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HYDROGEOCHEMISTRY AND GROUNDWATER QUALITY FOR DRINKING AND AGRICULTURAL PURPOSES: A CASE STUDY OF SRINAGAR DISTRICT, J AND K, INDIA

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ABSTRACT

Assessment of water quality has been carried out for the Srinagar district to determine the sources of dissolved ions in groundwater. Fifty nine water samples were collected from open wells, bored wells and springs. The quality assessment was made through the estimation of Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , HCO_3^- , total hardness as CaCO_3 , total dissolved solids (TDS), electrical conductivity (EC), and pH. Based on these analyses, parameters like sodium adsorption ratio (SAR), % sodium, salinity index, salinity hazard, residual sodium carbonate (RSC), potential salinity, index of Base Exchange and permeability index (PI) were calculated. As per the Gibb's diagram, majority of the samples fall in the rock dominance area. On the bases of these determined and calculated parameters, it is concluded that the groundwater in the study area is fit for agricultural and domestic purposes.

Keywords Srinagar District, sodium adsorption ratio (SAR), % sodium, residual sodium carbonate, permeability index

INTRODUCTION

The valley of Kashmir though has abundant water resources in the form of freshwater lakes, rivers and springs, yet great concern is expressed for supply of water for domestic and agricultural uses particularly in uplands of Karewas and urban areas in late summer dry months. The water supply has become more erratic and inadequate during summer and dry periods leading to water crisis. Thus groundwater in Srinagar district has become popular and is preferred over surface water because of non-availability of pure potable surface water sources and the consideration that surface-soil-strata act as a natural filter, providing safe and pure water. In the study area groundwater level is shallow, hence liable to the contamination from the sources like anthropogenic activities. Therefore, it becomes

imperative to study the hydrogeological regime and groundwater chemistry of the area to obtain the first hand information about the possible geological as well as anthropogenic influence on the groundwater in the study area. The hydrogeochemistry of groundwater helps to get insight into the contributions of rock and water interaction and anthropogenic influences on the groundwater quality processes of groundwater system (Mathess 1982; Kumar et al. 2006). Groundwater chemistry depends on a number of factors, such as general geology, degree of chemical weathering of the various rock types, quality of recharge water, inputs from sources other than water-rock interaction and subsurface geochemical processes (Domenico 1972; Schuh et al. 1997; Reza and Singh 2010; Vasanthavigar et al. 2010).

STUDY AREA

Srinagar district lies between $34^{\circ} 3' - 34^{\circ} 20' N$ latitude and $74^{\circ} 40' - 75^{\circ} 15' E$ longitude and covers an area of $2,228 \text{ km}^2$, is situated in the heart of Kashmir valley (Fig.1). The area is included in the survey of India Toposheet No. 43 J/16. The population of the district is 12, 02,447 with rural population 256,281 and the urban being population 946,166 (Census 2001). The population density in Srinagar is 401 per square kilometers, which is the highest in the state.

MATERIALS AND METHODS

Groundwater samples (59 in number) were collected from the study area in the post melting season i.e. Oct-Nov. Sample collection, transportation and analysis was done according to the methods and procedures published in the APHA (2005). The samples were collected after 10 minutes of pumping and were transferred to pre-cleaned plastic bottles. A few parameters like EC and pH were measured in the field using portable water analysis kit. The bottles caring samples were then labeled and transported to the laboratory for the analysis of other parameters. Na^+ and K^+ were measured by using a flame photometer. Total hardness as CaCO_3 , calcium (Ca^{2+}), carbonates (CO_3^{2-}), bicarbonate (HCO_3^-) and, chloride (Cl^-) were analyzed by volumetric methods. Mg^{2+} was calculated from total hardness and calcium. Sulphate and Nitrate were determined by spectrophotometry. Total dissolved solids were measured by weighing the residue after evaporation of the samples and also calculated by formula $\text{TDS} = \text{EC}$ in mhos/cm at $25^{\circ}\text{C} \times 0.64$ (Hem 1991). All the concentrations were expressed in Mg/l except for pH which is expressed in dimensionless number.

RESULTS

The analytical data, calculated values, and statistical parameters like mean, maximum, minimum, standard deviations, are given in Table1. In the study area the pH of the

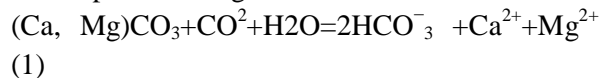
groundwater ranges from 6.63 to 8.54 with a mean value of 7.42 and EC varies from 60 to 1830 micro mhos per cm and has an average of 460.6 micro mhos per cm. The groundwater in the study area falls in slightly acidic to slightly alkaline categories. Very large variations in the electric conductivity may be attributed to variation to total dissolved solids. The higher EC of the water is result of ion exchange and solubilization in the aquifer system (Sanchez-Perez and Tremolieres 2003). Total dissolved solids (TDS) in the study area ranges from 44.8 to 1171 mg/l with mean value of 311mg/l. The groundwater in the study area falls under fresh ($\text{TDS} < 1000 \text{ mg/l}$) to brackish ($\text{TDS} > 1000 \text{ mg/l}$) types of water (Freeze and Cherry 1979). Based on total dissolved solids, groundwater is classified into desirable for drinking (up to 500 mg/l), permissible for drinking (500–1,000 mg/l), useful for agricultural purposes (up to 3,000 mg/l), and unfit for drinking and irrigation (above 3,000 mg/l) (Davis and De Wiest 1966). The majority of the samples (97.30%) from the study area fall in the desirable to permissible category for drinking purposes, and only 1.69% of the samples fall above the permissible limit. However, all the samples are fit for agricultural uses according to the mentioned criteria (Table 2).

DISCUSSION

Major Cation Chemistry

The major cations (Ca, Mg, K, and Na) in the groundwater of the study area are well below standards prescribed by WHO (1984) for drinking purposes. The abundance of the major cations in the study area is in the order $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$. Calcium and magnesium ions present in groundwater are particularly derived from leaching of limestone, dolomites, gypsum and anhydrites (Eq. 1). The calcium ions can also be derived from cation exchange process (Garrels 1976). The concentration of calcium ions in the study area ranges from 37.8 mg/l to 126.33 mg/l

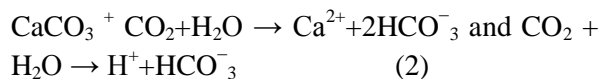
and magnesium ranges from 13.2 mg/l to 103.7 mg/l with an average value of 88 mg/l 15.52 mg/l respectively. This indicates calcium ion concentration in the study area is relatively high as compared to magnesium ion concentration.



The $(Ca^{2+} + Mg^{2+})$ vs. $(HCO_3^- + SO_4^-)$ scatter diagram (Fig. 2, after Datta and Tyagi 1996) shows that majority of the samples fall above the equiline indicating that the carbonate weathering is the dominant process for supply of the calcium and magnesium ions to the groundwater. The possible source of sodium concentration in groundwater is due to dissolution and weathering of sodium bearing minerals. In the study area the concentration of sodium and potassium ranges from 14 mg/l to 157 mg/l and 0 to 175 mg/l with an average value of 55.53 mg/l and 28.51 mg/l respectively. If the halite dissolution process is responsible for the sodium concentration in the ground water, Na/Cl ratio should be approximately 1, whereas the Na/Cl ratio greater than 1 typically indicates that the sodium was released from silicate weathering (Meyback 1987). In the study area the majority of the samples show Na/Cl ratio greater than 1 indicating that the silicate weathering is the dominant process for the release of sodium in the groundwater Fig 3(A). Potassium ion concentration in the groundwater also comes from the above said process. Silicate weathering, dominant process in the area, is also supported by HCO₃ vs. Na scatter diagram (Fig 3 (B), after Datta and Tyagi 1996), where all the samples fall below the equiline.

Major Anion Chemistry

The carbonate and bicarbonate concentration in groundwater is derived from carbonate weathering as well as dissolution of carbonic acid in the aquifers (Jeevanandam *et al.* 2006; Kumar *et al.* 2009; Eq. 2).



The anions in the groundwater of the study area are in the order $HCO_3^- > Cl^- > SO_4^{2-}$. Bicarbonates in the study area range from 110 mg/l to 298 mg/l with a mean value of 184.56 mg/l. Bicarbonate is the dominant anion among the anions of the groundwater of the study area. The increase in the bicarbonate may be attributed to availability of the carbonate minerals in the recharge area (Elango *et al.* 2003). The concentration of chlorides ranges from 2.7 mg/l to 159.38 mg/l with a mean value of 20.74 mg/l. The natural process such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the groundwater, which is supported by Cl^-/HCO_3^- ratio of 0.01 to 0.7 (Luszczynski and Swarzenski 1996). The concentration of sulfate ranges from 0.8 mg/l to 4.42 mg/l with a mean value of 2.48 mg/l. Sulfate ion concentrations are derived from weathering of sulfate and gypsum-bearing sedimentary rocks (Elango *et al.* 2003; Jeevanandam *et al.* 2006). The concentration of nitrate ranges from 0.05 to 1.51 mg/l with a mean value of 0.94 mg/l. The sources of nitrate content in the groundwater of the study may be credited to the irrigation return flow as lot of fertilizers are used in the agricultural fields in and around the study area.

Index of Base Exchange

It is essential to know the changes in chemical composition of groundwater during its travel in the sub-surface (Sastri 1994). The Chloro-alkaline indices CAI 1 and CAI 2 suggested by Schoeller 1977, indicate the ion exchange between the groundwater and its host environment. The Chloro-alkaline indices used in the evaluation of Base Exchange are calculated using the below given equations (Eq. 3 and 4).

$$\text{Chloro - Alkaline Indices 1} = \frac{[Cl - (Na + K)]}{Cl} \quad (3)$$

$$\text{Chloro – Alkaline Indices 2} = \frac{[\text{Cl} - (\text{Na} + \text{K})]}{(\text{SO}_4 + \text{HCO}_3 + \text{CO}_3 + \text{NO}_3)} \quad (4)$$

If there is ion exchange of Na^+ and K^+ from water with magnesium and calcium in the rock, the exchange is known as direct and the indices are positive. Whereas, in the reverse condition exchange is said to be indirect and the indices are found to be negative. The chloro-alkaline indices calculated for the ground water of the study area shows that 98% samples show negative indices i.e. indirect exchange and only 2% samples fall in the direct exchange category.

Hydrochemical facies

The hydrochemical regime of a study area can be easily known by plotting the analytical values obtained from the groundwater on Piper (1944) trilinear diagrams. These plots include two triangles, one on left hand side for plotting cations and the other on right hand side for plotting anions. The cation and anion fields are then combined to show a single point in a central diamond shaped field from which inference is drawn on the basis of the hydrogeochemical facies concept. This diagram reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups (Todd 2001). This diagram is very useful in bringing out chemical relationships among groundwater in more definite terms (Walton 1970; Todd 2001). This diagram is divided into six sub categories viz. 1. (Ca- HCO_3 type), 2. (Na-Cl type), 3. (Mixed Ca-Na- HCO_3 type), 4. (Mixed Ca-Mg-Cl type), 5. (Ca-Cl type) and 6. (Na- HCO_3 type).

From the studied samples, 81.13%, 8.47% and 3.38% samples fall in the field 1, 3 and 6 of the Piper trilinear diagram (Fig. 4), respectively. From the plot it is observed that majority of samples are of Ca- HCO_3 type followed by Mixed Ca-Na- HCO_3 type and a little percentage falls under Na- HCO_3 type suggesting that throughout most of the study area alkaline earths (Ca^+ and

Mg^+) dominate over alkalies (Na^+ and K^+) and weak acids (HCO_3^-) dominate over strong acids (Cl^- and SO_4^{2-}) in the groundwater.

Mechanisms Controlling Groundwater Chemistry

Reactions between groundwater and aquifer minerals have a significant role on water quality, which are also useful to understand the genesis of groundwater (Cederstorm 1946; Gupta *et al.* 2008; Subramani *et al.* 2009). To know the groundwater chemistry and the relationship of the chemical components of water to their respective aquifers such as chemistry of the rock types, chemistry of precipitated water, and rate of evaporation, Gibbs (1970) has suggested diagrams in which ratio of dominant anions and cations are plotted against the value of TDS. Gibbs diagrams, represents the ratio 1 for cations and ratio 2 for anions (eq. 5 & 6) as a function of TDS. These diagrams are widely employed to assess the functional sources of dissolved chemical constituents, such as precipitation, rock, and evaporation dominance (Gibbs 1970).

$$\text{Gibbs Ratio 1 for cations} = \frac{(\text{Na} + \text{K})}{(\text{Na} + \text{K} + \text{Ca})} \quad (5)$$

$$\text{Gibbs Ratio 2 for anions} = \frac{\text{Cl}}{(\text{Cl} + \text{HCO}_3)} \quad (6)$$

The studied groundwater samples are plotted in Gibbs diagrams (Fig 5), majority of these samples fall in the rock dominance area suggesting that chemical weathering is the dominant process which has affected the groundwater by dissolution of the rock forming minerals of the aquifer. Only five samples fall in the precipitation dominance area suggesting the influence of precipitation on the ground water.

Groundwater quality for agriculture

The quality of water, type of soil, and cropping practices play an important role for a suitable irrigation practice. Presence of excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, thus reducing productivity. The physical effect of

these ions is to lower the osmotic pressure in the plant structural cells, thus preventing water to reach the branches and leaves of the plant. The chemical effect is to disrupt plant metabolism. Water quality problems in irrigation include indices for salinity, chlorinity, sodicity, and alkalinity (Mills 2003).

Total hardness

To determine the suitability of groundwater for domestic and industrial purposes, hardness is an important criterion, as it is involved in making the water hard. Water hardness has no known adverse effects; however, it causes more consumption of detergents at the time of cleaning, and some evidence indicates its role in heart disease (Schroeder 1960). The total hardness (TH) in ppm (Hem 1985; Ragunath 1987; Todd 2001) has been determined by Eq. 7:

$$TH = 2.497 Ca^{2+} + 4.115Mg^{2+} \quad (7)$$

The classification of the groundwater of the study area based on hardness (Sawyer and McCarthy 1967) is presented in Table (3). Accordingly the groundwater of the study area is hard to very hard with 11.87% of samples falling in hard category and 88.13% samples falling in very hard category.

Sodium adsorption ratio (SAR)

Excess sodium in water produces undesirable effects of changing soil properties and reducing soil permeability (Kelly 1951). High sodium depositing waters are generally not suitable for irrigating crops, as higher deposition of sodium may deteriorate the soil characteristics. SAR of water is directly related to the adsorption of sodium by soil and is a valuable criterion for determining the suitability of the water for irrigation. Excessive sodium content relative to calcium and magnesium reduces soil permeability (Kelly 1951). and thus inhibits the supply of water needed for the crops. The SAR measures the relative proportion of sodium ions to those of calcium and magnesium in water. SAR is used to

predict the sodium hazard of high carbonate waters especially if they contain no residual alkali. The excess sodium or limited calcium and magnesium content are evaluated by SAR (Kalra and Maynard 1991), which is computed using Eq. 8 as:

$$SAR = \frac{Na}{\frac{\sqrt{(Ca + Mg)}}{2}} \quad (8)$$

The classification of groundwater samples from the study area with respect to SAR (Todd 1959; Richards 1954) is presented in Table (4). The SAR value in the study area ranges from 0.24 to 2.82 with mean value of 1.04 which means that all the samples from the study area are classified as excellent for irrigation as all the samples fall in S1 category (sodium hazard class).

Salinity hazard

The total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. Classification of groundwater based on salinity hazard is presented in Table (5). It is found from the salinity hazard classes that 18.64% of the samples fall in the excellent category, 67.79% samples fall in good category and 13.55% samples fall in doubtful category for irrigation purposes. Groundwater samples that fall in the low salinity hazard class (C1) can be used for irrigation of most crops and majority of soils. However, some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability. Groundwater samples that fall in the medium salinity hazard class (C2) can be used if a moderate amount of leaching occurs. High salinity (C4 and C5) can be suitable for plants having good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage (Karanth 1989; Mohan et al. 2000). High salinity water (C3, C4, and C5) cannot be used in soils with restricted drainage. Even with adequate drainage, special management for salinity control is required, and crops with good salt tolerance should be selected.

Such areas need special attention as far as irrigation is concerned. A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity (Fig. 12) data on the US Salinity Laboratory (USSL) diagram (Richards 1954). Accordingly, 11 samples fall in the category of C1S1 (18.64%), indicating a low salinity/low sodium type. Of the remaining 48 samples, 39 samples belong to C2S1 (67.79%), showing medium salinity hazard/ low sodium hazard and 9 samples belong to C3S1 (13.55%), category, indicating a high salinity/low sodium type water.

Salinity index

On the bases of salinity index classification of groundwater samples is given in Table 6 (Handa 1969). It is found that all the samples fall under low to high salinity classes. The majority of the samples (67.79%) belong to the medium salinity category, indicating that the water is of good quality. The salinity index of the groundwater samples was computed using the measured electrical conductivity values. Water exhibiting low to medium salinity (classes 1 and 2) are not considered very harmful to soils or crops, whereas those exhibiting high salinity (class 3) are suitable for irrigating the medium and high salt-tolerant crops. High salinity water (class 4) is suitable for irrigating high salt-tolerant crops, whereas water of salinity class 5 or above is generally unsuitable for irrigation. All of the groundwater samples in the study region are categorized as classes 1–3 and thus may be considered as suitable for irrigation.

Percent Sodium (Na %)

If the concentration of Na^+ is high in irrigation water, Na^+ gets absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^+ in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability of the soil and eventually results in poor internal drainage of the soil. Hence, air and water circulation is restricted during wet conditions and such soils are usually

hard when dry (Collins and Jenkins 1996; Saleh *et al.* 1999). Methods of Wilcox (1955) and Richards (1954) have been used to classify and understand the basic character of the chemical composition of groundwater, since the suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. Percent sodium can be determined using equation 9 as:

$$\text{Na}\% = \frac{(\text{Na} + \text{K})100}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \quad (9)$$

The classification of groundwater samples with respect to percent sodium is shown in Table (7) and it is found that 28.81% of the samples fall in the excellent category, 52.54% of the samples fall in the good category, 16.94% of the samples fall in the permissible category while only 1.69% samples fall in doubtful category, showing that majority of the samples in the study area are suitable for irrigating the most types of soils. Based on percent sodium, Eaton (1950) classified irrigation water into two categories with percent sodium greater than sixty percent as unsafe and the water with percent sodium less than sixty as safe. Accordingly the 98.30% of the samples from the study area fall in the safe category and only 1.69% samples fall in the unsafe category (Table 8).

Wilcox (1955) used percent sodium and specific conductance in evaluating irrigation waters using Wilcox diagram. In the Wilcox diagram %Na is plotted against specific conductance. An appraisal of the Wilcox diagram (Fig. 7) shows that most of the samples from the study area fall under excellent to permissible fields of the diagram with only two samples falling in doubtful to permissible field, indicating that majority of the samples from the study area are suitable for the irrigation purposes for majority of crops and most of the soils.

Residual sodium carbonate

When concentration of carbonates and bicarbonates exceeds that of calcium and

magnesium, there may be possibility of complete precipitation of calcium and magnesium. Bicarbonate and carbonate is considered to be detrimental to the physical properties of soils, as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate, and this excess, denoted by RSC, is calculated as given below (Eaton 1950; Ragunath 1987: Eq. 11).

$$\text{RSC} = (\text{HCO}_3^- + \text{CO}_3) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (11)$$

According to the US Department of Agriculture, water having more than 2.50 epm of RSC is not suitable for irrigation purposes. A high value of RSC in water leads to an increase in the adsorption of sodium in soil (Eaton 1950). The groundwater in the study area is classified on the basis of RSC (Richards 1954) and the results are presented in Table (10). Accordingly, 98.30% of samples fall in the suitable category and only 1.69% of the samples fall in the unsuitable category.

Permeability Index

The permeability of the soil is affected by the long term use of water influenced by Na^+ , Ca^{2+} , Mg^{2+} , and HCO_3^- Doneen (1964) and Ragunath (1987) evolved a criterion for assessing the suitability of water for irrigation based on permeability index (P.I.). The permeability index can be calculated as given below (Eq. 13):

$$\text{PI} = \frac{\text{Na} + \sqrt{\text{HCO}}}{(\text{Ca} + \text{Mg} + \text{Na})} \quad (13)$$

Where, all the ions are reported in milliequivalents. As per the Doneen's chart waters can be classified as Class I, Class II, and Class III. Class I and Class II represent waters which are good for irrigation with 50–75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. The permeability index of the groundwater in the study area varied

from 20.26 to 62.84 with an average of 37.22. An appraisal of the figure (8), shows that all the samples from the study area fall in class I field of the Doneen's Chart showing that maximum permeability is more than 75% which indicates that the water is excellent for the irrigation purposes.

Potential salinity

The suitability of water for irrigation is not dependent on the concentration of soluble salts in the water (Doneen 1961, 1964). (Doneen 1962) is of the opinion that low solubility salts precipitate in the soil and accumulate with each successive irrigation, whereas the concentration of highly soluble salts increases the salinity of the soil. (Doneen 1962) introduced an important parameter "Potential salinity" for assessing the suitability of water for irrigation uses which may be defined as the chloride concentration plus half of the sulfate concentration (Eq. 14).

$$\text{Potential salinity} = \text{Cl} + \frac{1}{2}\text{SO}_4 \quad (14)$$

It is generally found that PS values are more pronounced in the estuarine region than in the fresh water region samples and is expressed in milliequivalents per liter. The huge amount of potential salinity in the estuarine region is due to the presence of chlorides, which are derived from sea source. The potential salinity of the water samples in the study area varied from 0.10 to 4.51 with an average value of 0.61 meq/l. It shows that the potential salinity in the groundwater of the study area is low, thus, making the water useful for irrigation purposes.

CONCLUSION

The groundwater in the study area is slightly acidic to slightly alkaline, and belongs to hard to very hard categories. Based on TDS the groundwater in the region is fresh to brackish and (97.30%) of the samples fall in the desirable to permissible category for drinking purposes, with only 1.69% of the samples falling above the

permissible limit while all the samples are fit for agricultural uses.

The abundance of the major cations in the study area is in the order $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$ While that of major anions is $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. Carbonate weathering is the dominant weathering process in the study area, however, silicate weathering processes are also responsible for the supply of the some ionic species to the groundwater. The negative index of Base Exchange for most of the samples (>90%) indicate that there exists a chloro-alkaline disequilibrium, i.e., ion exchange between the groundwater and its host environment during residence or travel time. Based on the hydrochemical facies the groundwater in the study area consisted of three main facies viz. Ca-HCO₃ type (81.13%), Mixed Ca-Na-HCO₃ type (8.47%) and Na-HCO₃ type (3.38%), indicating that throughout most of the study area alkaline earths (Ca⁺ and Mg⁺) dominate over alkalis (Na⁺ and K⁺) and weak acids (HCO₃⁻) dominate over strong acids (Cl⁻ and SO₄²⁻). Based on the Gibb's diagram it can be concluded that in more than ninety one percent of the samples the major ion chemistry is controlled by rock-water interaction whereas the chemistry of the remaining meagre amount of the samples is the result of mixing of meteoritic water with the groundwater.

The suitability of groundwater for irrigation was evaluated based on the irrigation quality parameters like SAR, Salinity hazard, Salinity index, %Na, RSC, potential salinity and permeability index,. According to the values of these parameters the groundwater of the study area was found excellent, excellent to doubtful, excellent to permissible, excellent to doubtful, suitable to unsuitable, satisfactory, excellent to permissible, useful, excellent, suitable to unsuitable and suitable to unsuitable respectively. However looking at the results it may be concluded that all the parameters show that more than 90% of the samples can be used for

irrigating most of the crops and majority of the soils.

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Figure 1 Showing location of the study area

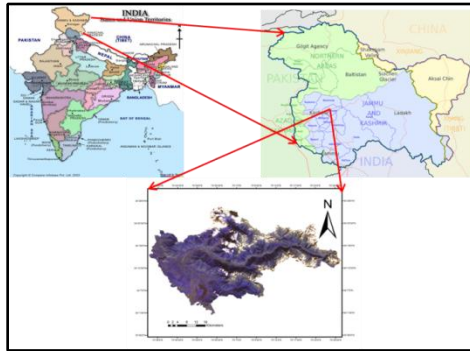


Figure 2 Showing (Ca +Mg) vs. (HCO +SO) Plot (After Dutta & Tyagi 1996)

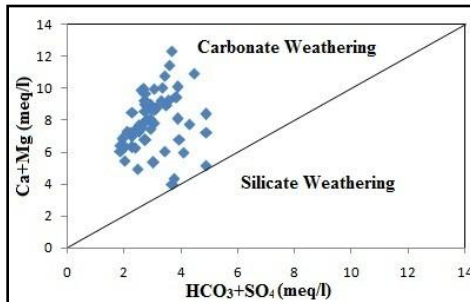


Figure 3 (A &B) Showing Na Vs Cl Plot(A; after Meyback 1987) and (HCO₃Vs. Na) Plot (B; After Dutta & Tyagi 1996)

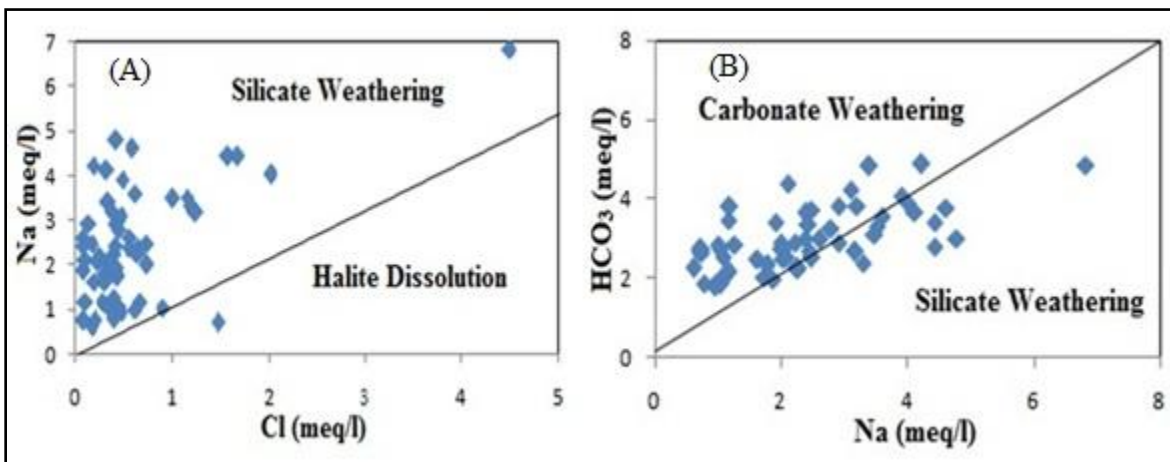


Figure 4 Showing Piper Trilinear Diagram (After Piper 1944)

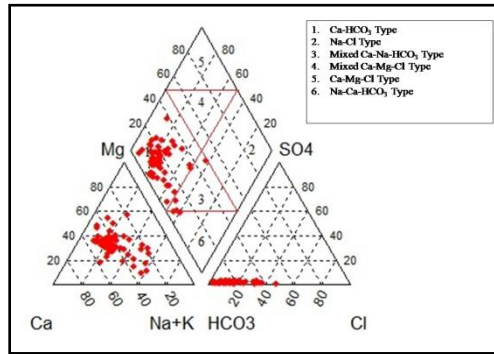


Figure 5 Showing Gibbs Diagram (After Gibbs 1950)

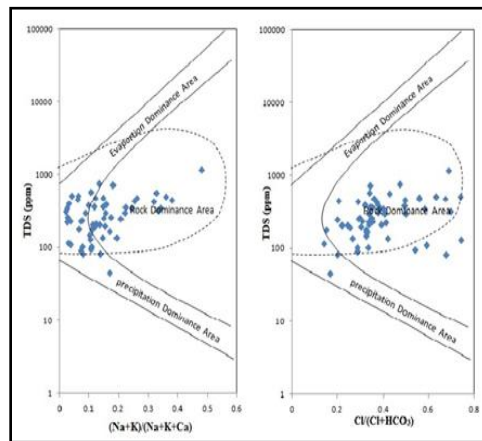


Figure 6 Showing USSL Salinity Hazard Diagram (Richards 1954).

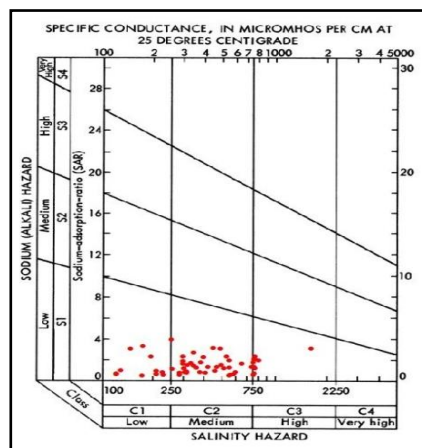


Figure 7 Showing Wilcox Diagram (After Wilcox,1955)

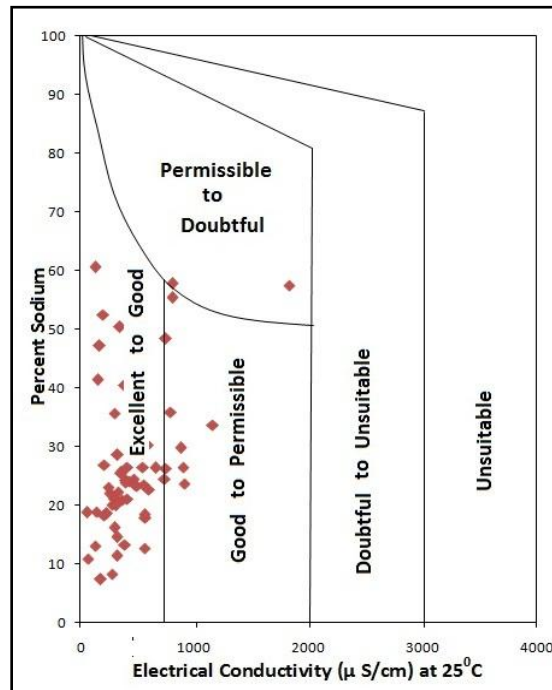


Figure 8 Showing Doneen's Chart of Permeability Index (After Doneen 1964)

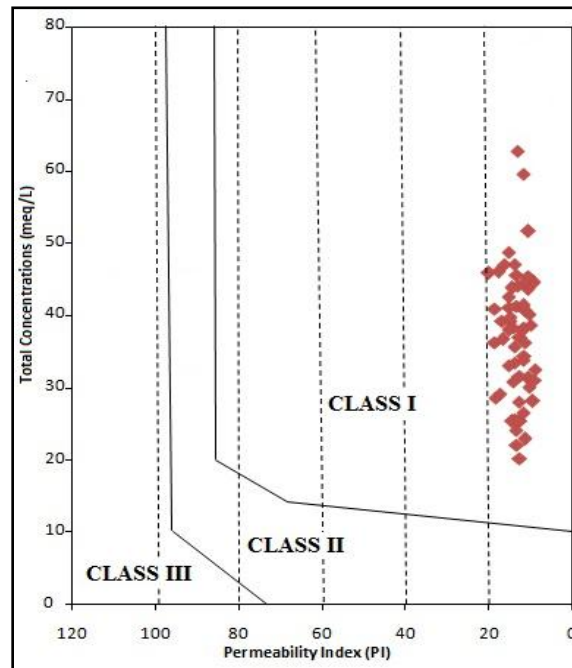


Table 1 Showing analytical data, calculated values, and statistical parameters

S.No.	pH	EC	TDS	T. Alkalinity	T. Hardness	Ca	Mg	Na	K	Cl	HCO ₃	SO ₄
1	7.85	306.00	230.40	293.00	395.01	81.63	46.46	47.00	2.00	7.57	166.00	1.82
2	8.30	280.00	179.20	242.00	367.45	75.60	43.42	41.00	2.00	10.57	146.00	1.87
3	8.25	210.00	134.40	210.00	316.02	64.58	37.61	52.00	2.00	13.77	138.00	1.69
4	7.73	280.00	179.20	195.00	423.91	85.08	51.39	14.00	6.00	5.79	138.00	2.20
5	8.32	370.00	236.80	272.00	435.31	101.56	44.16	51.00	3.00	8.79	177.00	2.31
6	7.80	400.00	256.00	280.00	312.67	95.52	18.02	41.00	8.00	14.67	143.00	2.72
7	7.82	790.00	505.60	356.00	402.04	70.83	54.72	102.00	2.00	55.86	171.00	1.62
8	8.45	500.00	320.00	310.00	245.81	39.10	36.01	76.00	46.00	42.44	146.00	4.42
9	7.55	230.00	147.20	210.00	451.25	84.08	58.64	46.00	2.00	11.77	177.00	1.92
10	7.98	180.00	115.20	280.00	496.87	97.06	61.85	17.00	2.00	2.85	162.00	1.98
11	7.95	260.00	166.20	210.00	318.50	72.43	33.45	40.00	2.00	14.80	123.00	2.08
12	8.54	810.00	518.40	562.00	258.97	81.96	13.20	78.00	144.00	11.80	294.00	3.25
13	8.05	810.00	518.40	394.00	216.57	37.82	29.68	57.00	113.00	5.79	227.00	1.96
14	7.85	330.00	211.20	190.00	367.65	81.91	39.64	47.00	2.00	12.57	152.00	1.92
15	7.72	350.00	224.00	282.00	391.49	77.37	48.19	60.00	3.00	2.67	183.00	2.78
16	7.99	550.00	352.00	253.00	363.96	82.69	38.27	57.00	5.00	25.66	153.00	1.60
17	7.39	320.00	204.80	472.00	494.73	77.68	73.09	25.00	7.00	14.41	156.00	2.96
18	7.35	1160.00	742.40	522.00	472.13	106.78	49.94	106.00	7.00	20.72	230.00	3.12
19	7.42	570.00	364.80	370.00	617.36	97.72	90.73	55.00	11.00	22.70	222.00	2.71
20	7.17	740.00	473.60	416.00	572.28	58.29	103.70	83.00	4.00	21.92	217.00	2.52
21	7.35	470.00	300.80	344.00	349.29	66.17	44.73	52.00	0.00	22.58	137.00	2.11
22	7.40	360.00	230.40	331.00	274.16	68.43	25.10	43.00	0.00	2.70	121.00	1.92
23	7.27	880.00	563.20	392.00	539.10	123.25	56.22	102.00	5.00	58.96	209.00	0.84
24	7.53	1830.00	1171.20	388.00	419.15	102.27	39.80	157.00	175.00	159.38	297.00	0.92
25	7.31	750.00	480.00	327.00	501.94	126.33	45.32	81.00	2.00	41.11	201.00	3.23
26	7.36	660.00	422.40	326.00	451.73	109.04	43.61	73.00	2.00	44.15	163.00	2.95
27	7.17	320.00	204.80	204.00	361.10	86.44	35.30	27.00	2.00	9.87	132.00	3.25
28	7.16	390.00	249.60	206.00	321.25	77.45	31.07	22.00	1.00	16.77	110.00	3.13
29	7.23	410.00	262.40	270.00	338.12	90.24	27.41	56.00	0.00	2.72	165.00	2.17
30	7.00	210.00	134.40	120.00	301.97	73.90	28.54	24.00	12.00	15.89	113.00	2.02
31	7.14	130.00	83.20	412.00	364.53	86.81	35.91	25.00	0.00	11.84	126.00	2.95
32	6.65	70.00	44.80	372.00	341.30	82.30	33.00	18.00	2.00	13.81	115.00	2.73
33	6.87	140.00	89.60	456.00	375.23	85.08	39.56	37.00	5.00	6.80	151.00	2.75
34	6.85	60.00	102.40	466.00	382.50	87.00	40.16	37.00	6.00	10.80	151.00	2.61
35	6.63	250.00	102.40	272.00	375.15	89.00	37.16	48.00	6.00	7.80	156.00	3.73
36	7.90	750.00	480.00	590.00	267.91	48.61	35.61	110.00	9.00	14.72	183.00	2.04
37	7.69	540.00	345.00	598.00	437.67	106.92	41.48	80.00	3.00	35.38	189.00	2.12
38	8.02	326.00	208.60	422.00	374.00	93.32	34.26	67.00	3.00	14.49	177.00	1.35
39	8.00	300.00	192.00	430.00	440.16	99.10	46.83	29.00	17.00	13.68	173.00	2.21
40	7.05	470.00	300.00	450.00	433.01	103.49	42.43	60.00	2.00	19.74	183.00	3.21
41	7.10	560.00	358.40	469.00	461.63	108.21	46.52	64.00	1.99	15.41	199.00	2.95
42	7.39	310.00	198.40	296.00	499.83	112.91	52.95	55.00	3.98	19.74	184.00	2.81
43	7.19	900.00	576.00	462.00	447.78	124.83	33.07	44.00	51.00	14.63	208.00	4.25
44	7.45	600.00	384.20	270.00	459.58	113.34	42.91	27.00	59.00	23.42	212.00	4.11
45	7.35	410.00	262.40	321.00	400.46	98.71	37.42	23.00	44.00	21.71	174.00	4.25
46	6.92	130.00	83.20	500.00	199.56	58.05	13.27	94.70	78.60	11.30	224.00	1.65
47	6.89	170.00	108.80	446.00	361.68	89.06	33.85	97.10	86.80	6.60	298.00	1.08
48	7.01	200.00	128.00	560.00	299.81	45.40	45.31	90.00	105.50	17.10	249.00	1.43
49	6.95	150.00	96.00	419.00	301.93	72.30	29.50	55.80	71.50	14.30	205.00	3.41
50	6.91	497.00	342.00	345.00	473.79	108.50	49.30	27.10	66.40	3.40	232.00	2.32
51	6.89	432.00	311.70	499.00	546.97	114.90	63.20	48.50	53.20	3.30	268.00	3.12
52	6.97	393.00	399.00	446.00	505.09	106.20	58.30	67.10	9.70	4.50	233.00	3.25
53	6.77	561.00	441.00	145.00	483.89	107.60	52.30	16.00	27.40	52.10	148.17	1.95
54	6.73	563.00	432.00	162.00	429.34	93.50	47.60	23.70	35.00	32.00	165.53	1.87
55	7.46	592.00	451.00	184.00	339.92	59.50	46.50	17.00	85.60	7.00	187.23	1.78

56	6.99	301.00	299.00	476.00	405.04	89.70	44.00	73.70	49.60	13.30	234.00	3.25
57	7.02	347.00	345.00	430.00	339.60	98.10	23.00	92.40	112.20	71.60	237.00	3.53
58	7.33	389.00	380.00	415.00	387.10	107.30	28.96	71.50	82.90	16.60	258.09	2.98
59	7.91	911.00	704.00	197.00	459.96	108.40	46.00	46.20	33.00	25.60	200.25	0.80
Min.	6.63	60.00	44.80	120.00	199.56	37.82	13.20	14.00	0.00	2.67	110.00	0.80
Max	8.54	1830.00	1171.20	598.00	617.36	126.33	103.70	157.00	175.00	159.38	298.00	4.42
Avg.	7.43	460.64	310.97	351.47	396.14	87.99	42.88	55.54	28.51	20.74	184.56	2.48
S. Dev	0.48	299.47	196.33	120.09	87.59	20.66	15.53	29.10	40.89	23.59	46.52	0.85

Table 2 Showing water Quality for Drinking and agricultural purposes (After Davis and De Wiest 1966).

TDS mg/l	Remarks on Quality	No. of Samples	%age of Samples
Up to 500	Desirable for Drinking	51	86.44
500-1000	Permissible for Drinking	07	11.86
Up to 3000	Useful for Agricultural	01	1.69
>3000	Unfit for Drinking and Irrigation	----	----

Table 3 Showing water Hardness Classes (After Sawyer and McCarthy 1967)

TH as CaCO ₃ (mg/l)	Water Classes	No. of samples	%age of Samples
<75	Soft	----	----
75-150	Moderately hard	----	----
150-300	Hard	07	11.87%
>300	Very hard	52	88.13%

Table 4 waters classes based on SAR values (Todd 1959; Richards 1954) and sodium hazard classes based on USSL classification

SAR	Sodium hazard class	Remarks on Quality	No. of Samples	%age of samples
<10	S1	Excellent	59	100%
10-18	S2	Good	----	---
19-26	S3	Doubtful/ Fair/ Poor	----	---
>26	S4 and S5	Unsuitable	----	---

Table 5 Salinity Hazard classes (After Richards 1954)

Salinity Class	Hazard	EC (µS/cm)	Remarks on Quality	No. of Samples	%age of Samples
C1		100- 250	Excellent	11	18.64
C2		250-750	Good	40	67.79
C3		750-2250	Doubtful	8	13.55
C4 and C5		>2250	Unsuitable	----	-----

Table 6 Salinity Hazard classes (After Handa 1969)

EC (µS/cm)	Water salinity	No. of Samples	%age of Samples
0-250 Low	Low (excellent quality)	11	18.64
251-750	Medium (good quality)	40	67.79
751-2,250	High (permissible quality)	08	13.55
2,251-6,000	Very high	----	----
6,001-10,000	Extensively high	----	----
10,001-20,000	Brines weak concentration	----	----
20,001-50,000	Brines moderate concentration	----	----
50,001-100,000	Brines high concentration --	----	----
>100,000	Brines extremely high concentration	----	----

Table 7 Water Classes Based on Percent Sodium (After Wilcox 1955)

% Sodium	Water Class	No. of samples	%age of samples
<20	Excellent	18	28.81
20-40	Good	24	52.54
40-60	Permissible	12	16.94
60-80	Doubtful	04	1.69
>80	Unsuitable	----	----

Table 8 Water Classes Based on Percent Sodium (After Eaton 1950)

% Sodium	Water Class	No of samples	%age of samples
<60	Safe	58	98.30
>60	Unsafe	01	1.69

Table 9 Water Classes Based on RSC (After Richards 1954)

RSC Value	Water Quality	No. of Samples	%age of samples
<1.25	Suitable	58	98.30%
1.25-2.5	Marginal	----	----
>2.5	Not Suitable	01	1.69%