Hydrochemical and isotopic investigation of groundwater regime in Jalandhar and Kapurthala districts, Punjab, India

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Abstract: The groundwater samples from different aquifers (shallow, intermediate and deep) were collected from Jalandhar and Kapurthala districts, Punjab and analysed for major ions, stable isotopes of oxygen and hydrogen and environmental tritium activity. The groundwater in shallow and intermediate aquifer is Ca-Mg-HCO_3 and in deep aquifer is Na-HCO_3 hydrogeochemical facies. The groundwater chemistry in the study area is influenced by silicate dissolution of host rock. The shallow aquifer shows recharge is mainly through local precipitation. Location around R. Beas show significant contribution from the river. The Bist- Doab canal shows very less contribution to shallow aquifer. The enriched nature of isotopic composition in the shallow aquifer is mainly due to evaporation of water during filtration through impermeable clayey layer. The groundwater in deep aquifer gets recharged mainly from the precipitation from outside the study area.

***Key Words*:** *Bist Doab, Jalandhar and Kapurthala districts, Groundwater, Hydrochemistry, Stable Isotope, Evolution, Groundwater Recharge*

1. Introduction

In recent decades, increasing population, human activities, growing demands and catchment degradation have made mapping of groundwater potential as one of the major concern for the water managers. The sources of recharge to a groundwater system include both natural components (precipitation, lakes, ponds, rivers and other aquifers) and human- induced phenomena (includes irrigation loss from canals and fields, leaking water mains and over irrigation of parks, gardens and etc.). Environmental stable isotopes of water (oxygen-18 (^{18}O) and deuterium (D)) have been in use since last few decades in different sectors of water resources and its management. In case of groundwater, these have been extensively used to identify and estimate recharge sources (Mathieu and Bariac, 1996; Gupta, 1983), to determine the effects of evaporation on groundwater systems (Hendy et al 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 1996).

The Jalandhar and Kapurthala districts in the state of Punjab, India depends mainly on groundwater for agricultural and domestic purpose despite the presence of two perennial rivers, R. Satluj and R. Beas, and well connected canal network. The groundwater quality for drinking and agricultural purpose is suitable in these districts (CGWB, 2007a&b). The groundwater has suffered high decline in groundwater table with the areas Phagwara in Kapurthala and Shahkot and Nakodar areas of Jalandhar districs experiencing high decline (CGWB, 2007a&b). The urban regions in Jalandhar and Kapurthala districts mainly depend on the groundwater contributing more than 80% of the total (Tiwana et al 2007). The irrigation activity in these districts is done through canal systems and groundwater. But there has been decrease of over 35% in the use of canal system in the state for irrigation purpose with increase in usage of groundwater (Tiwana et al 2007). The usage of canal system is very minimal for irrigation purpose with about 11.37% in Jalandhar and none in Kapurthala districts resulting in more usage of groundwater. Due to these intense usage of groundwater the groundwater in all the blocks of Jalandhar and Kapurthala districts has been experiencing high groundwater draft and have resulted in overexploitation with high groundwater stage of 254% and 204% in Jalandhar and kapurthala districts respectively (CGWB, 2007a&b). Hence, it becomes imperative to understand the groundwater evolution and recharge sources in these districts. The present study is aims to understand the evolution of groundwater and to

characterize groundwater using hydrochemical and stable isotopes for understanding the source of recharge.

Study Area

The study area, Jalandhar and Kapurthala districts lies between latitude 30°59′ to 31°39′N and longitude 74°55′ to 75°57′ with a total geographical area of about 4000 sq.km (CGWB, 2007a&b) (Fig. 1). The study area is part of Bist Doab Tract, which is inter- alluvial plain between Beas and Satluj River. The district kapurthala comprises of two non-contiguous parts with Tehsil Phagwara as separated portion. Jalandhar District is bounded in the south by R. Satluj and Kapurthala, Hoshiarpur and Nawanshahar districts in W- NW, N-NE and Eastern part respectively. Kapurthala District is bounded partly in the North and wholly in the West by the Beas River. The Phagwara block is surrounded on three sides, the NW, W and SW by Jalandhar District, on the NE and E by Hoshiarpur District and by Nawan Shahar in the South. Climate in the study region is classified as tropical and dry sub humid. The study area receives average annual precipitation 701mm and 779 mm in jalandhar and kapurthala districts respectively with almost 70% of rainfall occurring during the southwest monsoon (CGWB, 2007a&b). The jalandhar district is well connected with the Bist Doab canal system, mainly from the R. Satluj, for irrigation purpose. In case of Kapurthala the district is connected with canal only in Phagwara area and

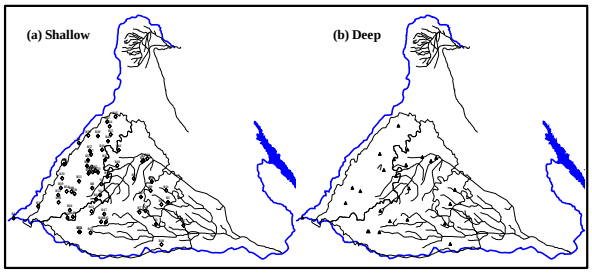

Figure 1. Sampling location map of the study area (Jalandhar and Kapurthala Districts)

Kapurthala area. Physiographically, the study area comprises of recent alluvium belonging to Indo-Gangetic alluvial plain of Quaternary age (CGWB, 2007a&b). The Jalandhar district is mainly drained by the R. Satluj and its tributaries East (White) and West (Black) Bein and the Kapurthala district by the R. Beas. The groundwater flow in the Jalandhar district is towards South-West direction and in Kapurthala district is from north to southeast direction (CGWB, 2007a&b).

Sampling and analysis

The sampling of groundwater at different depths from peizometer (shallow (<30m), intermediate (30-60m) and deep aquifer (>60m)) was carried out during 2007- 2009 from various locations in the Jalandhar and Kapurthala Districts (Fig. 1) by Central Groundwater Board, Northwest Region (CGWB(NWR)), Chandigarh. The collected groundwater samples were analysed for major cations and anions at the chemistry lab in the CGWB (NWR), Chandigarh.

The precipitation samples were collected from five (5) locations in the study area namely, Jalandhar, Nakodar, Phillaur, Bholath and Kapurthala during the year 2010 for the present study and used to derive LMWL. The river water samples from various places in the Bist- Doab region were carried out during the year 2009 and 2010 for deriving river lines. The isotopic analyses ($\delta^{18}O$ and δD) of collected water samples were carried out at the Nuclear Hydrology Laboratory of the National Institute of Hydrology (NIH), Roorkee, using Dual Inlet Isotope Ratio Mass Spectrometer (DIIRMS), mostly for $\delta^{2}H$ measurements, and Continuous Flow Isotope Ratio Mass Spectrometer (CFIRMS), mostly for $\delta^{18}O$ measurements. The $\delta^{2}H$ and $\delta^{18}O$ were measured by Pt–H_2 and CO_2 equilibration methods, respectively, following the standard procedure (Epstein and Mayeda, 1953; Brenninkmeijer and Morrison, 1987). To determine $\delta^{2}H$ and $\delta^{18}O$, a three-point calibration equation was used with the isotopic water standards Vienna standard mean ocean water (V-SMOW), Greenland ice sheet precipitation (GISP), and standard light arctic precipitation (SLAP) obtained from the IAEA (precision is ±1.0‰ and ±0.1‰ for $\delta^{2}H$ and $\delta^{18}O$, respectively). Due care was taken for having isotopic analytical results of water samples analyzed with CFIRMS and DIIRMS comparable using the measured values of $\delta^{18}O$ secondary standards with DIIRMS. The results were expressed by convention as parts per thousand deviations from the Vienna standard mean ocean water (V-SMOW) the calculation is as follows:

$$\delta_{sample} = (R_{sample}\text{-}R_{V\text{-}SMOW}/R_{V\text{-}SMOW})x1000‰$$

Where, R is the ratio of D/H or $^{18}O/^{16}O$ in sampled water (R_{sample}) or in V-SMOW ($R_{V\text{-}SMOW}$). The reproducibility of measurements was better than ±0.1‰ for $\delta^{18}O$ and better than ±1‰ for δD.

Isotopic Analyses of samples were done at the National Institute of Hydrology, Roorkee, India.

Results and Discussion

Major Ion chemistry

The pH of the groundwater in the study regions shows alkaline nature irrespective of the aquifer sampled. The shallow and intermediate aquifer show less alkalinity with pH values ranges from 7 to 8 whereas, the deeper aquifer show higher alkalinity with values ranging between 7.6 and 8.2. The electrical conductivity (EC) of the groundwater samples in the shallow aquifer shows high values than the desirable value of WHO Standards (782 µS/cm) but less than that of WHO standards for permissible limit (2340 µS/cm). The other two aquifers (intermediate and Deep) show lower EC with the values less than the desirable limit of Indian (BIS, 1991) and WHO (2004) standard.

The total dissolved cations and anions are well balanced within ±5% of normalized inorganic charge balance (NICB). The sodium dominates the overall major cations concentration in the groundwater followed by calcium, magnesium and potassium ions (Table 1) in all the aquifers. Among the anion, in general bicarbonate ion dominates the total anion concentration in all the aquifers followed by chloride. The concentration of chloride in the shallow aquifer at Kartarpur is very high (445 mg/l) indicating high evaporation activity in this part of the study area. This shows that the groundwater in the study area is less affected with anthropogenic activities.

Classification of Groundwater

To understand the similarities between the groundwater in the study area they have been classified hydrochemically using the major cations and anions with the conventional Piper trilinear diagram (Piper, 1944) and Chadha's diagram (Chadha, 1999). The Piper- plot (Fig. 2) shows that the groundwater in the study area is rich in alakaline earths with the location Kartarpur showing alkalis rich water in the shallow aquifer. The groundwater in shallow aquifer samples fall mostly on the Ca-Mg-HCO_3 field with the samples at locations Goraya, Bholath fall on the field and at Kartarpur falls on the Ca-Mg-Cl field (Fig. 2). The groundwater in the intermediate aquifer shows mixed trend with the samples fall in the Ca-Mg-HCO_3 and Na-HCO_3 fields (Fig. 2). The plot shows that deep groundwater is of Na-HCO_3 type (Fig. 2).

The Chadha's diagram (Fig. 3) clearly shows that most of the water samples at shallow groundwater fall on Ca-Mg-HCO_3 field with samples at location Goraya and Bholath falling at $NaHCO_3$ field and with Kartarpur falling at $NaClSO_4$ field. The intermediate groundwater shows mixed characteristics with the samples falling both at Ca-Mg-HCO_3 and Na-HCO_3 field. The groundwater at deeper aquifer shows the water is mainly of $NaHCO_3$ type with the samples at locations Adampur and Phillaur showing $CaMgHCO_3$ type. Hence, the water type in the study area can be stated as follows:

Shallow aquifer: Ca-Mg-HCO_3 + Na-HCO_3 (Goraya + Bholath) + CaCl (Kartarpur)

Intermediate Aquifer: Ca-Mg-HCO_3 + Na-HCO_3

Deep Aquifer: Na-HCO_3 + Ca-Mg-HCO_3 (Adampur, Shahkot)

Water Rock Interaction

The Gibbs plot (Gibbs, 1970, 1971) of log TDS against Na/ (Na+Ca) and Cl/(Cl+HCO_3) is used to decipher the source of groundwater in an area. The log TDS vs Na/ (Na+Ca) and log TDS vs Cl/ (Cl+HCO_3) plot (Fig. 4a&b) shows that almost all samples plot at the centre of the Boomerang diagram indicating weathering of rocks playing a big role in the chemistry of the groundwater in the study area. The shallow groundwater at Nakodar shows precipitation dominance whereas groundwater location Kartarpur shows dominance of evaporation (Fig. 4b) which might be the reason for high concentration of chlorine in the groundwater.

To understand the rock types contributing for the chemistry of the groundwater in the study area Ca/Na vs Mg/Na and HCO_3/Na plot (Gaillardet et al 1999) is given in Fig. 5a&b. The plots show that groundwater chemistry in the study area is mainly governed by the weathering of silicate rock with a minor contribution from the carbonate rocks The elements in ionic form are adsorbed on the crystal lattices of minerals such as clay minerals. When these minerals come into contact with the groundwater the adsorbed ions in the mineral lattice are replaced by the ions in the groundwater. This process takes place till a thermodynamic equilibrium is achieved.

Table 1. Major Ion and Stable Isotope composition of *groundwaters in Jalandhar and Kapurthala Districts, Bist Doab Region*

Location	pH	EC (µS/cm)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	Na^{+} (meq/L)	K^{+} (meq/l)	HCO_3^{-} (Meq/l)	Cl^{-} (Meq /l)	SO_4^{2-} (meq/l)	NO_3^{-} (meq/l)	F^{-} (meq/l)	NICB (%)
Shallow												
Kartarpur (J)	7.20	1595	8.63	6.17	2.10	0.20	3.23	12.54	0.83	0.01	0.02	1.41
Goraya (J)	7.73	1100	1.80	2.30	6.90	0.18	9.48	0.99	0.35	0.32	0.04	0.01
Nakodar (J)	7.00	750	2.24	1.56	3.49	0.10	6.38	0.54	0.21	0.32	0.02	-0.38
Shakot (J)	7.00	1213	3.64	5.35	3.49	0.20	7.31	2.06	2.60	0.71	0.01	0.01
Phillaur (J)	7.80	1244	3.34	4.69	4.59	0.18	10.97	0.96	0.52	0.39	0.05	-0.33
Bholath (K)	7.15	795	4.74	1.48	1.75	0.15	6.33	1.38	0.29	-	0.02	0.62
Kapurthala (K)	7.25	700	3.54	1.73	1.88	0.16	4.92	0.99	0.81	0.90	0.02	-2.21
Sultanpur Lodhi (K)	7.25	1006	2.34	2.96	5.24	0.12	7.82	1.24	1.25	0.02	0.01	1.62
Phagwara (K)	7.52	850	2.44	2.63	3.06	0.18	6.21	1.49	0.50	0.90	0.01	-4.62
Intermediate												
Adampur (J)	8.04	710	1.45	1.32	4.93	0.10	5.25	1.75	0.81	-	0.06	-0.41
Jalandhar (J)	7.28	510	2.34	0.62	2.01	0.08	4.46	0.39	0.12	-	0.04	0.27
Sarih (J)	7.00	670	1.75	1.56	3.23	0.15	6.02	0.39	0.29	-	0.02	-0.21
Kartarpur (J)	7.25	958	2.69	0.91	6.81	0.13	6.80	2.06	1.37	0.04	0.04	1.13
Goraya (J)	8.15	784	2.19	3.46	1.75	0.16	6.92	0.56	0.07	-	0.03	-0.13
Nakodar (J)	7.18	702	1.55	2.88	2.97	0.17	6.69	0.42	0.19	-	0.03	1.58
Bholath (K)	7.79	455	1.85	0.66	2.10	0.10	4.08	0.56	0.00	-	0.03	0.33
Deep												
Adampur (J)	7.83	400	1.50	0.82	2.10	0.08	4.11	0.24	0.10	0.00	0.01	0.24
Sarih (J)	8.05	565	0.49	0.39	5.07	0.08	4.30	0.37	1.25	0.00	0.01	0.84
Jalandhar (J)	8.05	550	0.60	0.74	4.02	0.05	4.34	0.87	0.19	0.02	0.04	-0.59
Kartarpur (J)	7.60	510	1.05	0.62	3.10	0.05	4.34	0.28	0.15	0.01	0.01	0.21
Goraya (J)	7.98	660	1.10	0.82	4.67	0.10	5.64	0.28	0.56	-	0.02	1.47
Nakodar (J)	7.53	685	0.70	0.99	5.20	0.07	6.08	0.54	0.17	-	0.03	1.05
Shakot (J)	7.62	704	0.60	0.30	6.20	0.05	4.21	1.10	1.66	-	0.03	1.10
Phillaur (J)	7.68	690	2.04	2.30	2.53	0.19	6.62	0.28	0.12	-	0.02	0.18
Bholath (K)	8.03	410	1.05	0.41	2.53	0.05	3.26	0.56	0.19	-	0.02	0.13
Kapurthala (K)	7.63	510	0.65	0.46	4.06	0.05	4.33	0.48	0.33	0.03	0.02	0.32
Sultanpur Lodhi (K)	8.01	503	0.50	0.20	4.45	0.04	3.20	1.01	0.83	0.03	0.02	0.97
Phagwara (K)	7.93	655	1.30	1.56	3.89	0.14	6.00	0.28	0.37	-	0.03	1.51

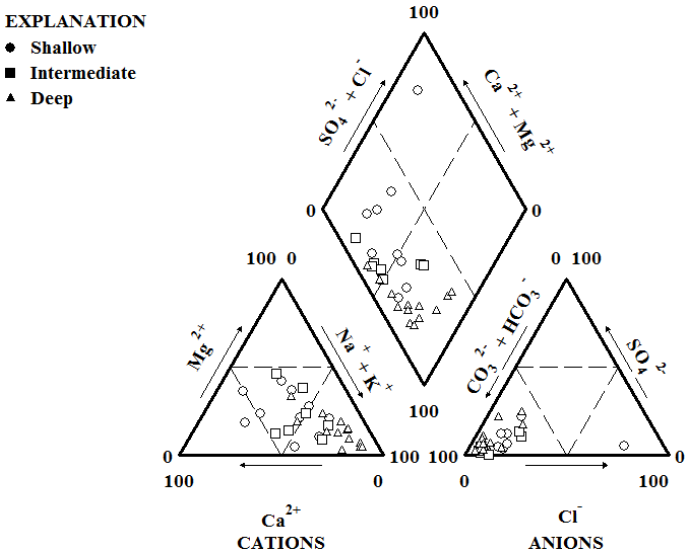

Figure 2. Piper Plot of the groundwater at different aquifers in Jalandhar and Kapurthala Districts of Bist- Doab region

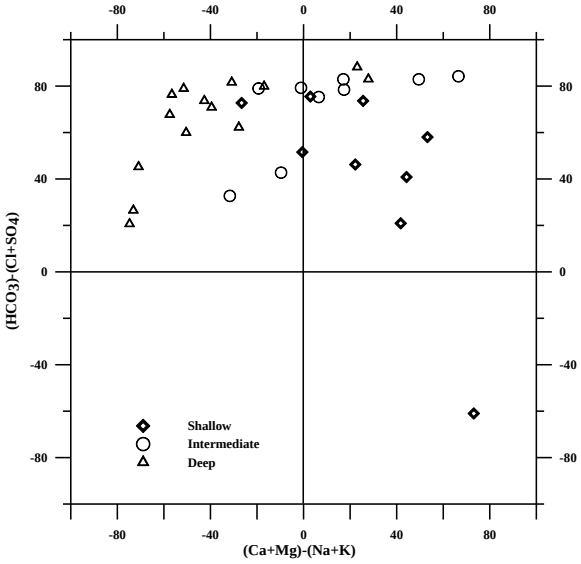

Figure 3. Chadha's Classification of groundwater at different depth in the Jalandhar and Kapurthala districts of Bist- Doab region

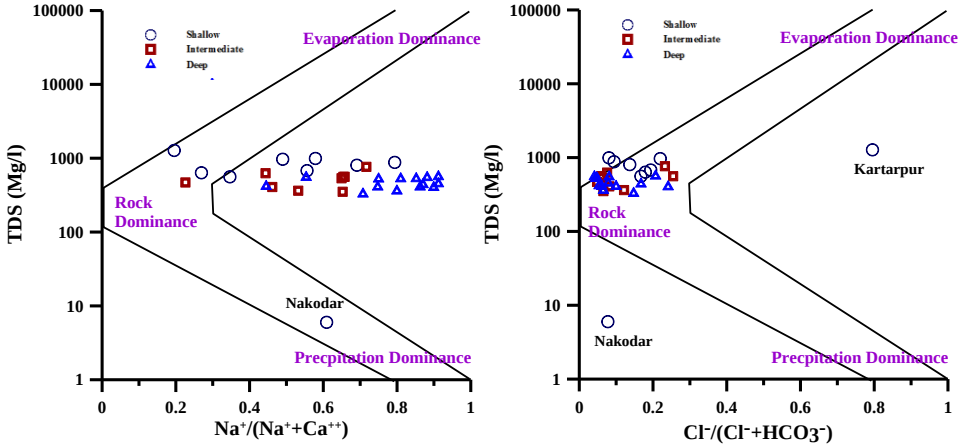

Figure 4. a: log TDS vs Na/ (Na+Ca); b: logTDS vs Cl/ ($Cl+HCO_3$) plot showing dominant source of groundwater chemistry.

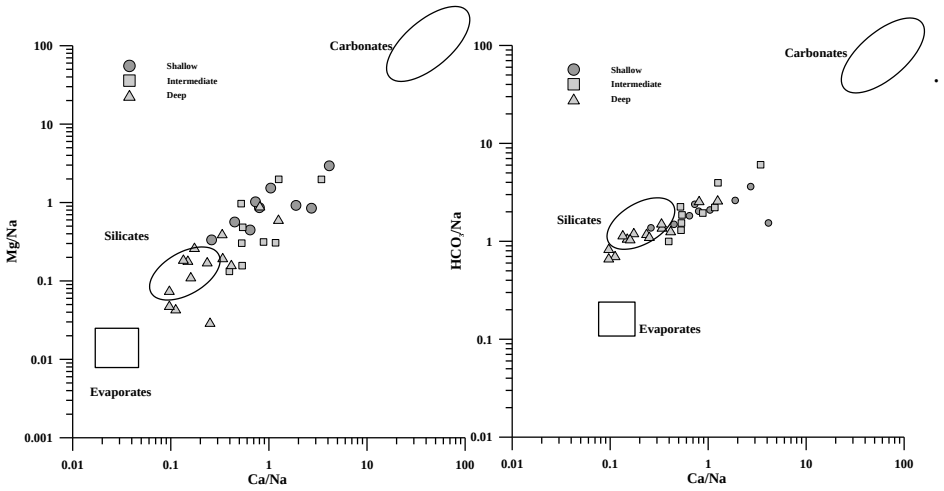

Figure 5. a: Mg/Na vs Ca/Na b: HCO_3/Na vs Ca/Na plots showing the major rock source for water chemistry in the study area. End-member compositions of carbonates and silicates are from Gaillardet et al. 1999.

To determine the type of exchange, i.e. from rock to groundwater or vice versa, Schoeller (1965, 1977) suggested 2 chloroalkaline indices CAI1 and CAI2 to indicate the exchange of ions between groundwater and its host environment. These indices are calculated using the formula:

$$CAI1 = Cl - (Na+K/Cl)$$
$$CAI2 = Cl - (Na+K/Cl) / (HCO_3+SO_4+NO_3)$$

All the values are in Meq/l. This is positive when there is an exchange of Na and K from the water with Mg and Ca of the rocks, and is negative when there is an exchange of Mg and Ca of the waters with Na and K of the rocks. The present study shows that all the groundwater samples in study area show a negative value indicating exchange of Mg and Ca of water with Na and K of the rocks except on sample in the shallow aquifer (Kartarpur) showing an opposite ion exchange process.

Isotopic Characteristics of Groundwater, River and Precipitation

The isotopic composition of precipitation in the study area and river water in the whole Bist- Doab region is used for better understanding of the source of groundwater in Jalandhar and Kapurthala districts. The $\delta^{18}O$ and δD values of the precipitation in the study area varies from -14.32‰ to -0.52‰ and –107.30‰ to 2.38‰ respectively. The isotopic composition of rainfall is enriched during the beginning of monsoon and depletes with the progress of monsoon. The isotopic composition shows maximum depletion during the recession of monsoon. The variation occurs due to relative contribution of local as well as oceanic water vapours.

To identify the recharge source of the groundwater in the study area, the local meteoric water line and river water lines (for both R. Satluj and R. Beas) was made using the isotopic composition of precipitation in the study area and river water samples. The $\delta^{18}O$- δD bi plot (Fig. 6) of precipitation in the study area shows similarity with that the regional meteoric water line of Bist- Doab region (RMWL Bist- Doab), Indian Meteoric Water Line for the north region (IMWL-North) (Kumar et al 2010) and GMWL (Rozanski et al 1993) except the change in intercept. The slope of regression equation (eq. 1) derived for the precipitation in the study area is above IMWL- North (eq. 3) and less than RMWL (Bist- Doab) and GMWL (eq. 4) and change in intercept indicates change of source or the rain out process.

LMWL (Jal & Kap):

$$\delta D = 8.16 \times \delta^{18}O + 6.87; \quad R^2 = 0.96, n = 111 \qquad \text{(eq. 1)}$$

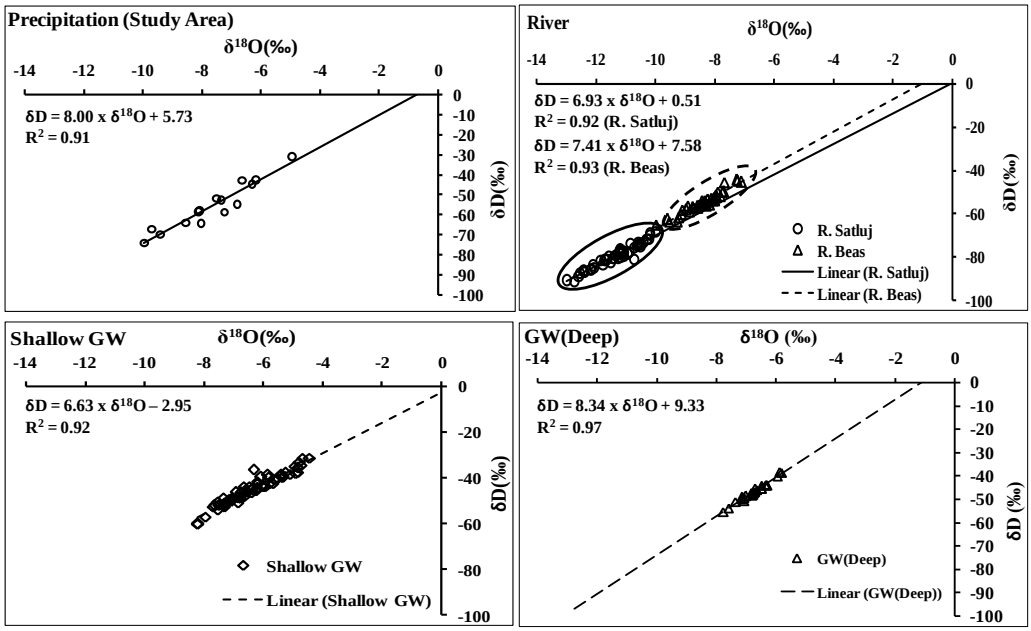

Figure 6. $\delta^{18}O$- δD bi plot of Precipitation in the study area, Rivers, Shallow and Deep

RMWL (Bist Doab):

$\delta D = 8.13 \times \delta^{18}O + 7.63$; $R^2 = 0.96$ (eq. 2)

IMWL- North:

$\delta D = 8.15 \times \delta^{18}O + 9.55$; $R^2 = 0.99$ (eq. 3)

GMWL:

$\delta D = 8.17 \times \delta^{18}O + 11.27$; $R^2 = 0.99$ (eq. 4)

The water sample was collected from the rivers Satluj and Beas after the emergence from the Bhakra Nangal and Pong Dam respectively. The isotopic composition of R. Beas is similar to that of precipitation and enriched than that of R. Satluj (Fig. 6a&b). This is due to the origin of R. Beas relatively from lesser altitude than that of river Satluj. The low intercept of regression lines derived for the river water indicate that both rivers show evaporation effect with R. Satluj showing higher evaporation effect than R. Beas (eq. 5 and eq.6 respectively) due to higher residence time of water in the Bhakra Nangal dam than the smaller Pong dam.

$\delta D = 6.92 \times \delta^{18}O - 1.08$; $R^2 = 0.91$, n = 47 (eq. 5)

$\delta D = 7.49 \times \delta^{18}O + 7.84$; $R^2 = 0.87$, n = 21 (eq. 6)

The isotopic composition of groundwater in shallow aquifer shows enriched values ranging from -4.44‰ to -8.20‰ and -31.32‰ to -60.42‰ in $\delta^{18}O$ and δD respectively. The spatial distribution (Fig. 7a) of oxygen isotopic composition in shallow aquifer shows depleted nature at some places with the values greater than -7‰. The depleted nature mainly occurs in the locations near to canal network (Bist- Doab canal of R. Satluj) indicating a possible contribution from the canal. $\delta^{18}O$ vs. δD bi-plot was used to decipher the source of groundwater in shallow aquifer. The isotopic composition of groundwater near the banks of R. Beas fall along the river water line (RWL) (Fig. 10 b) indicating a significant contribution from the river to shallow aquifer. The average isotopic composition of precipitation in the study area is -7.5‰ wheras the R. Satluj water signature is <-10‰, hence, it is considered that groundwater with isotopic composition less than -7.5‰ should bear signature of R. Satluj. It is interesting to note that only four locations (Fig. 10 c) near the canal fed region show isotopic signatures less than -7.5‰ indicating very less contribution from the river satluj canal. But, Naidu et al. (Surinaidu et al 2010) found significant recharge through canal systems in the Jalandhar district using electrical tomography. This leads to an assumption

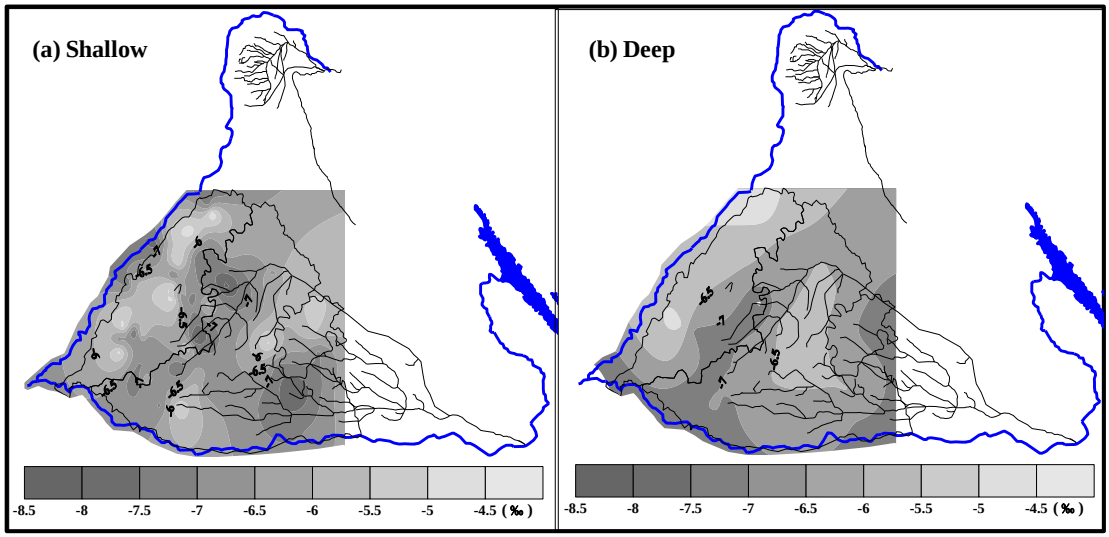

Figure 7. Spatial Distribution of $\delta^{18}O$ in different aquifers of the study region a: Shallow, b: Deep aquifer

that the enriched nature of groundwater might be due to the evaporation of infiltrating water from the agricultural field which uses these canal water. To support this detailed study with close network of sampling locations around the canal network, and is in progress. A few locations, way from the canal network, also show depleted nature of isotopic composition of groundwater and are due to evaporation of precipitation during infiltration (Fig. 8a). The groundwater in the shallow aquifer at the western part of study area shows enriched isotopic composition (Fig. 8a) this is due to the presence of salt encrustations and precipitation of clay particles on the soil matrix making the upper layer impermeable. This causes evaporation and lesser infiltration resulting in the enrichment of isotopic composition.

The spatial distribution of isotopic composition of groundwater in deep aquifer show very less variation with values ranging from -6.50‰ to -7.08‰ and -45.34‰ to -50.80‰ in $\delta^{18}O$ and δD respectively. The $\delta^{18}O$ vs. δD bi-plot shows isotopic composition of deep aquifer falls along the LMWL of Bist- Doab region indicating precipitation in the region, especially Kandi region, as recharge source.

Conclusion

The groundwater quality in the shallow aquifer is suitable for drinking purpose with few locations (like Kartarpur, Goraya, Shahkot, Phillaur and Sultanpur Lodhi) showing high salinity with electrical conductivity more than 1000 µS/cm. The intermediate and deep aquifers are also suitable for drinking purpose values of both EC and major ions lying within the permissible range of Indian and W.H.O standards. The Gibbs plot shows that the ground water chemistry mainly depends on the lithology of the study area. The Piper plot and Chadha's Diagram shows that groundwater in the shallow and intermediate aquifer are similar i.e. Ca+Mg+Na bicarbonate type whereas the deep aquifer shows $NaHCO_3$ type of water. Overall, the groundwater chemistry is dominated by the dissolution of silicate rocks in the study area, which is evident from choloroalkaline indices showing removal of sodium and potassium from the rock to groundwater. The isotopic study shows that precipitation in the study area resembles IMWL-North and GMWL with the lower intercept showing little evaporation effect.

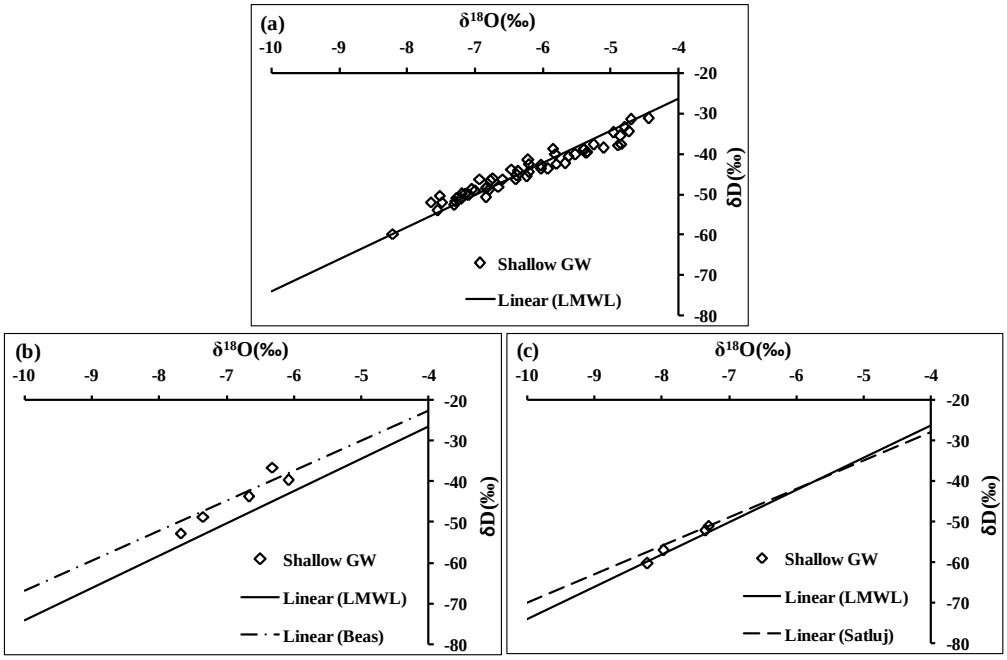

Figure 8. $\delta^{18}O$- δD bi plot of Shallow aquifer in different regions of Jalandhar and Kapurthala Districts, a: Precipitation Dominant, b: R. Beas Dominant, C: R. Satluj Canal Dominant

The isotopic composition of shallow aquifer in location near R. Beas indicates recharge from the river. The canala system (Bist- Doab canal) of R. Satluj shows very little contribution to recharge shallow aquifer. The enriched nature of isotopic composition of shallow aquifer is due to the formation of clay particles, resulting in impermeability of top soil layer resulting in evaporation of water during infiltration. The deep aquifer shows recharge is mainly through precipitation from the outside the study area.

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