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Isotopic Characteristics of Waters of Bist- Doab and their Hydrological Significance

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Abstract: A study was conducted to characterize various water resources in the Bist- Doab region, Punjab using stable isotopes. Characterizing the water resources in a region like Bist- Doab, which has varied geo-morphology, intensive cultivation of crops and a long network of canal system, is most critical and important factor. Taking into account all these factors, the use of stable isotopic technique could be suitable to characterize the waters of Bist- Doab region. To accomplish the study, the surface water samples from the rivers Sutlej and Beas and shallow groundwater, and rainfall samples from the Bist- Doab region were collected randomly to get representativeness of the entire study region. The isotopic composition ä^{18}O of rainfall, Rivers (Saltluj and Beas) and shallow groundwater is -16.3‰ to 1.1‰, -11.4‰ to -6.6‰ (Satluj) -7.3‰ to -6.6‰ (Beas), and -7‰ to -4.9‰ (shallow groundwater) respectively. The slope of LMWL derived for the study area is similar to that of GMWL and IMWL (north). Whereas, the intercept of the same differs varies from IMWL (north) and GMWL indicating difference in source of precipitation. Among the rivers, Satluj show depleted isotopic composition than that of the Beas. The isotopic composition of the R. Satluj shows enriched character near the confluence with R. Beas indicating a probable mixing of R. Beas or influence of groundwater as base-flow. The groundwater composition shows similar isotopic character to that of precipitation near Kandi belt and at the central part of the study area. The high depleted isotopic concentration of groundwater surrounding Garhshankar might be due to the influence of canal draining from R. Satluj. The best- fit lines of precipitation, groundwater and rivers derived from the ^{18}O and D plot shows that the groundwater behaves similar to that of precipitation with a minor influence from the rivers.

INTRODUCTION

In recent decades, increasing population, human activities, growing demands and catchment degradation have made investigation of groundwater recharge sources as one of the major concern for the water managers. The sources of recharge to a groundwater system include both natural (precipitation, lakes, ponds, rivers and other aquifers) and human- induced (includes irrigation loss from canals and fields, leaking water mains and over irrigation of parks, gardens and etc.) phenomena. Environmental stable isotopes (oxygen- 18 (^{18}O) and deuterium (D)) have been used during last decades in water resources development in many ways. In case of groundwater these have been used to identify and estimate recharge sources (Mathieu and Bariac, 1996; Gupta, 1983), to determine the effects of evaporation on groundwater systems (Hendry and Schwartz, 1988; Clark, 1987; Deshpande *et al.* 2003; Gupta *et al.* 2005), to estimate advection/ diffusion rates in unsaturated/saturated zones (Gupta 1983), and to examine groundwater and surface water interactions (Krabbenhoft *et al.* 1990).

The Bist- Doab region, the interfluves region between R. Sutlaj and Beas; Doab: local word for interfluve, experiences high amount of groundwater depletion despite input from two perennial rivers. Due to increasing agricultural activity water demand in the region is increasing day by day putting more pressure on groundwater causing groundwater mining, and exploitation. Groundwater stage in the region has gone up to 300% with almost 80% of the regions showing more than 100 % (CGWB, 2007). The high amount of over exploitation of groundwater in this region has caused an emergency for identification of groundwater recharge sources in the region. There is no known stable isotopic study have been carried out in theBist- Doab area. Hence, in the present study we have tried to characterize various water resources and index the source waters of Bist- Doab region.

Stable Isotopes of Oxygen and Hydrogen

Oxygen has mainly three isotopes i.e. ^{16}O, ^{17}O and ^{18}O and all the three are stable in nature. The hydrogen also has three isotopes ^{1}H, ^{2}H and ^{3}H but the first two are stable while the third is radioactive. Stable isotope compositions are normally reported as δ values in units of parts per thousand (denoted as ‰) relative to a standard of known composition. The ä values are calculated using: δ (in‰) = $(Rx/Rs-1)1000$. Here R denotes the ratio of heavy to light isotope (e.g. $^{18}O/^{16}O$ or D/H) and Rx and Rs are these ratios in the sample and standard respectively. δD and $\delta^{18}O$ values are normally reported relative to SMOW (Standard Mean Ocean Water) or the equivalent VSMOW (Vienna–SMOW) standard. In spite of the great complexity in different components of the hydrological cycle, $\delta^{18}O$ and δD in meteoric waters behave in a predictable manner and correlate to define a global meteoric water line (GMWL). This correlation was further refined as (Rozanski *et al.* 1993):

$$\delta D = 8.17(\pm 0.07)^{*}\ \delta^{18}O + 11.27(\pm 0.65)‰\ \text{VSMOW} \quad (1)$$

Deviation of regional or local meteoric water lines (LMWLs) from GMWL help to identify the climatic and geographical dimensions of hydrological processes and provenance of different water masses (Gupta and Deshpande, 2005).

During isotopic fractionation processes (e.g., condensation of water) heavier isotopes tend to prefer condensed phase (liquid phase in the case of condensation). As a result, along the trajectory of the air masses, each rainout preferentially removes the heavy isotopes from the vapour. The remaining vapour then becomes progressively depleted both in ^{18}O and D. Isotope fractionation, can be (i) equilibrium type (e.g., condensation of vapour in cloud water during rain) or (ii) non equilibrium type or kinetic type (e.g., evaporation in open space). The kinetic fractionation of ^{18}O is more than D (as compared to equilibrium fractionation). Hence, relative enrichment of ^{18}O (in liquid phase of water) during evaporation process is more than D. As the evaporation proceeds, the residual water not only enriches in heaver isotopes but also shows progressively lower *d-excess* (= $\delta D - 8\delta^{18}O$) values due to relatively more enrichment of ^{18}O (Clarke and Fritz, 1997; Gupta and Deshpande, 2005). The resulting vapour on the other hand shows the opposite effect. The condensation, and consequently rainout, does not significantly alter the *d*-excess (~10) as it is an equilibrium process (with slope ~8 of $\delta^{18}O$ & δD line). Due to the involvement of evaporation (kinetic fractionation) during infiltration, most groundwater show slope lower than 8 in its $\delta^{18}O$ & δD systematics. Due to large reservoir size of groundwater, recharge component due to each rain event is a small fraction of the total reservoir. Therefore, rather than isotopic composition of individual rains, isotopic composition of groundwater shows weighted annual composition of precipitation.

In general, isotopic composition of precipitation depletes with increasing latitude (*latitude effect*), altitude (*altitude effect*), distance away from coast (*continental effect*) and rainfall intensity (*amount effect*). Therefore, the isotopic signature of different types of water like precipitation, rivers, lakes, reservoirs, groundwater, ocean etc. varies because of the processes explained above, operating kinetic/equilibrium isotopic processes, depending on the nature of source of water and its location. Hence, the isotopic signature of different water sources becomes very important to understand various hydrological processes.

STUDY AREA

The Bist- Doab is a triangular region covering an area of 9060 sq.km lies between 30° 512 and 30° 042 N latitude and 74° 572 and 76° 402 E longitude (Fig. 1). It comprises of the districts Jalandhar, Kapurthala, Nawanshahar, and Hoshiarpur of Punjab State. The region is bounded by Siwalik's (360- 900 m. amsl) all along its NE-SE portion, the river Beas in the north and west direction and the river Satluj in SE and southern boundary. The two rivers coalesce at Harike. The area is drained by canal and tributaries of the river Satluj and Beas. The drainage density is high at the NE strip bordering Siwaliks and moderate to low in the rest of the area. The region experiences an average of 715 mm annual rainfall with rainfall trend deceasing from Siwaliks to plains (Chopra and Sharma, 1993).

Geological Setting

Geomorphologically, the region is divided into three zones: the Siwaliks, Kandi watershed, and flood plain area (Bowen ,1985). Kandi (or Bhabhar which is a piedmont zone) lies immediately. The area, part of Indo- Gangetic plain, receives huge pile of sediments of Pleistocenece to recent age due to erosion in the mountains and deposited by the rivers Satluj, Beas and other streams draining the area. Lithologically, three sequences are observed: (i) Surface deposits of recent origin also locally known as Khadd, (ii) Sirowal (or Tarai) sediments. It is low relief and very fertile land. The groundwater in Sirowal occurs as seepage in the beds of choes (springs) and in small depressions forming pools. It is mainly recharged at Kandi belt. The alluvium of Sirowal is poor in calcareous matter and; (iii) Boulder beds with interbedded clays of Pleistocene origin.

Sampling and Analysis

The river water (12 samples) and groundwater (80 samples) samples were collected in the year 2009 from the entire study area to avoid any biasness in the interpretation. Daily precipitation (Fig. 1) sampling of monsoon period of 2009 was done from five rainfall collection sites, four from Kandi belt (Ropar, Baddi, Maili dam, and Dolwaha dam) where the region experiences high rainfall (Chopra and Sharma, 1993) and one from Harike (plains) to derive LMWL. The collected samples were analysed for oxygen and deuterium isotopes using CF-IRMS and DI-IRMS in isotope laboratory, National Institute of Hydrology, Roorkee, India

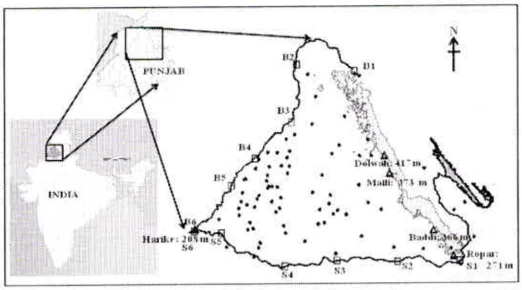

Fig.1. Location and Sampling sites in the study area. The Open triangle denotes Precipitation (values in parenthesis indicates altitude above mean sea level), Open Squares indicates river (Satluj (S) and Beas (B) respectively) Samples and closed circles denotes shallow groundwater sampling locations.

RESULTS AND DISCUSSION

Precipitation

Elevation, rainfall and isotopic composition of precipitation measured at the sampling locations are given in the Table 1. The isotopic composition of rainfall varies from -16.3 to 1.4‰ (^{18}O) and -128.5 to 16.2‰ (D) in the kandi belt and -9.8 to -1.5‰ (^{18}O) and -77.0 to -5.9‰ (D) in Harike. The variation of the isotopic composition of rainfall with time and amount is given in Figure 2 (a-d) which shows that the isotopic composition at Kandi region varies irrespective of the amount of precipitation. The isotopic composition of rainfall is enriched during the onset of monsoon (before mid-August) and depletes with the progress of monsoon. The isotopic composition shows maximum depletion during recession of monsoon (1st-2nd week of September). It can be seen from the example of Dholwah that rain of July 30 and September 1st is almost of equal magnitude but, September rain is more depleted (– 14‰) compared to July rain (– 4‰). The change in isotopic signature might be due to difference in source of origin of air moisture/cloud. The amount weighted isotopic composition of precipitation (Fig. 3) in the kandi area shows similar trend with that of the Indian Meteoric Water Line (IMWL) for the north region (Kumar *et al.* 2010) and GMWL (Rozanski *et al.* 1993). The slope of the regression equation derived for the Kandi region is similar to that of the IMWL-North and GMWL (Fig. 3) and change in intercept indicates an additional source of moisture for precipitation. The LMWL fall below IMWL-North and GMWL (Fig. 3) might be due to effect of local moisture from reservoir and dams (Bhakra, Govind Sagar, Pong, and other minor reservoirs) of the region. A detailed study on isotopic signatures of precipitation is required to understand the effects produced by the manmade structures present in the study region.

Table 1 : Isotopic composition of precipitation at Kandi belt and Harike, Bist- Doab region

Source	Elevation (m)	Amount (mm)	$\delta^{18}O$ (‰)	δD (‰)
Dholwah	417	511	-6.83	-48.62
Maili	373	481	-6.22	-41.61
Baddi	366	690	-6.01	-47.15
Ropar	271	609	-7.28	-52.71
Harike	208	282	-6.89	-54.01

Table 2 : Isotopic characterization of waters of Bist- Doab region

Source	$\delta^{18}O$ (‰)	δD (‰)
Precipitation (at Kandi)	-7.3 to -6.0	-52.7 to -41.6
River Beas	-7.3 to -6.6	-44.2 to -40.6
River Satluj	-11.4 to -6.7	-74.3 to -69.0
Shallow Groundwater (Near Kandi)	-10.0 to -6.0	-62.0 to -42.0
Shallow Groundwater (Near Harike)	-6.0	-46.0 to -42.0

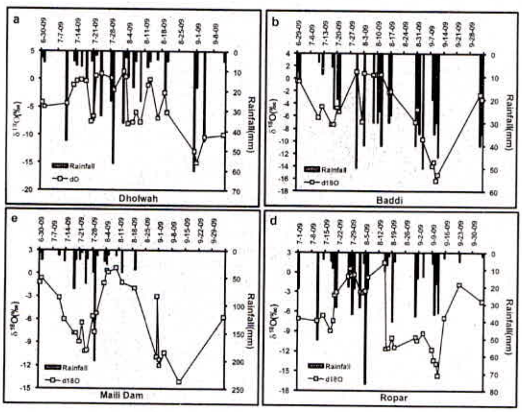

Fig.2 : Time series plot of ä^{18}O and Precipitation during Monsoon 2009

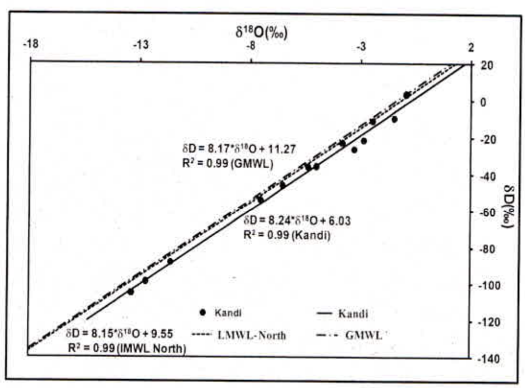

Fig.3 : ä^{18}O vs äD plot of monthly weighted average of precipitation in Kandi belt

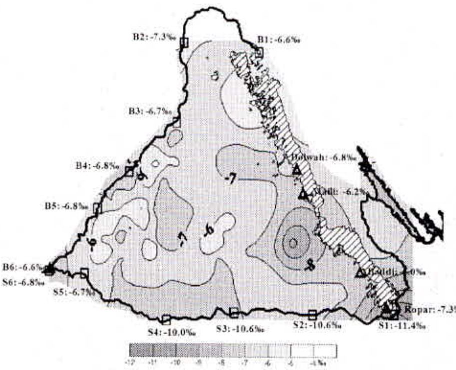

Fig.4 : ä^{18}O Composition of Rivers and Shallow aquifer of the study area

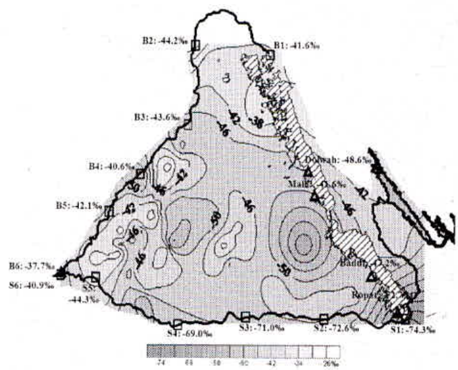

Fig.5 : äD Composition of Rivers and Shallow aquifer of the study area

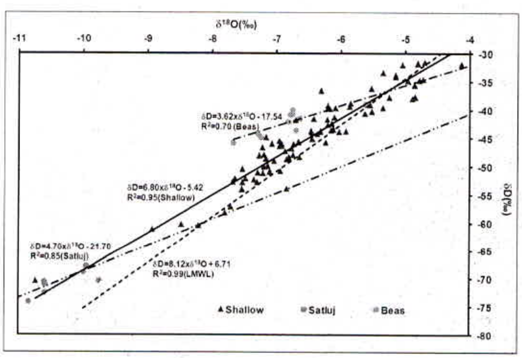

Fig.6 : δ^{18}O vs äD bi- plot of Rivers, Precipitation and groundwater in Bist- Doab region

Isotopic Characterization of Rivers and Groundwater

Isotopic composition of R. Beas varies from -5.6 to -7.6‰ for δ^{18}O and -39.1 to -44. 2‰ for δ D and the R. Satluj varies from -6.6 to -11.3‰ for δ^{18}O and -37.7 to -74.3‰ for δD (Table 2, Fig. 4& 5). The isotopic composition of R. Beas is enriched than that of R. Satluj and is similar to that of precipitation. This indicates that major component of discharge in the R. Beas is derived directly or indirectly (groundwater base flow component) from local precipitation and the contribution of discharge due to high altitude glacial/snowmelt or surface run-off is less. The depleted isotopic composition of R. Satluj indicates that it is derived from much higher altitude. Isotopic composition of rivers shows that δ^{18}O and δD values show similar composition at the confluence of rivers i.e at Harike. This might be due to the influence of river Beas on Satluj at confluence or that the river Satluj might be fed by the base flow of groundwater.

The isotopic composition of groundwater of the Bist- Doab region shows variation in δ^{18}O over the range from -4.46‰ to -8.93‰ and δD over the range from -26.63 to -61.11‰. In major part of the study region, the isotopic composition of groundwater in the study area is similar to that of local precipitation, i.e. around -6‰ to -7‰. Highly depleted value of δ^{18}O (-9‰ -10‰) around Garhshankar might be due to the presence of canal that is drained from R. Satluj. Groundwater in areas close to the R. Beas shows isotopic composition similar to that of the composition of R. Beas indicating a good interaction between groundwater-river Satluj. But, such an interaction is rarely observed in the case of River Satluj.

The δ^{18}O vs δD bi- plot (Fig. 6) for groundwater shows that groundwater samples fall mostly along the LMWL with some of the samples falling along with the rivers. The regression equation of the groundwater with a slope near to that of LMWL indicates influence of local precipitation compared to that of rivers. Similarity between isotopic composition of precipitation, groundwater and river Beas (with moderately enriched composition in the river Beas) indicate that a component of groundwater recharged through local precipitation is contributing base-flow to the river Beas. The slope comparison in the regression equation between $\delta^{18}O$ vs δD plot for rivers and groundwater (Fig. 6) indicate that groundwater is least subjected to evaporative effect during recharge process (slope =6.8) followed by moderately affected Satluj river water (slope =4.7) and then the river Beas water which is highly affected by evaporation process (slope= 3.6).

CONCLUSION

The groundwater in the Bist- Doab region is experiencing increasing depletion due to increasing agricultural activity and rapid industrialization. Detailed isotopic analysis of groundwater, precipitation and river water revealed various hydrological features. The monsoon precipitation at Kandi region is influenced by some additional moisture source which may be arising from recycling of moisture originating from local dams and reservoirs. Groundwater in the study region is recharged mainly through local precipitation. The recharge is highest in Kandi region. The impact of Satluj canal on groundwater is marginal and very local. A fraction of groundwater is discharging as base-flow into the river Beas, making its isotopic composition similar to the local groundwater. The base flow contribution is very less to the R. Satluj compared to the river Beas. At the confluence zone of rivers Beas & Satluj the groundwater and surface water composition is similar to the composition of river Beas.

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