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Estimation of Run-off Components from a High Altitude River, Indian Himalayas using Stable Isotope Tracers

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Abstract : Punjab state is drained by five rivers namely Beas, Sutluj, Ravi, Chenab and Jhelum of the Himalayan origin. Discharge of these rivers vary seasonally due to varying contributing discharge components viz., glacial melt, direct rainfall, run-off, base flow etc. Identification of individual contributing components and their magnitude is important in river water management (as these are the major sources for irrigation and power generation). Isotope composition of river water varies seasonally depending upon magnitude of the contributing sources in the total discharge; therefore, isotopic investigations are effective in modelling the seasonal discharge. In the present study, this has been demonstrated successfully using the case study investigated on river "Parbati", a tributary of "Beas river", Himachal Pradesh (HP) of India. About 150 samples were collected from head waters of Parbati river during the period 2002-2005 to study seasonal variations of isotopic composition and to estimate run-off components. By using lean period data, a constant runoff component of sub glacial spring water from bed rock of the glaciers in the region is estimated to be 35 m^3/sec. The runoff components during summer months are estimated and show a increasing trend from March to May from snow / surface ice melting to Parbati river. The contribution from local spring water dominates during lean period compared to the year. Similar investigations can be extended to rivers of Punjab to decipher the runoff components.

Key words : Himalayan river, runoff components, isotopic composition, Seasonal variations.

INTRODUCTION

Stable isotope composition (deuterium [δD] and oxygen 18 [$\delta^{18}O$]) of water have successfully been used as naturally occurring hydrologic tracers to constrain estimates of the contributions of different water sources to stream flow, including snowmelt, glacier meltwater and groundwater baseflow (Behrens et al. 1978; Dinçer et al. 1970; Rodhe 1981). Although there have been a number of important hydrological investigations in Himalayan rivers, the use of isotopic tracers in studies to identify contributions of rain, snowmelt, groundwater baseflow and glacier meltwater to stream flow in Himalayan catchments has received little attention. Potential effects of climate variability and forest disturbances on stream flow are highly uncertain. Stable isotope tracers combined with model analysis techniques can play a prominent role in reducing this uncertainty.

The $\delta^{18}O$ and δD of rivers will reflect how the relative amounts of precipitation (rain), snow/ice melt and groundwater vary with time. Seasonal variations will be larger in streams where recent precipitation is the main source of flow, and smaller in streams where groundwater is the dominant source. As the basin size increases, the isotopic composition of rivers are increasingly affected. Local precipitation events are an important component of river water in the headwater of large basins. The dual nature of river water can be exploited for studying regional hydrology or climatology (Kendall and Coplen 2001). Knowledge of the isotopic composition of the major water sources can be used to quantity the time-varying contribution of these sources to river water.

Most of the rivers, including rivers flow in Punjab state, originated from Himalayas have two or three components. Those are (1) recent precipitation that has reached the river by surface runoff (2) groundwater/spring waters (3) Snow / surface ice melt waters during summer months (4) sub glacial spring water i-e. old ice melt waters from bed rock/bottom of the glaciers throughout year. The relative contributions of these sources differ in each basin and depend on the physical setting of the drainage basin (e.g. topography etc.) , climatic parameters (e.g. precipitation amount etc.), and human activities (e.g. dams, reservoirs, irrigation usages etc.). In this study, we used isotopic tracers to distinguish sources of stream discharge in a river which originates from Himalayas and flows into Punjab state before entering into Arabian Sea, by partitioning stream flow into that derived from baseflow, glaciermelt, snowmelt, and summer precipitation.

METHODOLOGY

The general technique for Hydrograph separation using environmental isotopes to stream/river flow is to solve a mass balance for the constituents of interest. The prerequisite for the successful application of this technique is that all source waters are identified, have differing but constant isotopic composition, and mix conservatively. For example, a two component mixing model for assessing stream water sources consists of two equations one for the mass of water and other for the isotopic content which also must include the mass components for water.

$$X_2 = (C_S - C_1) / (C_2 - C_1)$$

Where X is the fraction of source water, subscript s represents the stream, 1 and 2 represent the two respective sources , and C is the tracer concentration. The source chosen for the two components are typically either precipitation and groundwater for rain storms, or snow/surface ice and ground/spring water for snowmelt. Two- component mixing models assume that both the source waters are isotopically uniform (Kennedy et al., 1986). Almost all hydrograph separations have been made using only two sources of water, ignoring the possibility that soil waters. However, stream flow in Himalayan rivers may contain more than two sources but can be considered only two sources during different seasons. For example, during lean period (winter), the contribution is only from sub glacial spring water from the glacier located in the study area and ground/ spring water where as in summer, the contribution is mainly from snow/surface ice melt and ground/spring waters. The two-component separation is still valid, provided that the components are simply mixtures of "new" and "old" water and are not characterized by water from a different sources and with a different tracer identity. The mixing models are oversimplified with several limitations. The water isotopes (^3H, δD, $\delta^{18}O$) are part of the water molecule and, hence are more "conservative" than solutes, but can still be affected (fractionated) by phase changes such as liquid to gas during evaporation . The technique has been extensively used by the hydrological community to track the components of runoff in small and large river system. We also attempted to use this model to estimate runoff components from a Himalayan river in this paper.

SAMPLING LOCATIONS

The river Parbati is a major tributary of the river Beas which flows into Punjab state before entering into Arabian Sea. It rises in the snowy wastes of upstream of Manikaran on the foothills of the main Himalayan range in kulu district of Himachal Pradesh. The glaciers which feeds this river descends down from the steep southern slopes of the main Himalayan. The Parbati river basin is fed by almost thirty-six glaciers forms an aerial extent of 188 km^2 Melt waters from these glaciers forms an important source of run-off in Parbati river. In terms of economics, the Parbati basin is important because an 800MW power project is under construction and another 520MW power project is being planned (Kulkarni et al 2005). There fore the knowledge of the changes in run-off components in different seasons is important to asses future changes in river run-off. The Parbati river starts (Fig. 1) as a small channel from the snout of the glacier and flows towards west to join the river Beas at Shamshi in kulu valley. Hot water springs at Manikaran pour their water into this river (Negi 1991). The valley of the Parbati river is deep and narrow right from its origin to its confluence with the Beas river. Small terrace are found on either sides of the river. These have been formed by it over the past thousands of years. A number of small stream merge with the Parbati. The entire catchment of the Parbati river is covered by sub-alpine temperate and sub- tropical coniferous and deciduous forests. The water sample collection is done at Jia (Lat. 31°53'N, Long. 77°09'E), near Bhuntar, Kullu, HP State. This is about 1km upstream of the Confluence point (Fig. 1). About 150 samples were collected during the period Jan 2002 to October 2005 on weekly basis from middle of the river or flowing part of the stream to avoid any standing water which is not well mixed and may show effects due to evaporation or pollution. Samples were collected in pre-cleaned 60-mL polypropylene bottles. (Tarsons). These were rinsed twice at site with river 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.

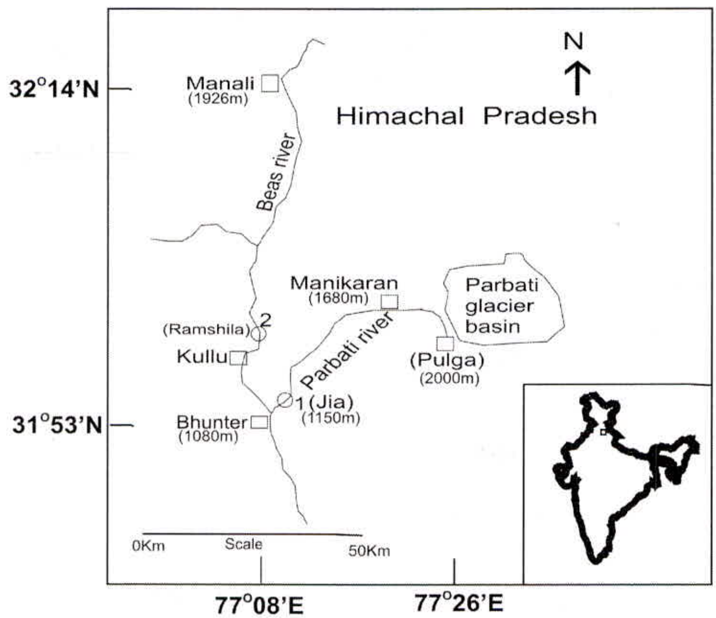

Fig. 1 : Location map of the sampling location for water samples at Jia on Parbati river. India map is shown in inset.

MEASUREMENT TECHNIQUE

The oxygen and hydrogen isotope measurements were carried out using a water equilibration system coupled to a GEO 20–20 mass spectrometer (PDZ Europa, UK). For oxygen and hydrogen isotopes, 1 mL of water sample was equilibrated with tank CO_2 (at 35°C, for 12 h) and tank H_2 (at 35°C, for 2 h in the presence of Pt catalyst (Hukko beads), respectively, and aliquots of equilibrated CO_2 and H_2 were separated cryogenically. The flushing, filling and sampling of gases were carried out using a Gilson auto sampler controlled by the mass spectrometer software. The isotopic compositions of CO_2 and H_2 were analyzed following standard IRMS (Isotope Ratio Mass Spectrometry) procedures. Along with each batch of samples, a laboratory water standard (NARM, Narmada River Water, $\delta^{18}O$ = -4.52‰, δD = -35.2‰ relative to Vienna Standard Mean Ocean Water (VSMOW)) was also measured, from which the final sample δ-values (relative to V-SMOW) were calculated. The overall precision, based on repeat measurements of about a 40-50 samples, is $\pm$0.1‰ for $\delta^{18}O$ and $\pm$ 1.0‰ for δD.

RESULTS AND DISCUSSION

This is a continuous data set on oxygen and hydrogen isotopic composition ($\delta^{18}O$ and δD) from a Himalayan river for a period of 4 years for the period Jan. 2002 to October 2005. The range of $\delta^{18}O$ is -8.3 to -13.2‰ where as δD varies from -52 to -91‰ for the whole period. The data shows, in general, seasonal variation of these isotopes (detailed discussion of these aspects are published elsewhere). Monthly averages of the $\delta^{18}O$ and δD are computed for the presented study. The Figure-2 shows the comparison of monthly averages of $\delta^{18}O$ and δD with hydro graph of water discharge. We considered the discharge data from a place "Pandoh", down stream of Beas river (Data from Global River Discharge Centre) for discussion of our isotopic data since the water discharge data is not available from our sampling site. It clearly shows more depleted values of $\delta^{18}O$ and δD are found during high discharge time when the contribution of river water is dominated by rain during July, August and September. The average value of $\delta^{18}O$ and δD in these three months are -11 and -73‰ which are depleted values when compared to that of average values of 9.2 & -59.5‰ during summer months (March, April and May). This depletion is due to "Amount effect".

In summer months, the melting of snow/ice from higher altitudes in Parbati valley dominates to river discharge. During summer ablation period, the snow/surface ice melt water running off directly, with enriched (high) $\delta^{18}O$ and δD values which either originates from summer precipitation or was enriched in heavy isotopes through extended exposure of the glacier surface. During the month of June, the river

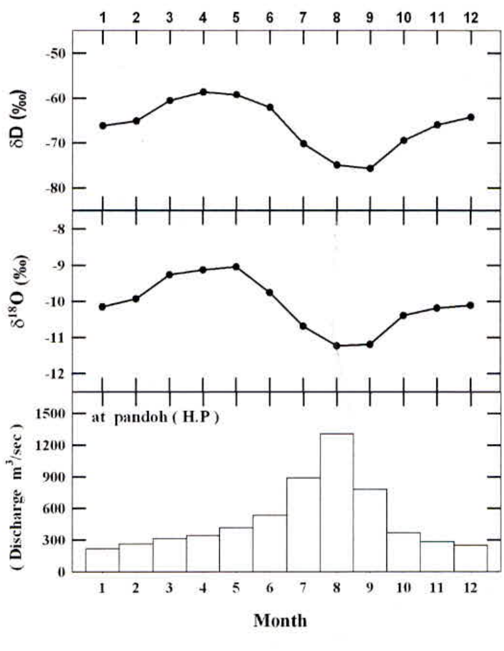

Fig. 2 Monthly averages of $\delta^{18}O$, δD and discharge for all four years are plotted against time. The discharge data is takenfrom a place "Pandoh", down stream of Parbati and Beas river.

water may have some contribution from rainfall apart from melting of snow/surface ice . Remaining months, the river contain mostly contribution from either ground water or hot/cold springs in Parbati valley. Apart from these source contributing to river discharge , there is another small component throughout the year called sub glacial spring waters i.e. the water running off underground through the channel system of the glacier and the ground , characterized by depleted (low) $\delta^{18}O$ and δD values owing snow cover. This is mainly due to heat from earth surface below the glacier. This contribution is more or less constant except some variation in summer. Since there is little/no rain and very low temperatures during winter period, the river waters must have contribution either from local hot/cold spring located near Manikaran area of Parbati valley or from ground waters. To estimate these contributions of different sources, we need to know the signature of $\delta^{18}O$ and δD in these sources from the study area .

Estimation of source signature

Signatures of $\delta^{18}O$ and δD in Snow/surface ice

Direct measurements of $\delta^{18}O$ and δD in precipitation (either rain or snow) are not available in this region. However limited data is available in snow and surface ice samples collected from the following glaciers in western and central Himalayas. 1) Tiprabank glacier in valley of flowers of Uttaranchal, 2) Chhota Shigri glacier, Lahul spiti valley , Himachal Pradesh (Nijampurkar and Rao 1992), 3) Dokrinai Bamak glacier , Garhwal Himalaya, U.P (Nijampurkar et.al 2002). The Snow and Surface ice samples were collected at different altitudes from these three glacier. The range and mean values are given in Table. 1. From this data, the signature of $\delta^{18}O$ for snow/surface ice is estimated to be -8.34‰.The $\delta^{18}O$ and δD values are also measured in sub glacial spring waters from the snout of Tiprabank glacier and they are -15.3 and -108.3‰ respectively.

Isotopic composition of spring waters in Parbati valley

Giggenbach et. al had collected about 50 samples from cold and hot water springs from Manikaran, Kasol and Jan area of Parbati valley in 1979 to study the isotopic composition of these waters and the results were reported (Giggenbach et. al 1983). The range of $\delta^{18}O$ is -9.86 to -7.79‰ with an average of -9.15‰ where

Table 1 : Range and mean values of $\delta^{18}O$ (‰) in snow and surface ice]samples from the central and western Himalayan glaciers.

Sr no	Glacier	Altitude (m)	Snow Range	Snow Mean	Surface Ice Range	Surface Ice Mean
1	Chhota Shigri (H.P) (August 1987)	4000 to 4700	-3.75 to -9.80	-6.54 ± 1.81	-6.2 to -11.0	-9.06 ± 1.78
2	Tiprabank (Uttaranchal) (August 1985)	3900 to 4600	-5.12 to -7.82	-6.47± 1.91	-10.68 to -13.51	-11.76 ± 1.08
3	Dokriani Bamak (Uttaranchal) (November 1993)	3960 to 4700	-4.82 to -9.86	-7.60 ± 1.77	-11.02 to -12.16	-11.73 ± 0.62
4	Dokriani Bamak (Uttaranchal) (May-June 1994)	-do-	-3.04 to -9.85	-5.33 ± 2.57	--	--

as δD varies from -63.0 to -52.1‰ with an average of -59‰ which can be used as signatures for spring waters in this region. The means of $\delta^{18}O$ and δD for snow/surface ice, sub glacier spring waters along with that for hot/cold spring water can be used as signature for the respective sources contributing to Parbati river waters.

Estimate of runoff components in different seasons

Lean period

As discussed in previous section, during the lean period, the river water contains contribution from hot/cold spring (also know as shallow ground waters) and sub glacial spring water. By using two component mixing model , $\delta^{18}O$ and δD values of sources and river water, the runoff components for spring water is calculated and given in Table. 2 . The estimates obtained by $\delta^{18}O$ and δD separately are similar with in errors and hence average values are computed for the months November, December, January and February. From this data, the contribution from sub glacial spring water is calculated and given in Table. 2. The data indicates a more or less a constant value during this period except in the month of November. The higher value in this months may be probably due to the reason that the temperature during this month is slightly higher compared to the other three months. Therefore, even though it is assumed that the contribution from sub-glacial spring water is constant, this will be more during summer months due to higher temperatures.

Summer period (March, April and May)

The river water has contributions from three sources during summer as discussed earlier. Since our model is only meant for two sources, one of the source (sub glacial waters) can be assumed as constant run-off to the river. As we have mentioned in previous paragraph that, the contribution from sub glacial spring water during summer can be higher by 15-20% more compared to that in lean period. The remaining two sources contribution is calculated using two component model and their $\delta^{18}O$ signatures. The data (Table. 3) indicate that the contribution from snow/surface ice melt is increasing from march to may and this could be due to higher temperatures in May. Where as the contribution from spring water is more or less constant but these values are 5-10% of that calculated for the winter months. This can be explained as follows : during the monsoon period, the higher reaches of

Table 2 : Runoff components due to glacier ice melt and spring water during lean period.

	Month	Discharge (m^3 /sec)	□^{18}O (‰)	□D (‰)	Spring Water (from □^{18}O)	Spring Water (from □D)	Average contribution	gl. ice melt contribution
1	Jan	215.9	-10.17	-65.30	180.2	188.5	184.4	31.5
2	Feb.	261.8	-9.93	-64.15	220.8	234.7	231.7	30.1
3	Nov.	283.5	-10.18	-66.22	236.2	242.3	239.2	44.3
4	Dec.	248.2	-10.11	-64.50	209.6	220.7	215.2	33.0

Table 3 : Runoff components due to snow/surface ice melt and spring water during summer (March, April and May).

	Month	Discharge (m^3 /sec)	$\delta^{18}O$ (‰)	Snow /surface ice	Spring Water
1	March	313	-9.27	213	65
2	April	340	-9.21	235	70
3	May	415	-9.35	315	65

Manikaran gets recharged with rain water and flows down ward via subsurface channel and reaches to springs in Parbati valley in a few months time and hence the contribution from springs increases after the monsoon period.

Monsoon period (July, August and September)

During the monsoon period, the river water is dominated by direct precipitation and the contributions from other sources like spring water or snow/surface ice melt waters are very less. Only the other source which contributes to river is sub-glacial spring water irrespective of the season. Hence the contribution from rain is estimated by simply subtracting the sub-glacial spring water contribution from total discharge during of June since this month there may be significant contributions from both rain and snow/surface ice melt along with spring water and glacier melt. The above estimated runoff components can be plotted along with hydrograph of river discharge for further use. The present study demonstrated successfully the use of stable isotopes of water to delineate the runoff components of a river discharge at sampling location.

CONCLUSIONS

By using lean period data , a constant run-off component of sub glacial spring water from bed rock of the glacier in the region is estimated to be 35m^3/sec in Parbati river waters. The runoff components during summer months (March, April and May) are estimated and the data indicate that the contribution from snow/surface ice melt is increasing from march to may which could be due to the higher temperatures during May. Similar investigations can be extended to the other rivers of the Punjab to decipher the run-off components.

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