APPLICATION OF $\delta^{18}O$ and δD TO IDENTIFY THE SOURCE OF PRECIPITATION, SURFACE WATER AND GROUND WATER IN SRINAGAR, KASHMIR (INDIA)

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ABSTRACT

The stable isotopes of water ($\delta^{18}O$ and δD) were employed to identify the source of precipitation (rain), surface waters and groundwater in Srinagar, Kashmir Valley (India). In case of surface waters, $\delta^{18}O$ and δD values range from -8.90‰ to -4.70‰ and 52.47‰ to -29.78‰, respectively, whereas in groundwater $\delta^{18}O$ and δD values range from -8.55‰ to -6.21‰ and -52.88‰ to -36.08‰, respectively. Besides, winter (December to February), the depleted isotopic values in precipitation (rain) were observed in the month of August and enriched isotopic values were observed in September. The depleted heavier isotopes of water in August were attributed to the SW monsoons whereas, the enriched values (September) were attributed to the secondary evaporation of rain drops. The local meteoric water line (LMWL), $\delta D = 6.85*\delta^{18}O + 6.17$ ($r^2 = 0.94$), for Srinagar, Kashmir showed slightly lower slope and intercept than the global meteoric water line (GMWL). The regression line of surface water has lower slope and intercept than LMWL and that of groundwater has lower slope but higher intercept than LMWL and GMWL. The surface water and groundwater showing significant correlation with each other indicating the same source of surface water and Groundwater or surface water is recharging ground water dominantly. The study suggests that the snowmelt dominantly contributes to the surface water and groundwater.

Keywords: Stable isotopes; $\delta^{18}O$ and δD, precipitation, surface water, groundwater, srinagar

INTRODUCTION

The stable isotopes of water (deuterium and oxygen-18) are direct markers of the water molecule. The movement of water in hydrological cycle has been traced by the use of stable isotopes (Zimmerman *et al.*, 1967; Gonfiantini, 1967; Dincer *et al.*, 1970), which inturn has a tremendous significance in water resources development and management. The stable isotopes vary in precipitation due to several climate 'effects' including amount, temperature, continental, altitude effects (Dansgaard, 1964; Rozanski *et al*., 1993). The physiographical and meteorological effects results in a characteristic isotopic signature of meteoric water at a specific location (Clark and Fritz, 1997; Price and Swart, 2006). This characteristic nature results in the utilization of these stable isotopes in identifying and/or distinguishing the source and pathways of streams and groundwater recharge (Price and Swart, 2006; Jeelani *et al*., 2010). Over the past two decades, interpretation of changes in the δ^{18} O isotopic signatures of catchments waters have provided insights into identifying hydrological source areas or flow paths under different flow conditions and in estimating mean catchment residence times (Sklash, 1990; Genereux and Hooper, 1998; Kendall and Coplen, 2001; Burns, 2002). To date, isotopes in small catchments have been useful in assisting the conceptualization of runoff generation models (Uhlenbrook *et al*., 2002) and can complement runoff gauging measurements through quantification of the travel time of water and pollutants through the catchment, assessment of sources of runoff, evaporation losses and delineation of infiltration and exfiltration zones along streams (Kendall and Coplen, 2001). D-excess is a second order parameter, defined as d = **$\delta D - 8^* \delta^{18}$ O. It** is another important parameter utilized to identify the moisture source (Marlivat and Jouzel, 1979). The D excess increases in the atmospheric vapor due to moisture recycling and consequently in the precipitation after its condensation. Thus D excess appears an indicator of evaporated moisture recycling. Stable isotopes have been monitored in precipitation, surface water and groundwater in Srinagar, Jammu and Kashmir.

The main objectives of the present study were: i) to identify the sources of precipitation, surface water and groundwater of the Srinagar/Kashmir valley, ii) to assess the impact of hydrometeorological processes on the isotopic composition of precipitation, and iii) to find the dominant source contributing to surface water and groundwater.

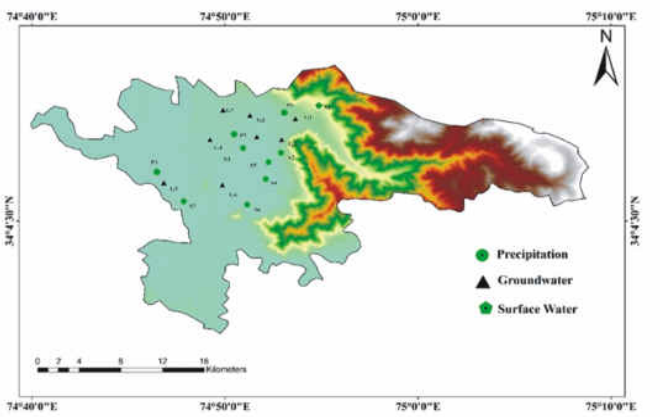

Fig. 1. Map showing sampling locations of precipitation, surface water and groundwater samples in Srinagar, Kashmir

STUDY AREA

Srinagar district situated in the heart of Kashmir valley lies between 34° 3' 34° 20' N latitudes and 74° 40' - 75°15' E longitudes and covers an area of 294 km² (Fig.1). The study area is experiencing temperate climate with marked four seasons namely; spring (March - May), summer (June - August), autumn (September - November) and winter (December - February). The average annual temperature is 13.5 °C and total precipitation averages 710 mm annually. The average monthly temperature ranges from 24.1°C in July to 2.5°C in January. The average monthly minimum and maximum temperatures range from -2°C to 18.1°C and 7°C to 30.1°C (January & July) respectively. The average precipitation ranges from 28 mm (Sep & Nov) to 121 mm (March). Thus, March receives maximum precipitation and Sep & Nov receives minimum precipitation in the study area (www.srinagar.climatemps.com).

Geologically Srinagar area falls within the Kashmir Nappe Zone which comprises mostly Quaternary alluvium overlying the rock terrain. The Geological succession of the study area (worked by Raina and Kapoor, 1964) comprises: Alluvial deposits, Karewa beds, Triassic Formations, Zewan Series, Gangamopteris beds, Panjal traps, Agglomeratic Slate and Cambro-Silurian.

The study area is represented by two physiographic features viz: the highland and the low flat land. The highland is represented by the Zabarwan Range which is the offshoot of the Zanskar Range. It is confined to the northern, northeastern and southeastern extremity of the area. The average elevation of the range is 3,050 m. The low flat land formed of thick horizontal sedimentary pile confined to southern and southwestern part of the Srinagar area has an average height of 1,600 m. The main sources of fresh water in Srinagar are lakes, springs, rivers and streams. Some people are also using groundwater through hand pumps.

METHODOLGY

Monthly composite water samples were collected from three precipitation sites viz; Dara (P1), Mala Bagh (P2) and HMT (P3) from August to November 2013. Groundwater samples were collected from locations of Dara (G1), HMT (G2), Mala Bagh (G3), Harwan (G4), Habak (G5),Shalimar (G6) and Batapora (G7) while surface water samples (stream water and lake water) were collected from locations of Dara (S1), Shalimar (S2), Dal inflow (S3), Dal middle (S4), Boddal (S5), Dalgate (S6) and Jhelum (S7) from Sep 2013 to Feb 2014. Rain water samples were collected in homemade precipitation collectors, designed by IAEA (International Atomic Energy Agency/Global Network of Isotopes in Precipitation sampling guide). The precipitation collector consists of 5 litre plastic container fitted with a funnel and a long narrow tube to avoid evaporation. The samples of surface water and groundwater were collected in 100ml bottles without airspace and were first rinsed with same water to be collected. The water samples were analyzed for $\delta^{18}O$ and δD at the Isotope Application Division, Physical Research Laboratory Ahmedabad (PRL) using an isotope ratio mass spectrometer (Europa Geo 2020) equipped with an equilibration unit (Europa WES) and following the gas equilibration method (Epstein and Mayeda, 1953). The precision of the measurements was within 0.1‰ for $\delta^{18}O$ and 1.0‰ for δD. The stable isotopes Oxygen-18 and Deuterium in per mil (‰) are reported relative to Vienna Standard Mean Ocean Water (VSMOW).

RESULTS AND DISCUSSION

$\delta^{18}O$ and δD variation in precipitation

Stable isotopes in the precipitation (rain water) showed marked spatial and temporal variability. Spatially, the enriched and depleted values w.r.t heavy isotopes were observed at HMT and Malabagh respectively. The stable isotopic values in precipitation samples showed a range of -11.95‰ to -1.31‰ for $\delta^{18}O$ and -81.68‰ to -7.58‰ for δD (Table 1).Weighted mean values of $\delta^{18}O$ and δD varied from -9.19‰ to -7.59‰ and -61.48‰ to -48.15‰ (Table 1) respectively. Depleted values of $\delta^{18}O$ and δD in precipitation samples were found in the month of August and enriched values of $\delta^{18}O$ and δD in September (Fig.2). These temporal changes of isotopic composition in precipitation samples may be due to the temporal variability of temperature and precipitation amount. These parameters are negatively correlated with stable isotopes in precipitation i.e., low temperatures and high precipitation will yield depleted values in precipitation and vice versa (temperature and amount effect) (Dansgaard, 1964). Although high temperature in the month of August, the precipitation samples does not show temperature effect but instead of depicting enriched values show lower/depleted values. On the contrary side, the amount of precipitation is high in August. So, the lower/depleted values in the precipitation samples in this month may be attributed to the amount effect/rainout effect or the source that is characterized by these isotopic values. The lower values in the month of August are also found in Yushu, Eastern Tibetan Plateau (Tian *et al.*, 2008). This depleted character of precipitation in this month has been attributed to the SW monsoon in Yushu. This view is further supported by Jeelani *et al.* (2016). The enriched/higher values in September may be attributed to the secondary evaporation as due to high temperature and low precipitation. This is further supported by the d-excess (discussed under heading of d-excess).

Table 1. Statistical summary of minimum, maximum and mean of δ^{18}O and δD and mean d- excess values in precipitation (Site No. as in Fig.1).

			δ^{18}O (‰)				δD (‰)				d-excess
Sites	Site Name	Altitude	Min	Max	Mean	WM	Min	Max	Mean	WM	Mean
P1	Dara	1803	-9.59	-1.58	-5.70	-7.61	-64.25	-10.77	-32.87	-49.40	12.70
P2	Mala-Bagh	1574	-11.95	-1.58	-6.69	-9.19	-81.68	-11.67	-41.13	-61.48	12.40
P3	HMT	1568	-9.75	-1.31	-5.50	-7.59	-64.34	-7.58	-30.00	-48.15	14.00

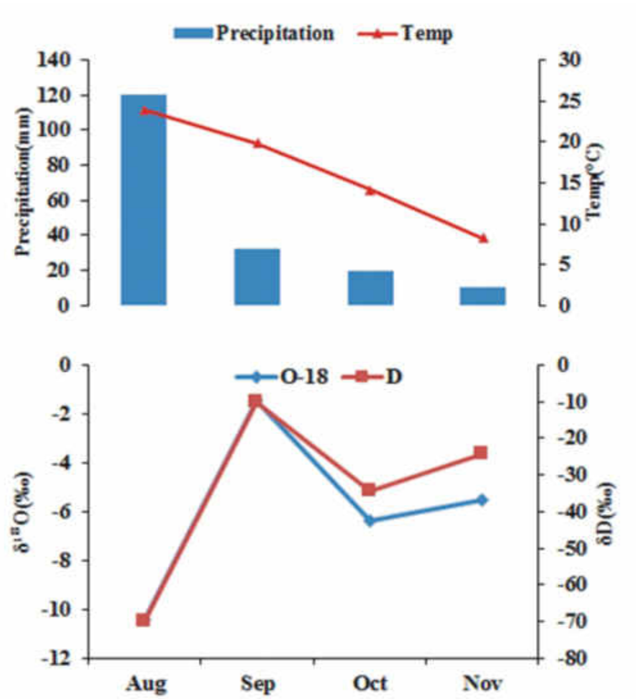

Fig. 2. Average stable isotopic composition of precipitation (3 precipitation sites) and their relation with temperature and precipitation.

δ^{18}O and δD variability in surface water

Minimum, maximum and mean δ^{18}O and δD in surface waters are summarized in Table 2. The δ^{18}O and δD in surface waters varied from -8.90‰ to -4.70‰ and 52.47‰ to -29.78‰ respectively. The minimum and maximum values of δ^{18}O and δD are observed in Dal Middle and Dalgate respectively. Near Telbal Nala and Dal Middle the water that enters might not have suffered higher evaporation while as the Dalgate (Dal outflow) showed enriched values due to the evaporation effect. The isotopic values become enriched w.r.t heavy isotopes in Dal lake from inflow towards outflow which is due to evaporation. Temporal variability of δ^{18}O and δD in surface water is shown in Figure 3. The enriched values of δ^{18}O and δD observed in the months of September & December (Monthly mean = -7.40‰ &-7.70‰ respectively) may be due to the surface water being subjected to the secondary evaporation and/or contribution from isotopically enriched precipitation. Secondary evaporation of surface water during September month seems most probable as there is low precipitation in this month.

The surface water does not show pronounced temporal variability as precipitation show. The comparative study of isotopes in precipitation and surface waters does not show significant correlation. Thus, during the monitoring period there is no immediate impact of precipitation on surface water isotopic composition or there may be very less contribution of precipitation. This correlation is also depicted by the scatter plots of $\delta^{18}O$ and δD of surface waters and precipitation (Fig.4).

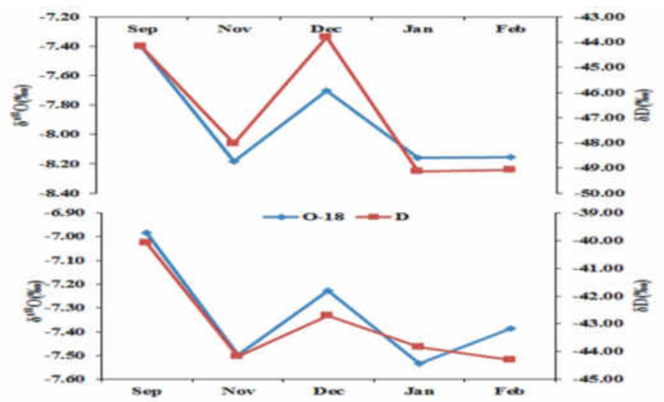

Fig. 3. Temporal variability of $\delta^{18}O$ & δD in groundwater (GW Lower) and surface water (SW Upper).

$\delta^{18}O$ and δD variability in groundwater

The statistical summary of minimum, maximum and mean of $\delta^{18}O$ and δD in groundwater are presented in Table 3. $\delta^{18}O$ and δD in groundwater ranges from -8.55‰ to -6.21‰ and -52.88‰ to -36.08‰ respectively. The data depicts that there is not pronounced temporal and spatial variability of stable isotopes in groundwater during the monitoring period. The temporal variability of groundwater is shown in Figure 3 (above). The enrichment w.r.t $\delta^{18}O$ and δD in the month of September was also reported in spring water samples from south Kashmir which was attributed to contribution from summer rainfall (Jeelani *et al.,* 2014). The variability in groundwater is similar to the variability in the surface water (depicted in Fig. 3). This suggests that there may be the same source through-out the monitoring period.

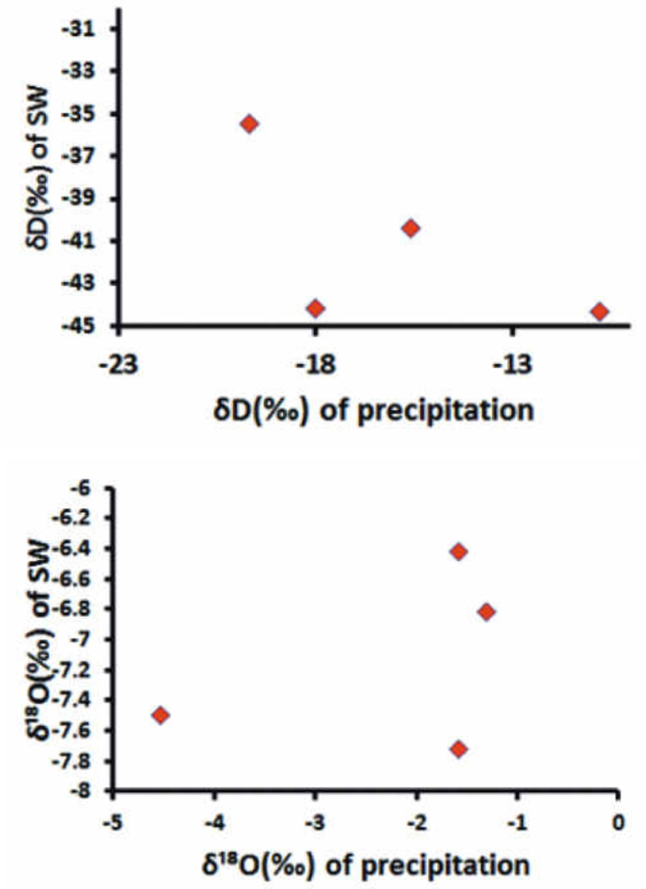

Fig.4. Scatter plots showing relationship of monthly stable isotopes between precipitation and surface water (SW).

Like surface water, groundwater does not show significant correlation with precipitation during the monitoring period. The groundwater shows same behavior isotopically as that of surface water. These results, thus, suggest that there is either very less contribution from the precipitation towards the groundwater or there is no immediate impact of precipitation on groundwater isotopic composition. This correlation is also depicted by the scatter plot of $\delta^{18}O$ and δD of groundwater and precipitation (Fig. 5).

Table 2. Statistical summary of minimum, maximum and mean of $\delta^{18}O$ and δD values in the surface water of Srinagar, J&K (Site No. as in Fig.1).

Site No.	Site Name	Altitude (m)	$\delta^{18}O$(‰)			δD(‰)			D-excess
			Min	Max	Mean	Min	Max	Mean	Mean
S1	Dara	1785	-7.9	-7.50	-7.71	-46.58	-43.55	-44.66	17.03
S2	Shalimar	1585	-6.42	-6.42	-6.42	-48.15	-35.51	-43.32	16.09
S3	Dal inflow	1587	-8.73	-7.83	-8.20	-51.53	-51.53	-51.53	18.33
S4	Dal Middle	1583	-8.90	-8.90	-8.90	-52.47	-52.47	-52.47	18.71
S5	Bod Dal	1581	-6.82	-6.82	-6.82	-40.43	-40.43	-40.43	14.09
S6	Dalgate	1582	-4.70	-4.70	-4.70	-29.78	-29.78	-29.78	7.79
S7	Jhelum	1587	-7.24	-6.08	-6.52	-41.36	-36.2	-38.59	14.21

Table 3. Statistical summary of minimum, maximum and mean of $\delta^{18}O$ and δD values in the groundwater of Srinagar, J&K (Site No. as in Fig.1).

Site No.	Site Name	Altitude (m)	$\delta^{18}O$(‰)			δD(‰)			D-excess
			Min	Max	Mean	Min	Max	Mean	Mean
G1	Dara	1786	-7.72	-7.50	-7.62	-43.65	-42.75	-43.31	17.64
G2	HMT	1582	-7.46	-6.21	-6.83	-44.26	-36.08	-40.17	14.50
G3	Malabagh	1595	-8.34	-7.92	-8.14	-49.40	-49.21	-49.29	15.86
G4	Harwan	1621	-7.82	-7.55	-7.69	-47.03	-41.13	-44.08	17.41
G5	Habak	1578	-8.55	-8.34	-8.48	-52.88	-48.82	-50.85	17.55
G6	Shalimar	1610	-7.80	-7.66	-7.73	-40.84	-40.84	-40.84	20.43
G7	Batapora	1539	-8.53	-8.28	-8.38	-51.34	-49.15	-50.41	16.66

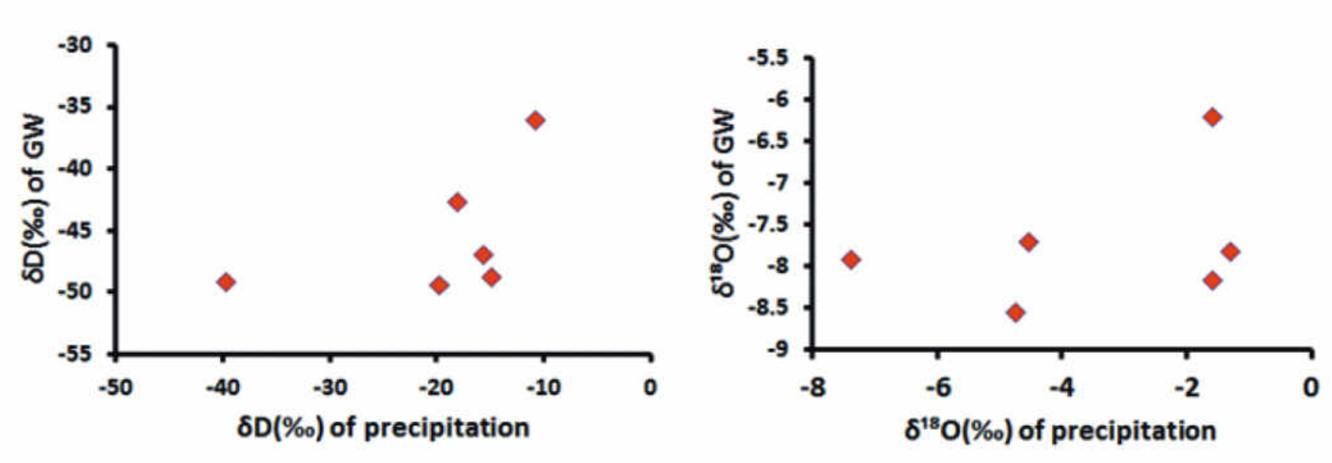

Fig. 5. Scatter plots showing relationship of monthly $\delta^{18}O$ and δD in precipitation and groundwater (GW).

Correlation between surface water and groundwater

The stable isotopes in surface water and groundwater show a significant correlation (r^2 = 0.94). Depletion or enrichment w.r.t heavy isotopes shown by the surface water is also shown by the groundwater. This significant correlation is also depicted by the scatter plots between $\delta^{18}O$ of surface water and groundwater and δD of surface water and groundwater (Fig.6). This type of correlation suggests that either, the surface water and groundwater are fed by the same source or there may be the intermixing of these waters. The detailed study of isotopic composition is required in order to find out the most probable reason of this correlation.

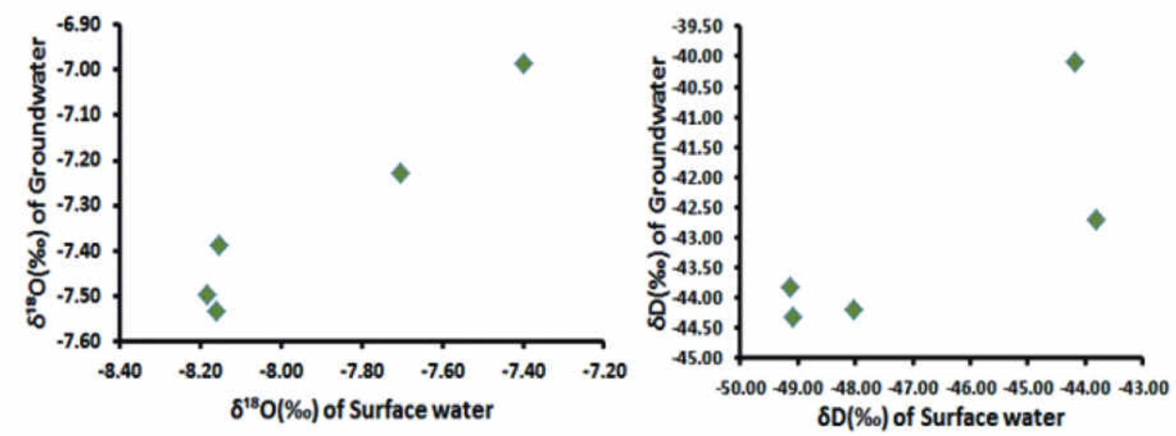

Fig.6. Scatter plots showing relationship of monthly average $\delta^{18}O$ and δD in surface water and ground water.

Local Meteoric Water Line (LMWL)

The correlation of $\delta^{18}O$ and δD with each other (Hoefs, 1973), based on monthly samples is $\delta D = 6.85*\delta^{18}O + 6.17$ (r^2 = 0.94) (Fig.7). The LMWL ($\delta D = 6.85*\delta^{18}O + 6.17$) for Srinagar lies very close to Kashmir Himalayas LMWL ($\delta D = 7.5914 * \delta^{18}O + 11.79$) (Jeelani *et al.,* 2012) and western Himalayas LMWL ($\delta D = 7.95 * \delta^{18}O + 11.5$) (Kumar *et al.,* 2010). Comparable to the GMWL ($\delta D = 8* \delta^{18}O + 10$) (Craig, 1961), this LMWL shows slightly lower slope and intercept. The precipitation samples fall well close to the GMWL. Secondary evaporation of raindrops beneath the cloud base (Dansgaard, 1964) and/or mixing of air mass with water-vapour originating from inland evaporation during summer (Zimmermann *et al.,* 1967) may be the cause of slightly lower slope and intercept. The lower slope and intercept of the LMWL is attributed particularly to the secondary evaporation of the raindrops. This is also depicted by the d-excess values discussed under the sub heading of d-excess.

Monthly mean $\delta^{18}O$ and δD of surface water samples are plotted with respect to the LMWL and GMWL (Fig. 7). The samples that fall below the GMWL are suggestive of evaporation effect. The Dalgate sample well below the GMWL indicates that the surface water in Dal lake have suffered evaporation from the point of inlet to the point of outlet i.e., Dalgate. The regression line ($\delta D = 5.44^* \delta^{18}O - 4.69$) of these surface water samples show lower slope and intercept than the Kashmir Himalayas LMWL and LMWL of Srinagar which thus suggests that the surface water have been effected by the process of evaporation.Similarly, monthly mean $\delta^{18}O$ and δD of groundwater samples are plotted w.r.t the LMWL of Srinagar and GMWL (Fig.7**)**. The regression line ($\delta D = 7.29^* \delta^{18}O + 11.65$) of these groundwater samples exhibits lower slope but slightly higher intercept than LMWL, Kashmir Himalayas LMWL and GMWL. This slight decrease in slope indicates that the groundwater may have been affected by slight evaporation before infiltration. The higher intercept may be due to the source of groundwater.

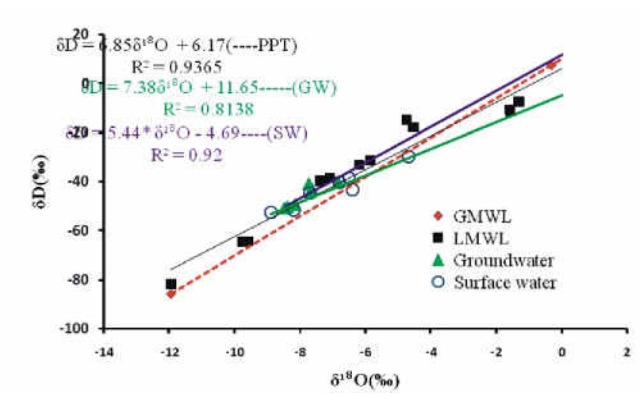

Fig. 7. Plot showing weighted mean $\delta^{18}O$ and δD of precipitation and mean $\delta^{18}O$ and δD of surface water and groundwater w.r.t. the GMWL along with their regression equations.

Deuterium excess

Deuterium excess has been used as a diagnostic tool in order to infer the origin of water-vapour that determines the precipitation in the study area (Hughes and Crawford, 2013; Wassenaar *et al.,* 2011). Humidity and temperature of the vapour source region determines the d-excess values as it is well related to them (Dansgaard, 1964). The mean d-excess in the precipitation varied between 12.40‰ to 14‰ (Table 1). The d – excess values in the month of August varied from 12.4‰ to 13.9‰ and respectively. This range suggests the different moisture source i.e., Indian summer monsoon (ISM) as it falls within the range of d-excess for SW monsoon. The precipitation also being depleted in August w. r. t $\delta^{18}O$ and δD evince further the source being SW monsoon. The d-excess in September range from 0.9‰ to 2.9‰ which suggests that the precipitation has undergone effect of evaporation. Monthly average d-excess values in months August, September, October and November are 13.33‰, 1.9‰, 16.65‰ and 20.24‰ respectively. The d-excess values lower than 10‰ indicates secondary evaporation of locally formed clouds (Araguas-Araguas *et al.,* 2000). Mediterranean moisture source is indicated by high d-excess ≥ 15‰ up to 22‰ (Vreca *et al.,* 2005). The d-excess values show progressive increase from October to November and are higher than 15‰ which indicates increasing effect of Mediterranean source. The lower values less than 15‰ in the month of August may be due to the monsoonal effect, which bring precipitation depleted in isotopic values.

The mean d-excess values in surface water varied from 7.79 (Dalgate) to 18.71 (Dal middle). This low d-excess value in Dalgate supports that the water at Dalgate has undergone the process of secondary evaporation. Similarly, the mean d-excess values in groundwater showed narrow range varying from 14.50 to 20.43. This narrow range in case of surface water and ground water indicate that both of these waters may have single source. These surface water and groundwater samples have d-excess values greater than 15‰ except Dalgate sample which suggests that these may have the same source i.e., Mediterranean Source.

CONCLUSION

The stable isotopes were used to identify the source of precipitation, surface water and groundwater in Srinagar, Kashmir Valley. The lower isotopic value and high d-excess of precipitation during the winter suggest the source of precipitation from western disturnabces. The higher isotopic values, lower d-excess, high temperature and lower humidity in September suggest that the rainfall has experienced evaporation during its descent from the cloudbase to groundsurface. However, the lower isotopic values, lower d-excess and high precipitation amount in August reflect the change in the source of precipitation from westerlies to southwest monsoons. A significant co-relation exists between surface water and groundwater suggesting the common source of surface water and groundwater and/or the groundwater is recharged by the surface water. The study suggests that the stream water and groundwater are dominantly contributed from snowmelt.

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