Hydrogeochemical assessment of groundwater in Kashmir Valley, India

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Groundwater samples ($n = 163$) were collected across Kashmir Valley in 2010 to assess the hydrogeochemistry of the groundwater in shallow and deep aquifers and its suitability for domestic, agriculture, horticulture, and livestock purposes. The groundwater is generally alkaline in nature. The electrical conductivity (EC) which is an index to represent the total concentration of soluble salts in water was used to measure the salinity hazard to crops as it reflects the TDS in groundwater ranging from 97 to 1385 $\mu\text{S}/\text{cm}$, except one well in Sopore. The average concentration of major ions was higher in shallow aquifers than in deeper aquifers. In general, Ca^{2+} is the dominant cation and HCO_3^- the dominant anion. Ca-HCO_3 , Mg-HCO_3 , Ca-Mg-HCO_3 , Na-HCO_3 were the dominant hydrogeochemical facies. High concentration of HCO_3 and pH less than 8.8 clearly indicated that intense chemical weathering processes have taken place in the study area. The groundwater flow pattern in the area follows the local surface topography which not only modifies the hydrogeochemical facies but also controls their distribution. The groundwater in valley flows into four directions, i.e., SW-NE, NE-W, SE-NW and SE-NE directions. The results suggest that carbonate dissolution is the dominant source of major ions followed by silicate weathering and ion-exchange processes. The concentrations of all the major ions determined in the present study are within the permissible limits of WHO and BIS standards. The results of Total Hardness, SAR, $\text{Na}\%$, Kelly Index, USDA classification, Magnesium absorption ratio, residual sodium carbonate, and PI suggested that groundwater is good for drinking, livestock, and irrigation purposes.

1. Introduction

Groundwater, being the largest freshwater resource after glaciers and polar ice in the world, plays an important role in socio-economic life of the people in Kashmir Valley for domestic, horticultural, agricultural, and hydropower generation purposes. The suitability of groundwater for different purposes depends upon its intrinsic quality which reflects inputs from the atmosphere, soil and rock weathering, as well as from anthropogenic activities. Public ignorance of environment and related considerations,

indiscriminate disposal of increasing anthropogenic wastes, unplanned application of agrochemicals, and discharges of improperly treated sewage have resulted in the deterioration of surface and subsurface water (Singh and Hasnain 1998; Mitra *et al.* 2007; Kumar *et al.* 2008; Ishaku 2011; Ewusi *et al.* 2013; Kalpana and Elango 2013). The value of groundwater lies not only in its widespread occurrence and availability but also in its consistent good quality (Rajmohan *et al.* 2000; UNESCO 2000). Assessment of water quality is very important for knowing the suitability for various purposes

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(Ifatimehin and Musa 2008; Jehangir *et al.* 2011). Hydrogeochemical study is a useful tool in understanding and identifying the processes that are responsible for chemical quality of groundwater (Subba Rao 2008; Kumar *et al.* 2013). Very few hydrogeochemical studies have been carried out in Kashmir Valley. Jeelani (2005, 2011) carried out the study on the chemical quality of springs south-east of the Kashmir Valley and suggested that congruent carbonate dissolution (calcite dissolution, dedolomitization) and incongruent silicate weathering were found to be the dominant processes controlling the groundwater chemistry. Jehangir *et al.* (2011) also carried out hydrogeochemistry of groundwater along river Jhelum in the southern part of Kashmir and suggested lithology as a dominant factor in controlling the water chemistry. However, a comprehensive study on hydrogeochemistry of whole alluvial basin is lacking till date. The present study is focussed on the general hydrogeochemistry of the groundwater in alluvial wells of the Kashmir Valley because of its unique aspects of hydrogeology and its relative importance of hydrogeology to this large part of valley, which is although preliminary in nature but gives a first hand idea about the chemical quality of the groundwater.

2. Study area

The intermountane valley of Kashmir formed by bifurcation of the great Himalayan range west of Ravi, occupies an oval shaped depression between two major orogenic axis of upheaval namely, folded Pir Panjal range to the southwest and much sheared ranges of north Kashmir to the northeast located between latitudes $32^{\circ}17'$ and $36^{\circ}58'N$ and longitudes $73^{\circ}26'$ and $80^{\circ}30'E$, possessing almost a complete stratigraphic record of rocks of all ages (figure 1) ranging from Archean to Recent (Middlemiss 1910, 1910; Wadia 1975; GSI 1977; Gunj and Khar 1984). The average length of Kashmir Basin is 140 km and width 40 km, covering an area of 5200 km², with an average elevation of 1850 m (amsl) (Agarwal *et al.* 1979). The central part of the valley, mostly covers the flood plains of the river Jhelum and adjoining streams, and is filled with recent alluvium. These deposits include alluvial tracts, flood plains, river terraces and talus and scree fans. The alluvial flats of the valley are bordered by the Karewa deposits whose denuded tops offer sharp contrast to the aggradational features of the low lying tracts (Jeelani 2007). The valley enjoys a temperate climate with marked seasonality. The valley experiences the highest rainfall of 275 mm in summer and the lowest 50 mm in

winter with a mean annual rainfall of 100 mm. The mean annual temperature of the valley is 19°C. The valley is mainly drained by river Jhelum.

3. Materials and methods

A total of 163 groundwater samples (104 from shallow groundwater = SGW and 59 samples from deep groundwater = DGW) were collected across the alluvial aquifer/s of Kashmir Valley during 2010 (figure 1). These wells were selected not only after a proper well inventory survey across the whole alluvial basin but also on the basis of demographic need and were classified on the basis of spatial variation in depth to water table from southern, central, and northern parts of the alluvial basin of the valley. The depths to water table in these alluvial wells were measured with a hand-held sensor capable of accuracy to about 0.1 inch, whereas data were recorded on a datalogger, which later was analysed in the ARC GIS 9.3 software by interpolating 163 data points by using Universal Kriging (UK) method with an exponential semi-variogram model, which is considered one of the most appropriate interpolation methods for contouring groundwater level, generally a non-stationary variable (Gundogdu and Guney 2007). The depths to water table in the range of 0–2 m were classified as shallow alluvial wells, whereas from 2 m or more were classified as deep alluvial wells. The water samples taken from these wells were filtered through $<0.45\ \mu\text{m}$ nucleopore membrane and collected in 500 ml HDPE bottles and were analysed for chemical parameters in the Hydrogeology Laboratory of the Department of Earth Sciences, University of Kashmir. The standard methods were adopted to analyse the dissolved chemical constituents (APHA, AWWA and WEF 2001). The *in situ* parameters including temperature, pH, electrical conductivity (EC) and alkalinity were measured at site. Total dissolved solids were estimated by calculating total cations and total anions (TZ concentration). Alkalinity was measured by HCl titration; Ca^{2+} and Mg^{2+} by EDTA titration; Cl^{-} by AgNO_3 titration; SO_4^{2-} , NO_3^{-} , Fe^{2+} and F^{-} by spectrophotometer; Na^{+} and K^{+} by flame emission photometry. During the analytical procedures, blanks and standards were run to check the reliability of the methods adopted. In most of the water samples, the total cation charge ($\text{TZ}^{+} = \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+} + \text{K}^{+} + \text{Fe}^{2+}$ in meq/L) balances that of the total anions ($\text{TZ}^{-} = \text{HCO}_3^{-} + \text{Cl}^{-} + \text{SO}_4^{2-} + \text{NO}_3^{-} + \text{F}^{-}$ in meq/L) within analytical uncertainties and the normalized inorganic charge balance ($\text{NICB} = \text{TZ}^{+} - \text{TZ}^{-} / \text{TZ}^{+} \times 100\%$) is found to be within $\pm 5\%$.

Figure 1. Geology of the study area and the location of sampling sites.

4. Results and discussion

4.1 Hydrochemistry: Spatial variation

The summary of the physico-chemical parameters generated from the analysis of the 163 samples were presented in table 1. The data was compared with drinking water guidelines of India (BIS-IS

10500:1991) and WHO (2006). The groundwater samples were mostly alkaline (pH: 6.7–8.8) with the exception of a few samples from Kangan, Srikaningund, Ajas and Babgund (pH: 6.7 and 6.9). The shallow groundwater samples were more alkaline (average pH: 7.6) than deep groundwater samples (average pH: 7.4). Electrical conductivity (EC) which is an index to represent the total

Table 1. Statistics of the Physico-chemical parameters of groundwater in Kashmir Valley.

Water quality parameter	Shallow groundwater				Deep groundwater			
	Min	Max	Mean dev.	St. dev.	Min	Max	Mean dev.	St. dev.
pH	6.7 Kangan (Pulwama)	8.8 Pampore	7.61	0.4	7 Shippora (Budgam)	8.4 Pampore	7.4	0.34
EC ($\mu\text{S}/\text{cm}$)	97 Udiopora (Kupwara)	1380 Imamabara (Srinagar)	532.1	231	202 SKUAST	1760 Sopore	509.1	317.4
HCO_3^- (mg/L)	49 Udiopora (Kupwara)	775 Malingpora (Ananthnag)	286.9	116.3	92 Sopore	1092 Jaubran	301.3	195.7
Cl^- (mg/L)	3.5 Festapur	92 Delina (Baramulla)	29.2	22.8	3.5 Malingpur	89 Islamia College (Srinagar)	17.36	14.66
TDS (mg/L)	71.7 Udiopora (Kupwara)	1108 Imamabara	460.3	285.9	174.8 Centure Hotel (Srinagar)	1495.4 Sopore	457.9	282.93
SO_4^- (mg/L)	0 Batingoo (Ananthnag), Udiopora	140.8 Hayatpora (Kupwara)	19.1	25.4	0 HMT	181.1 Islamia College (Srinagar)	17.5	29.66
NO_3^- (mg/L)	0.13 Bata Vina	135 Wuyan	11.9	20.2	0 Ranji Hamari	134 Islamia College (Srinagar)	10.9	22.00
F^- (mg/L)	0 Lodhwan (Kupwara)	1 Malingpur (Ananthnag)	0.2	0.1	0.01 Upper Athwajan	0.9 Pampora	0.1	0.194
Ca^{2+} (mg/L)	12 Udiopora	159 Batingoo (Ananthnag)	62.5	26	4.8 HMT	132 Sopore	53.2	26.24
Mg^{2+} (mg/L)	2.6 Rambelpur (Ananthnag)	79 Malingpur (Ananthnag)	20.8	13.8	4.5 Tragpora (Bandipora)	96 Sopore	23.4	18.87
Na^+ (m/L)	1.5 SKUST	112 Sopore	28.9	32.00	2 Udiopura	146 Malingpur	24.4	26
K^+ (mg/L)	0.1 Hadipura (Baramulla)	215 Kadelbal Pampore	6.8	23.7	0.1 Bifin	112 Islamia College (Srinagar)	3.5	14.84
Fe^{2+} (mg/L)	0 Zakura	5.7 Sadiopura	1.0	1.4	0 Shippora	12.8 Mamet (Budgam)	2.5	3.39

concentration of soluble salts in water varied from 97 to 1385 $\mu\text{S}/\text{cm}$ except at one well in Sopore (1760 $\mu\text{S}/\text{cm}$), with an average of 523.7 $\mu\text{S}/\text{cm}$. EC is mostly higher in shallow groundwater (average EC = 532.1 $\mu\text{S}/\text{cm}$) than in deep groundwater (average EC = 509.1 $\mu\text{S}/\text{cm}$). The higher values of EC may be due to the long residence time and the existing lithology of the region. Total dissolved solids (TDS), which is a general indicator of water quality generally used to understand the amount of contaminant present in the groundwater (Bhardwaj and Singh 2011; Kumar *et al.* 2013), which was calculated by multiplying the EC with 0.64, ranged from 71.7 to 1495.4 mg/L with an average of 459.4 mg/L, being higher in shallow groundwater (average = 460.3 mg/L) and lower in deep groundwater (average = 457.9 mg/L).

Among the cations (TZ^+) the concentration of Ca^{2+} , essential for bones and teeth varied from 12 to 159 mg/L with an average of 59.2 mg/L, being higher in shallow groundwater (average Ca^{2+} = 62.5 mg/L) than in deep groundwater (average Ca^{2+} = 53.2 mg/L). The concentration of Mg^{2+} , essential element for membrane structure ranged from 2.6 to 96 mg/L with an average of 21.8 mg/L. The deep groundwater was more enriched in Mg^{2+} (average Mg^{2+} = 23.4 mg/L) than shallow groundwater (average Mg^{2+} = 20.8 mg/L). The Na^+ concentration, essential for controlling of fluid level and nerve conduction ranged from 1.5 to 146 mg/L with an average of 26.1 mg/L being high (average Na^+ = 28.9 mg/L) in shallow groundwater and low (average Na^+ = 24.4 mg/L) in deep groundwater. The K^+ , necessary in muscle contraction varied from 0.1 to 215 mg/L with an average of 5.7 mg/L, higher (average K^+ = 6.89 mg/L) in shallow groundwater as compared to deep groundwater (average K^+ = 3.59 mg/L).

Among the major anions (TZ^-) the concentration of HCO_3^- , although having no adverse effects but preferably within the permissible limits (BIS 1991; Bhalme and Nagarnaik 2012), ranged from 49 to 1092 mg/L with an average of 292.2 mg/L. The deep groundwater being more enriched (average HCO_3^- = 301.3 mg/L) than shallow groundwater (average HCO_3^- = 286.9 mg/L). Similarly, the concentration of Cl^- , essential for metabolism ranged from 3.5 to 92 mg/L with an average of 25 mg/L with higher concentration (average Cl^- = 29.2 mg/L) in shallow ground water and lower (average Cl^- = 17.3 mg/L) in deep ground water. The concentration of SO_4^- , essential for many biological processes like in the formation of brain tissue and Mucin proteins in gut walls (Kuchel *et al.* 1986; Dawson 2013), ranged from 0 to 181 mg/L with an average of 18.5 mg/L, being higher (average SO_4^- = 19.1 mg/L) in shallow groundwater than deep groundwater (average

$\text{SO}_4^- = 17.5 \text{ mg/L}$). Nitrate concentration, which is an index of anthropogenic activities, varied from 0.13 to 135 mg/L with an average of 11.33 mg/L. The higher concentration (average $\text{NO}_3^- = 11.9 \text{ mg/L}$) was observed in shallow groundwater than in the deep groundwater (average $\text{NO}_3^- = 10.9 \text{ mg/L}$). The spatial variation maps (figure 2) clearly indicate that recharge areas feeding these alluvial wells are in carbonates (limestone), silicates (Panjal Trap and Karewa) which surround the basin. These spatial variation maps also depict completely that rock–water interaction, velocity and quantity of groundwater flow, nature of geochemical reactions, and anthropogenic activities are the processes that have played a major role in the spatial variation of these major ions in the groundwater in the study area.

4.2 Sources of major ions in groundwater

Groundwater chemistry in the study region is regulated by diverse processes and mechanisms. Experiencing subtropical climatic condition, besides rock–water interaction, precipitation and evaporation may also contribute to the groundwater chemistry. The Gibbs mechanisms (Gibbs 1970) were employed in the study area suggesting that groundwater chemistry in the region has been controlled by the chemical weathering of rock forming minerals existing mainly in the volcanics, carbonates and Karewa, as weathering and ion exchange processes are the major solute acquisition mechanisms controlling the concentration of chemical constituents in groundwater besides the inputs from anthropogenic sources (Apodaca *et al.* 2002; Martinez and Bocanegra 2002; Singh and Hasnain 2002; Jeelani and Shah 2006; Bhardwaj *et al.* 2010; Li *et al.* 2010).

It was observed that most of the major ions were high in shallow groundwater aquifers except Mg, HCO_3 and Fe. The sources of major ions in shallow groundwater may be attributed to lithogenic and anthropogenic activities. It is important to mention here that the shallow groundwater is more prone and vulnerable to contamination. In the study area, the unmanaged and untreated sewage and water logging is widespread. The lower concentration of major ions in the deeper aquifer indicates that the source of major ions is lithogenic in deeper aquifers, which are naturally more protected from contamination by anthropogenic activities. However the higher concentration of Mg, HCO_3 and Fe in the deeper aquifer may be due to interaction of water with dolomite and/or ferro-magnesium minerals of Panjal Trap. This is also supported by the plot Mg *vs.* HCO_3 (figure 3d). The plot Mg *vs.* HCO_3 shows a good correlation in deeper

aquifers than in shallow aquifers, suggesting that dolomite and/or Panjal Trap is a source. However, the relative proportion of various dissolved ions in the groundwater depends on their abundance in the host rock/aquifers and its solubility (Sarin *et al.* 1989). The present study has been carried out in the alluvial tract (host lithology) of the valley, surrounded on NE side by Triassic Limestone and Panjal Trap, which is rich in ferro-magnesium minerals and on SW side by carbonates, sulphides/evaporites and quarternary Karewa Group of sediments. The ion exchange between the ground water and its host environment during residence or during in movement process can be best understood by chlorine alkaline indices also known as Scholler index (Schoeller 1977) expressed as: $\text{CAI} = \text{Cl}^- - \text{Na}^+ + \text{K}^+ / \text{Cl}^-$. A majority of the samples from shallow groundwater (62%) showed positive CAI indicating base exchange reaction, whereas 38% of samples showed negative CAI indicating cation–anion exchange reaction. In the case of deep groundwater, most of the samples (58%) showed negative CAI indicating the dominance of cation–anion exchange reaction whereas 42% samples showed positive CAI indicating base exchange reaction. However, the sources of these dissolved constituents can be best evaluated from the relative abundance of individual ions and their inter-elemental correlation. The plots of Ca+Mg *vs.* HCO_3 , Na *vs.* Cl, and Ca+Mg *vs.* $\text{HCO}_3 + \text{SO}_4$ scatter diagrams (figure 3) helped to determine the possible sources of major ions in groundwater. In Ca+ Mg *vs.* HCO_3 plot, most samples fall along the line, although some of the samples fall below the line suggesting possible contribution from the carbonate lithology besides some contribution from other processes. The plot of Na *vs.* Cl showed that most points lie below the aquiline indicating the contribution from silicates, because Cl would prefer to associate with alkalis than alkaline earth elements. This phenomena was also noticed when Na/Cl ratio is greater than 1 which indicates that sodium is released from silicate weathering (Meybeck 1987). Hence in the present study about 51% and 72.88% samples from shallow and deep ground waters, respectively have Na/Cl ratio > 1, means Na has come from silicate weathering. The remaining 49% from shallow and 27.12% samples from deep ground water have Na/Cl ratio < 1 reflecting impact or presence of additional source. This is also evident in Ca+Mg *vs.* $\text{HCO}_3 + \text{SO}_4$ plot, where the majority of ionic concentrations fall below the aquiline suggesting dissolution process of carbonates and silicates/sulphides. The samples in the plot tend to shift right due to the large excess $\text{HCO}_3 + \text{SO}_4$ ions on the left of the plot because of reverse ion exchange and dominance of Ca+Mg over $\text{HCO}_3 + \text{SO}_4$ which suggests the interaction

Figure 2. Spatial variation of major ions in groundwater across the alluvial basin of the Kashmir Valley.

Figure 3. Scatter plots showing the sources of major ions in groundwater.

of groundwater with both silicate and carbonate lithology during the movement from higher head to lower head.

The maximum points of south Kashmir fall on the aquiline of the plot (Ca+Mg) *vs.* HCO_3 (figure 3a) indicating the carbonate lithology as the dominant source of major ions. This is also supported by the fact that south Kashmir is dominated by the carbonate lithology (Syringothyris Limestone and Triassic Limestone). However, many data points of northern and central Kashmir fall above the aquiline of plot (Ca + Mg) *vs.* HCO_3 and on the aquiline of plot (Ca + Mg) *vs.* ($\text{HCO}_3 + \text{SO}_4$) (figure 3b) and Na *vs.* Cl (figure 3c) suggesting additional sources of major ions including silicates and/or evaporites. The good correlation of Na *vs.* Cl may also be due to the contamination from domestic/municipal waste which is common in central and north Kashmir. The higher concentration of Mg, HCO_3 and Fe in groundwater in the central part is attributed to the ferro-magnesium minerals of the Panjal Volcanics and quarternary Karewa deposits which border the alluvial tract in this part of the valley.

4.3 Depth to water table and flow direction

The depth to groundwater is an important primary parameter, in determining the depth of material through which a contaminant/anthropogenic constituents must travel before reaching the aquifer. The depth to water level in the alluvial wells varies from 0–10 m below the ground. Out of 163 monitored wells, 69% of wells were classified as shallow with a water level of 0–2 m below ground level, while 6% of wells were classified as deeper with a water level of 3–7 m below ground level, in the alluvial basin of the valley. The depth to water table data and hydraulic gradient (figure 4) suggest that the groundwater flow in the area is largely controlled by the local surface topography (variation in elevation) as there is a general trend in groundwater levels from south to north of the valley besides a major river (river Jhelum) draining the whole Kashmir Basin and large water bodies (Wular lake, Dal lake, Nigeen lake, and Manasbal lake). The differences in the head produced by the topographic relief are the most significant driving force for groundwater flow in this region since the relief ranges from 0–1 m amsl within a span of 2 km.

The most significant water level changes due to recharge in the valley occur during spring season when precipitation in the form of snow starts melting. There are several wells in the observation well network that showed water-level increase

due to rapid groundwater recharge following significant precipitation events. These include observation wells near the Jhelum River which showed the response more quickly than wells farther away. All of these are relatively shallow wells with modest lengths of casing, drilled into unconfined aquifers. During the summer season people rely more on these wells because of diversion of surface water to the irrigation fields which results in more pumping of water from these wells, which later recover to their original levels during winter season due to heavy snow fall in the valley. Figure 4 shows the groundwater table map indicating that in general the flow occurs towards five directions, i.e., S–N, SW–NE, NE–W, SE–NW and SE–NE. Apart from this, the hydrogeochemical analysis of groundwater is considered useful not only in determining the chemistry of the groundwater, but also in understanding the movement of groundwater (Kumar *et al.* 2013). In the present study Ca/Mg, SO_4/Cl , Na/Cl and HCO_3/Fe ratios (refer figure 2) were used to determine the flow patterns in the alluvial basin of the valley. The Ca/Mg ratio decreases from south to central part, which clearly shows the flow direction from south to north and southwest to northeast direction but on the other hand, the ratios of SO_4/Cl increase towards the centre from both ends of the basin. The regions of high Ca/ Mg values coincide with the areas of low SO_4/Cl values, which are the regions of high topography and regions of low Ca/Mg values coincide with regions of high SO_4/Cl values indicating the groundwater movement. However, HCO_3/Fe ratios show that typical groundwater flow pattern of the basin, Fe ratios being high in central, is found in lower ratios towards northern and southern parts with a decreasing trend and increasing ratios of HCO_3 determines the overall flow pattern of the basin from south to north and southwest to northeast. These flow patterns in the area not only modify the hydrogeochemical facies but also control their distribution in the basin.

4.4 Hydrogeochemical facies

Statistical distribution diagrams such as Piper Trilinear (Piper 1944) were used not only to gain better insight into the hydrochemical processes operating in the groundwater system but also for the purpose of characterizing the water types present in the area (figure 5). The Ca– HCO_3 , Mg– HCO_3 , Ca–Mg– HCO_3 , and Na– HCO_3 being the most common hydrochemical facies, suggest that lithology and anthropogenic activities have played an important role in controlling the groundwater chemistry in the Kashmir Valley. The Ca–Mg– HCO_3 water type is regarded as recharged

Figure 4. Map showing spatial variation of groundwater level in alluvial basin of Kashmir Valley.

water from sources related to atmospheric precipitation and dissolution of carbonates. This type of facies represents 80% of the southern, 95% central, and 90% of the northern areas of the valley. This phenomenon indicates that the hydrochemical properties as well as the factors affecting the hydrochemistry of these areas are similar. The Na-HCO₃ facies are present 20% in the southern, 5% in central and 10% in the northern area of the valley. This water type is a strong indicator of cation exchange process. The presence of excess sodium provided by clay minerals replacing the availability of calcium from the recharged Ca-Mg-HCO₃ through the cation exchange reaction, in which Ca is retained in the aquifer material and Na is released to water, leads to the formation of Na-HCO₃ type of water. This was also confirmed by the indices of Base Exchange (CAI). From a geographical point of view, there is not much distinction between chemical properties of groundwater in north and central on one hand

and south on the other hand, reflecting the effect of chemical processes occurring between the minerals within the lithologic framework and the groundwater movement.

5. Groundwater quality assessment

The suitability of water lies not in quantity but its intrinsic quality that makes water an important resource for sustainable development. Only economic advantage cannot sustain the practice. Other issues such as ecological and social issues need to be taken into account in the development and management of the schemes. Quality of water is part of the ecological issue required to be considered in the beginning (Nata *et al.* 2011). The quality of water is very important to mankind, because it is directly linked to human welfare. The analysed chemical parameters of groundwater play an important role in classifying and assessing

Figure 5. Piper trilinear plot and the hydrogeochemical facies in the Kashmir Valley.

water quality particularly with regard to its portable nature.

5.1 Domestic purposes

The concentrations of various ions in the groundwater were compared both with the specifications of World Health Organization (WHO 2006) and Indian standards (BIS: 10500: 1991) for drinking water, where a majority of the samples from shallow and deep groundwater are within the permissible limits. The groundwater classification based on the hydrochemical properties and TDS for groundwater suitability, suggest that 65.68% from shallow groundwater and 69.49% from deep groundwater are below <500 mg/L of TDS which is desirable for drinking purposes without any risk and 31.37% and 22% from deep groundwater and shallow groundwater are permissible for drinking (Davis and Dewiest 1966; Freeze and Cherry 1979).

5.2 Livestock water quality

Water for livestock should be of high quality to prevent them from various diseases, salt imbalance, or poisoning by toxic constituents. Most of the water quality variables for livestock are the same as for human drinking-water, although the total permissible levels of total suspended solids and salinity

may be higher (Bhardwaj and Singh 2011). The total dissolved solids (TDS) is the main parameter usually used to evaluate the suitability of any water for livestock farming. Based on the Australian and UNESCO standards, the TDS value between zero and 2900 mg/L is suitable for all animals (Hamill and Bell 1986). In this case, the groundwater is good for livestock purposes as the TDS in groundwater ranged from 71.7–1495.4 mg/L.

5.3 Groundwater for irrigation purposes

Irrigation is one of the methods used to increase food production as it is directly linked to promoting economic growth and sustainable development of the Kashmir Valley. Groundwater as a source of water for irrigation would help the farmers in achieving maximum crop productivity; only then, when it can meet the quality criteria of WHO (2006) and BIS (1991) standards. Irrigation with poor quality waters may bring undesirable elements to the soil in excessive quantities affecting its fertility. To avoid this, suitability evaluation of groundwater becomes necessary. The following parameters were used to judge the suitability of water, sodium absorption ratio (SAR), residual sodium carbonate (RSC), United States Department of Agriculture (USDA) classification, Kelly index (KI), percentage sodium (% Na), magnesium ratio (MR) and permeability index (PI).

5.3.1 Sodium absorption ratio (SAR)

Sodium absorption ratio is an estimate of the degree to which sodium is absorbed by the soil and is used to evaluate the water for irrigation. SAR has been calculated by using the formula $SAR = Na / \sqrt{(Ca^{2+} + Mg^{2+})/2}$ (Richards 1954). The present study reveals that all the samples (shallow groundwater = 100% and deep groundwater = 100%) belong to sodium hazard class S1 which indicates that it is excellent for irrigation purposes.

5.3.2 Residual sodium carbonate (RSC)

According to USA Salinity Laboratory (1954) RSC value <1.25 meq/L is safe; if the value varies between 1.25 and 2.25 meq/L, it is of average quality and if more than 2.25 meq/L it is unsafe for irrigation. The following formula has been applied for RSC computation. $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$. The shallow groundwater and deep groundwater were analysed and the maximum number of samples (shallow groundwater = 97% and deep groundwater = 91%) fall in the safe range and only few percent of samples from shallow groundwater (2.64%) and deep groundwater (8.33%) exceeds the rate of hazard, which reveals that they are not safe for irrigation.

5.3.3 United States Department of Agricultural (USDA) classification

According to this classification the $EC < 250$ $\mu S/cm$ is excellent (C1 class), 250–750 is good quality (C2 class), 750–2250 is of permissible (C3 class) and 2250–5000 unsuitable (C4 class) for irrigation purposes. The present observation suggests that suitability of groundwater lies between C1 and C2 class as the TDS of the groundwater ranges from 71.7 to 1495 $\mu S/cm$ which means that the present status of groundwater in the Kashmir Valley is good for irrigation purposes.

5.3.4 Kelly index (KI)

Kelley (1940) and Paliwal (1967) introduced an important parameter for evaluating quality criteria for water for irrigation purposes by using the following formula, $Na^+ / (Ca^{2+} + Mg^{2+})$. The KI values computed for the study area ranged from shallow groundwater = 0.04–0.9 meq/L and deep groundwater 0.035–1.0 meq/L with mean of 0.2 and 0.27 meq/L, respectively. All the values fall within the normal range (1), which suggests that groundwater is suitable for irrigational practice.

5.3.5 Percentage sodium (%Na)

Sodium is an important ion used for the classification of irrigation water. Its reaction with soil reduces soil permeability (Hakim *et al.* 2009; Vasanthavigar *et al.* 2010). The sodium in irrigation water is usually expressed in %Na (Tank and Chandel 2010) expressed as, $Na\% = Na^+ + K^+ / (Ca^{2+} + Mg^{2+} + K^+ + Na^+) \times 100$. The present study suggests that groundwater is good for irrigation purposes as majority of samples fall in the range of shallow groundwater = 2.32–13.3% and deep groundwater = 0.53–11.09 with an average of 7.3 and 6.2%, respectively, which indicates the groundwater in the Kashmir Valley is good for irrigation purposes.

5.3.6 Magnesium absorption ratio (MAR)

Magnesium hazard ratio was proposed by Szabolcs and Darab (1964). Paliwal (1972) developed an index for calculating the magnesium hazard (MR) by using the formula, $MAR = [Mg^{2+} / (Ca^{2+} + Mg^{2+})] \times 100$. MAR value exceeding 50% is harmful and unsuitable for irrigation use. In the present study, the majority (94%) of samples fall under this range and 6% of samples exceed this limit. The excessive magnesium in these samples is due to influence of Dolomitic limestone in these areas (Malingpur, Bandipur, Sopore), which suggests that groundwater in the Kashmir Valley is good for agricultural purposes.

5.3.7 Permeability index (PI)

Doneen (1964) evolved a criterion for evaluating the suitability of water for irrigation based on PI. According to this classification, Class I and II possessing maximum permeability $>75\%$ are classified as good for irrigation while third category (Class III) having 25% maximum permeability are considered unsuitable for irrigation purposes (Nagaraju *et al.* 2006). PI is calculated using the following equation: $PI = (Na^+ + HCO_3^-) / (Ca^{2+} + Mg^{2+} + Na^+) \times 100$. The PI values computed ranged from 57–128.35% in case of shallow with a mean of 96% groundwater and 72–138% with an average of 98% in deep groundwater, respectively. The study suggested that groundwater in the study area falls under class I and II, and hence is considered good for irrigation.

6. Conclusion

The groundwater in the Kashmir Valley, India is generally alkaline having permissible limit of an electrical conductivity. Ca^{2+} was the dominant

cation and HCO_3^- was dominant anion in groundwater. The order of abundance of cations was $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and in anions the order follows $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$. The average concentrations of various chemical parameters were found to be higher in shallow aquifer than in deeper aquifer. High concentration of HCO_3^- and pH less than 8.8 clearly indicated intense chemical weathering processes have taken place in the study area. Four types of groundwater were found in the valley as: Ca-HCO_3 , Mg-HCO_3 , Ca-Mg-HCO_3 and Na-HCO_3 . The study suggested that the groundwater flow in the study area is largely controlled by the local surface topography (variation in elevation) as there is a general trend in groundwater levels from south to north of the valley. The flow patterns not only modify the facies but also control the distribution. The concentrations of various ions in the groundwater were compared both with the specifications of World Health Organization (WHO 2006) and Indian standards (BIS: 10500: 1991) for its suitability, which suggested that groundwater in the valley is good for all purposes (i.e., domestic, livestock, and irrigation). The groundwater quality analyses indicate that the host lithology plays a dominant role in controlling the groundwater chemistry and the carbonate dissolution process may be the dominant source of major ions followed by silicate weathering and ion-exchange processes in the Kashmir Valley.

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