below 22°C) except a hot spring (temperature 63°C) that exists in Gangnani at an altitude of 1950 m in the study area, which emanates through highly deformed, contorted and sheared phyllonite and mylonitized schist near the Vaikrita Thrust. The $\delta^{18}O$ and δD data of hot spring also fall with cold groundwater samples isotopic values. It suggests that hot spring is also recharged from local precipitation. Giggenbach et al. (1983) has reported similar results for hot springs emerging out in Parbati Valley of Himachal Pradesh.

Altitude Effect

As air masses are lifted orographically, they cool and ensuing precipitation is enriched preferentially in the heavier isotopes. As a result, the next phase of precipitation at still higher altitude condensing from the residual cloud mass is relatively depleted in heavy isotopes; the progressive depletion with height is known as the altitude effect (Yurtsever and Gat, 1981; Clark and Fritz, 1997). The altitude effects depend on factors such as precipitation history, topography and precipitable moisture remaining in the cloud. The altitude effect on $\delta^{18}O$ in mid-latitude precipitation generally ranges between -0.15‰ and -0.30‰ for each 100 m of altitude gained. Both continental effect and altitude effects are manifestations of Rayleigh distillation—one operating on a large spatial scale as a result of cloud migration; the other operating in a given region owing to continuous extraction of water from ascending cloud resulting from the drop in temperature with height. In Bhagirathi river basin altitude effect in precipitation varies between -0.25‰ and –0.28‰ per 100 m (Fig. 3). Similarly, plot between altitude and $\delta^{18}O$ groundwater shows that altitude effect for groundwater during pre-monsoon and post monsoon is almost similar (Fig. 4). The regression equations 1 and 2 represent the precipitation equations 3 and 4 for groundwater.

$$\delta^{18}O = -0.0025 \times \text{altitude (m)} - 8.33 \ (r = 0.86) \quad (1)$$

$$\delta^{18}O = -0.0028 \times \text{altitude (m)} - 19.54 \ (r = 0.92) \quad (2)$$

$$\delta^{18}O = -0.0024 \times \text{altitude (m)} - 4.97 \ (r = 0.86) \text{ post monsoon} \quad (3)$$

$$\delta^{18}O = -0.0024 \times \text{altitude (m)} - 5.42 \ (r = 0.92) \text{ pre-monsoon} \quad (4)$$

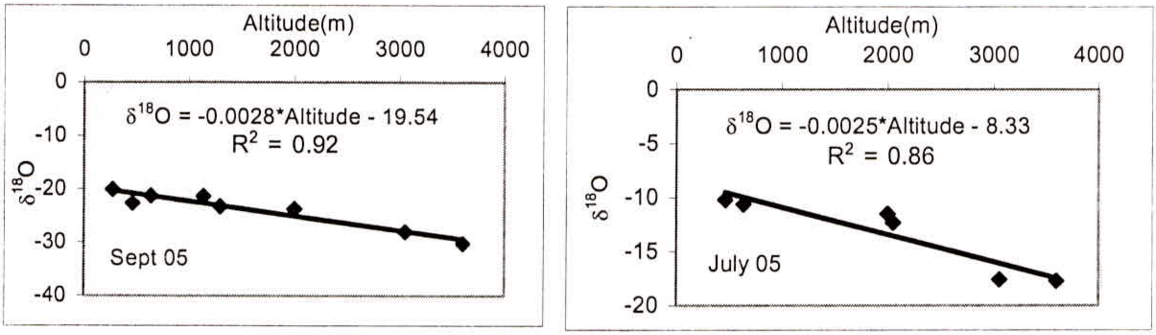

Fig. 3. Altitude effect in $\delta^{18}O$ in precipitation of Bhagirathi catchment.

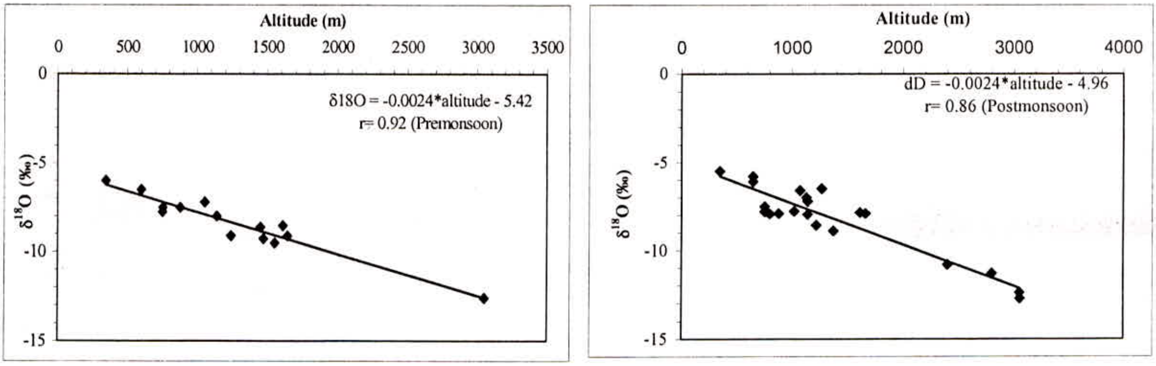

Fig. 4. Altitude effect in $\delta^{18}O$ determined in groundwater of Bhagirathi catchment for pre-monsoon and post monsoon period.

The slope of the regression lines yields an altitude effect of -0.24‰ per 100 m in $\delta^{18}O$. The altitude effect in $\delta^{18}O$ in groundwater is close to the altitude effect observed in precipitation. The similarity in altitude effect estimated using $\delta^{18}O$ reveals that groundwater in the study area originates with the precipitation of different altitudes. However, the slight depleted $\delta^{18}O$ in groundwater at particular altitude corresponding to the $\delta^{18}O$ value of precipitation indicates that there is a horizontal mixing of groundwater generated at higher altitude. The altitude effect in groundwater of Himalayan catchment is very useful in identifying the recharge zones of the springs whose discharge is dwindling due to various anthropogenic factors.

On the basis of preliminary analysis of $\delta^{18}O$ of 2004-2005, the altitude of recharge zones of groundwater at two sites namely, Devprayag and Gangotri has been estimated using the altitude effect in precipitation. At two sites, the annual average of $\delta^{18}O$ was computed for groundwater and precipitation on the basis of monthly data of 2004–2005 (Table 1). The $\delta^{18}O$ in groundwater of Devprayag and Gangotri is depleted in comparison to precipitation of these sites. This reveals that groundwater is being recharged from higher altitudes.

Table 1. Projected altitude of recharge zone of groundwater at two sites

Site	*Groundwater* $\delta^{18}O$ *(‰)*	*Precipitation* $\delta^{18}O$ *(‰)*	*Projected Altitude of Recharge (m)*	*Actual Altitude of Recharge (m)*
Devprayag	-7.4	-6.2	480	945 amsl
Gangotri	-12.4	-12	160	3210 amsl

CONCLUSIONS

The $\delta^{18}O$-δD relationship for groundwater samples yields a slope of 8.21 that is similar to Local Meteoric Water Line of Bhagirathi River basin. It reveals that isotopic composition of precipitation is well preserved in groundwater of the study area and evaporation during infiltration, if any, is minor. The distinct $\delta^{18}O$ in groundwater at each site reveals that groundwater in the area originates through only precipitation. The close similarity in altitude effect of groundwater and precipitation confirms that the source of recharge to groundwater is only precipitation. This study reveals that isotopic composition of precipitation and groundwater will be useful in identifying the source of recharge of groundwater/springs in a Himalayan catchment.

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