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Assessment of Drinking and Irrigation Water Quality of Surface Water Resources of South-West Kashmir, India

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Abstract

Surface water samples have been collected from various streams of SW Kashmir and analyzed for major ions and trace elements to determine the mechanisms controlling the surface water chemistry and suitability of water for drinking, domestic and irrigation purposes. The order of cations is Ca > Mg > Na > K and anions is HCO_3 > Cl > SO_4 > NO_3. As per the Gibb's diagram, the major ion chemistry of surface water is controlled by rock-water interaction. The evolution of surface water into Ca-Mg-HCO_3 water type of Piper trilinear plot is due to easy dissolution of carbonate minerals and less time for water-rock interaction. Surface water samples are characterized by one main trend of Ca-Mg-HCO_3 i.e., carbonate dissolution of Langelier-Ludwig diagram. The major ions and trace elements in the water samples are well below the standards prescribed by WHO and BIS for drinking purposes. Based on EC and TDS classification, the water is fresh, good for irrigation and desirable for drinking purposes. The water samples fall between soft to hard categories of hardness classification with 16.66% belonging to soft, 50% to moderately hard and 33.33% to hard categories. The suitability of water for irrigation was evaluated based on the quality parameters and plots of water like Magnesium Content, Sodium Percent, Wilcox diagram, US Salinity hazard plot and Doneen's plot. According to the values of these parameters the surface water of the study area was found suitable for irrigation and the water can be used for irrigating most of the crops and majority of the soils.

Keywords: Hydrochemistry; India; NW Himalayas; Surface water; SW Kashmir; Water quality

Introduction

Nature has bestowed the Valley of Kashmir with ample water resources in the form of glaciers, lakes, surface and groundwater. Towards the SW Kashmir, a network of headwater tributaries of River Jhelum (Main River of the Kashmir Valley) provides water for drinking, domestic and agricultural purposes [1,2]. However, due to rapid increase in population, the need to meet the increasing demands of irrigation and human consumption, the available water resources are getting depleted and the water quality has deteriorated. It is well known that major and trace elements in water can impact human health and agriculture. Like other Indian rivers, the rivers/streams of SW Kashmir are polluted due to discharge of untreated sewage and agricultural wastes. Streams, due to their role in carrying off the municipal and agricultural wastes in their vast drainage basins, are among the most vulnerable water bodies to pollution [3]. In essence, the quality of water in surface drainage system is a function of anthropogenic influences including urbanization, agricultural and industrial activities as well as natural processes like weathering and catchment erosion [4]. Among the natural factors, geology of the catchment area, degree of chemical weathering of the various rock types, inputs from sources other than water-rock interaction play a significant role in controlling the chemistry of the surface water [5-7]. Over several decades, numerous studies have been published about major ions, trace elements or heavy metals in surface water [8-10], giving information about the possible geological as well as anthropogenic influences on the quality of surface water [11]. Metals are naturally redistributed in the environment through geological or biological processes and differ from other toxic substances as they are neither created nor destroyed by humans. There are at least two ways by which the human utilization influence the potential for health effects i.e., either through environmental transport or by altering the speciation or biochemical form of the element (Yang and Rose) The chemical compositions in terms of major and trace elements of pristine headwater tributaries of the River Jhelum can serve as baseline information for understanding the geochemical evolution of the Jhelum river system and for assessing anthropogenic inputs, in a non-industrial and less human affected area of western Himalaya. However, no previous studies have reported the major and trace elements compositions of pristine headwater tributaries of the Jhelum River.

Description of the study area

The study area is located towards the South-West of Kashmir valley (Figure 1) between latitude 33˚41'10' to 34˚00' 00' N and longitude 74˚45' 00' to 75˚00' 00' E, covering an area of about 800 sq. Km. Physiographically, the area is mainly represented by Karewas - elevated table lands. The elevation is more towards south and north–eastern part and the central portion is represented by flood plains of River Jhelum [12,13]. The north-eastern parts are represented by mountainous hilly terrain with undulating topography marked by deep cut valleys, gorges and ravines. The elevation ranges from 1580 m above mean sea level (amsl) at Pampore town to more than 3000 m amsl near Deopur. The area has a temperate climate with four well developed seasons namely Spring (Mar – May), Summer (Jun – Aug), Autumn (Sep – Nov) and Winter (Dec – Feb). The area receives a mean annual precipitation of 1150 mm, most of which falls during winter and early spring in the form of snow and rain. The mean annual temperature is 12ºC [11]. Geologically, the area is exposed dominantly by the rocks of Karewa Group, which are underlain by Paleozoic - Triassic sequence and overlain by Recent Alluvium [14,15]. Permo-Triassics, Panjal Traps,

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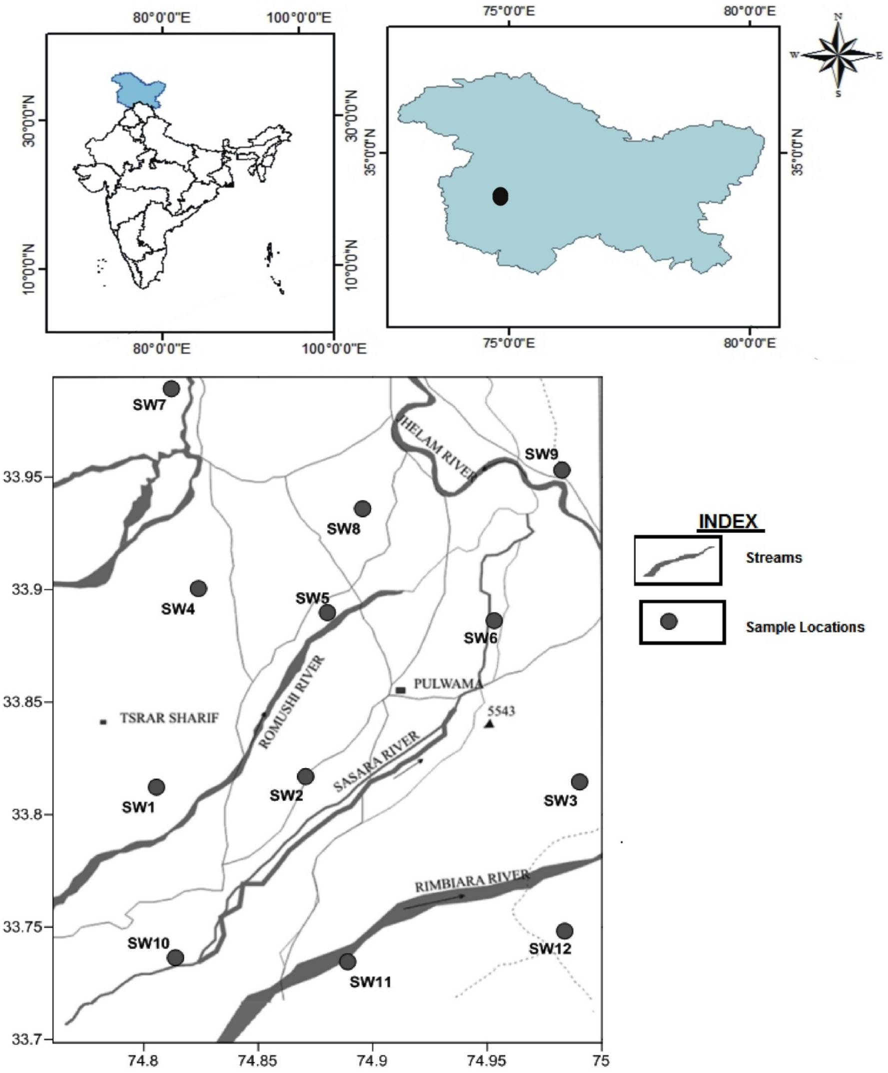

Figure 1: Location map of the study area along with sampling sites.

Mamal Formation and Zewan Beds form the basement for Karewas and are exposed towards the north-eastern part of the study area. The Plio-Pleistocene Karewa deposits are commonly divided into two lithologic units, the Lower Karewas (Hirpur Formation) and Upper Karewas (Nagum Formation) [16]. Lower Karewas are gently inclined and better exposed on the Pir Panjal side, have an unconformable contact with overlying nearly horizontal Upper Karewas which are better exposed on the Great Himalayan side [14]. The recent alluvium includes alluvial tracts, flood plains, river terraces, and talus and scree fans. The Recent unconsolidated sediments comprise clay, silt, and sand with occasional gravel [15,16].

Materials and Methods

Surface water samples were collected from different streams of SW Kashmir during peak ablation period i.e., Oct-Nov. Sample collection, transportation and analysis was done according to the standard methods and procedures [17]. To avoid the effect of floating debris, the samples were collected at depths greater than 30 cm below the water surface. Prior to sample collection, the containers were washed with concentrated HNO_3 and completely rinsed with distilled water and then using the water that was to be sampled. The preliminary chemical tests for pH, electric conductivity, dissolved oxygen, were carried out in the field. The samples were prepared and packed in plastic water bottles for further analysis at GSI Geochemical Laboratory. Major ion analysis was carried out according to the standard methods [17]. Ca^{2+} and Mg^{2+} were determined by titration with EDTA using P and R indicator and buffered at pH 12. Na^{+} and K^{+} were determined by Flame Photometry and Atomic Absorption Spectrophotometry at their respective wavelengths. HCO_3^- were carried out by titration with standard N/20, H_2SO_4 whereas Cl^- estimation was done by titrating the samples against $AgNO_3$ (0.02 N) using potassium chromate (5%) as an indicator. SO_4^{2-} was determined by Turbidimetry method using $BaCl_2$ and glycerin reagent followed by measurement at 420 nm with spectrophotometer or Turbidimeter. Nitrates were determined through ultra-violet method of estimation at 220nm with correction for organic matter at 275 nm for Nitrate using Membrane filtered water needed. Flouride was determined through spectrophotometric measurement of fading of colour(s) developed by Eriochrome Cyanine-R and Zirconium Oxychloride or Selective Ion Electrode Method using Ionmeter. Silica was measured spectrophotometrically by reduction of yellow molybdosilicic acid to molybdenum blue using metol-metabisulphite. Arsenic was determined Spectrophotometrically using silver diethyl dithio carbamate or Hydride Generation Technique (HG-AAS). Mercury was analysis by Cold vapour AAS technique or direct Mercury analyzer. Other trace elements were analyzed by ICP-AES and lCP-MS.

Results and Discussions

The results of the stream water samples are presented in Table 1. The water samples are neutral to moderately alkaline in nature with pH ranging from 6.92 to 8.24 at an average of 7.64. Electric Conductivity of the water samples ranges from 80 to 364 µS/cm, at an average of 242.75 µS/cm. TDS in the water samples vary from 55 to 225 mg/l with a mean of 147 mg/l. Major cation chemistry of the water samples is dominated by Ca followed by Mg, Na and K. The concentration of calcium ion in the study area ranges from 14 mg/l to 50 mg/l at an average of 34.33 mg/l and magnesium ranges from 1.2 mg/l to 21.6 mg/l with an average value of 10.2 mg/l. Calcium and magnesium ions are particularly derived from leaching of limestone, dolomites, gypsum and anhydrites. However, the calcium ions can also be derived from cation exchange process [18]. The $Ca^{2+} + Mg^{2+}$ vs. $HCO_3^- + SO_4^{2-}$ scatter diagram (Figure 2A) [19] shows that majority of the samples fall on the equiline indicating that both carbonate and silicate weathering play a role for supplying these ions to the surface water. To further examine the effect of lithological weathering, water samples of the study area were plotted between silicate and carbonate end members [20]. The samples fall towards the carbonate end member (Figure 2), which clearly signifies the dominant role of carbonate weathering on water chemistry. The concentration of sodium and potassium ranges from 1.1 mg/l to 7.6 mg/l and 0.6 to 7 mg/l with an average value of 3.6 mg/l and 2.6 mg/l respectively. The concentration of Na and K in surface water may be attributed to silicate weathering [11,21] as silicate rocks occur marginally to the study area. The anions in the water samples are in the order $HCO_3 > Cl > SO_4 > NO_3$. The Bicarbonates range from 49 mg/l to 232 mg/l with a mean value of 147.08 mg/l. The increase in the bicarbonate may be attributed to carbonate weathering of the catchment areas (Figure 2B). The concentration of chlorides ranges from 5 mg/l to 18 mg/l with a mean value of 9.9 mg/l. The natural processes such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the surface water, which is supported by Cl/HCO_3 ratio of 0.03 to 0.1 [22]. The concentration of sulfate ranges from 4.9 mg/l to 12 mg/l with a mean value of 8.6 mg/l. Sulphate ion concentrations are derived mainly from weathering of sulfate and gypsum-bearing sedimentary rocks [23-25]. The concentration of nitrate ranges from 1.53 to 11 mg/l with a mean value of 4 mg/l. The sources of nitrate may be credited to the irrigation return flow as lots of fertilizers are used in the agricultural fields in and around the study area. Among the trace elements, Lead concentration in all water samples is less than 0.05 ppb. Nickel concentration ranged from 0.05 ppb to 2.05 ppb with an average of 1.52 ppb. The concentration of Manganese ranged from 0.05 ppb to 22.04 ppb averaging at 7.38 ppb. Chromium in water samples ranged from < 4 ppb to 13.93 ppb at an average of 6.6 ppb. The concentration of Cadmium ranged from 0.15 to 0.31 ppb at an average of 0.16 ppb. Zinc concentration ranged from

S. No	pH	EC µS/cm	TDS	TH	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3
			mg/L		ppb									meq/L							
SW1	8.02	182	95	100	<1	<0.3	5.16	<1	266	<0.5	3.6	<1	1.70	1.4	0.6	0.09	0.03	1.84	0.17	0.10	0.88
SW2	6.92	213	125	110	<1	<0.3	<4	<1	351	<0.5	<1	1.13	15.44	1.5	0.7	0.20	0.09	2.08	0.37	0.13	1.60
SW3	7.81	268	180	150	<1	<0.3	<4	<1	376	<0.5	21	1.11	0.63	2.2	0.8	0.20	0.03	2.61	0.37	0.23	2.22
SW4	8.24	335	210	180	2	<0.3	<4	<1	386	<0.5	22	1.65	1.12	1.8	1.8	0.27	0.06	3.48	0.31	0.25	1.38
SW5	7.4	248	115	130	<1	0.31	5.30	<1	342	<0.5	2.8	1.57	1.38	2	0.6	0.11	0.12	2.56	0.17	0.19	1.00
SW6	7.3	354	210	175	1.7	<0.3	4.75	<1	348	<0.5	1.9	1.46	2.74	2.1	1.4	0.33	0.18	3.33	0.46	0.19	5.50
SW7	7.75	364	225	190	1.5	<0.3	7.39	<1	515	<0.5	1.2	2.05	1.60	2.5	1.3	0.16	0.05	3.80	0.31	0.25	2.50
SW8	7.82	360	220	180	<1	<0.3	4.12	<1	455	<0.5	13	2.02	1.14	2.5	1.1	0.26	0.12	3.56	0.51	0.23	3.00
SW9	7.66	247	160	135	1.56	<0.3	<4	<1	328	<0.5	<1	1.20	1.13	2	0.7	0.14	0.05	2.44	0.26	0.19	2.34
SW10	7.76	126	80	70	<1	<0.3	9.08	<1	136	<0.5	1.1	<1	1.53	0.9	0.5	0.05	0.02	1.16	0.14	0.17	1.15
SW11	7.48	136	90	80	<1	<0.3	3.54	<1	156	<0.5	3.8	<1	<0.5	1	0.6	0.07	0.02	1.28	0.17	0.10	1.70
SW12	7.4	80	55	40	<1	<0.3	13.93	<1	125	<0.5	2.2	<1	1.37	0.7	0.1	0.05	0.03	0.80	0.14	0.15	0.77

Table 1: Analytical data and calculated values of water samples of study area.

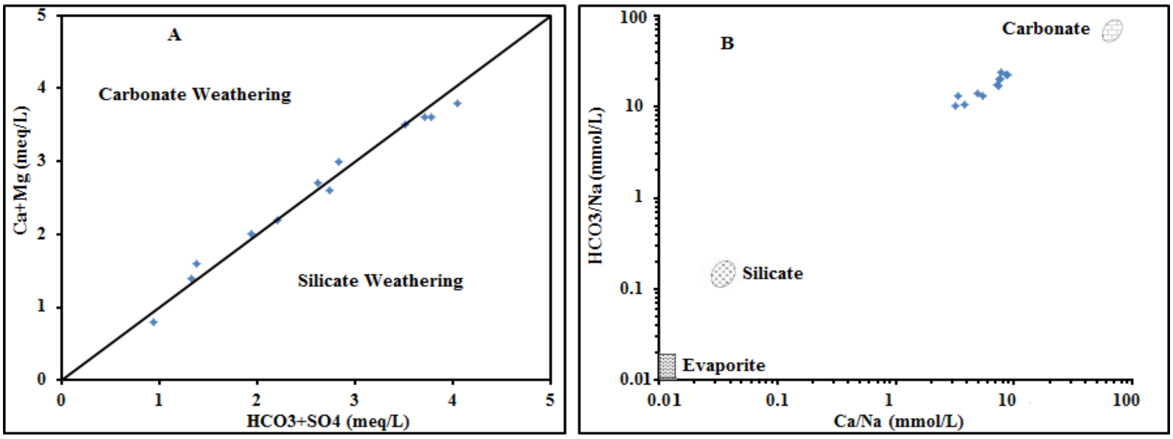

Figure 2: Scatter plots: (A) Ca + Mg vs. HCO3 + SO4 (Dutta and Tyagi, 1996) and (B) HCO3/Na vs. Ca/Na Plot [20].

0.25 ppb to 15.44 ppb averaging at 2.5 ppb. The copper concentration in all samples is less than 0.05 ppb (Figures 3 and 4).

Mechanisms controlling water chemistry

The major ion chemistry is a powerful tool for determining solute sources and for describing water evolution as a result of water-rock interaction leading to the dissolution of carbonate minerals, silicate weathering and ion exchange processes. In order to understand the source of the solutes in a broader perspective, the hydrochemical data was plotted in the Gibb's diagram [26]. All the samples fall in the rock dominance area of the diagram which suggested that chemical weathering of the rock forming minerals is the main process contributing ions to surface and groundwater. According to Piper Trilinear diagram [27], the order of hydrochemical water types identified as Ca-Mg-HCO_3. The evolution of surface water is observed to be simple with all streams changed into Ca-Mg-HCO_3 water type due to easy dissolution of carbonate minerals and less time for water-rock interaction. The water samples were plotted in Langelier-Ludwig diagram [28]. Surface water samples are characterized by one main trend i.e., carbonate dissolution. The plot shows that the stream water samples are dominated by the carbonate dissolution with Ca-Mg-HCO_3 as the principal water type (Figure 5).

Water quality for drinking and agricultural purposes

The water quality evaluation in the water samples of the study area is carried out to determine the portability in terms of drinking, domestic and agricultural purposes. The major and trace elements in water samples are well below standards prescribed by World Health Organisation [29] and Bureau of Indian Standards for drinking purposes (Table 2). Based on total dissolved solids, the water of both the streams and springs are 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). The samples of the study area fall in the desirable to permissible category for drinking purposes and all the samples are fit for agricultural uses according to the mentioned criteria (Table 3). As per the classification of TDS [30], all the water samples come under fresh water type (TDS < 1000 mg/L). Hardness of the water causes more consumption of detergents at the time of cleaning and some evidence indicates its role in heart disease. The classification of the water samples of the study area based on hardness [31] is presented in Table 4. Accordingly the water samples of the study area are soft to hard with 16.66% of samples falling in soft category, 50% in moderately hard and 33.33% falling in very hard category. The most influential water quality parameter on crop productivity is the water salinity hazard as measured by Electrical Conductivity (EC). The primary effect of high EC on crop productivity is the inability of plants to compete for water with ions in soil solution. Higher the EC, less water is available to plants. Water with EC less than 250 µS/cm is considered well and EC more than 750 µS/cm is unsuitable for irrigation. The EC of water samples of the study area ranges between 80 to 364 µS /cm, are good for irrigation. Similarly, water with TDS less than 3000 mg/l is considered good and concentration more than 3000 mg/l is unsuitable for agriculture. The TDS of the water samples ranged from 55 to 225 mg/l and are considered good for irrigation. Magnesium content, another important qualitative parameter in determining the quality of water for irrigation, will adversely affect crop yield as the soils become more alkaline if present in excess amounts.

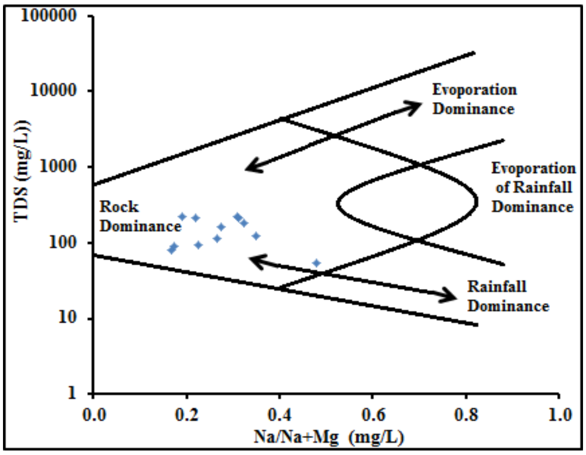

Figure 3: Gibbs diagram [26].

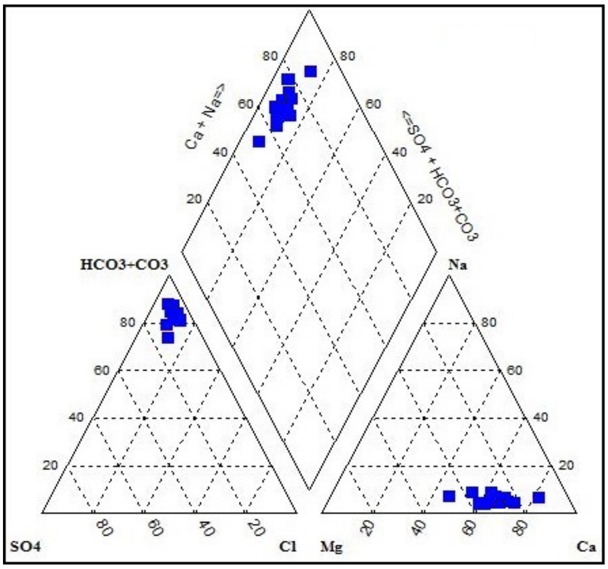

Figure 4: Piper trilinear diagram [27].

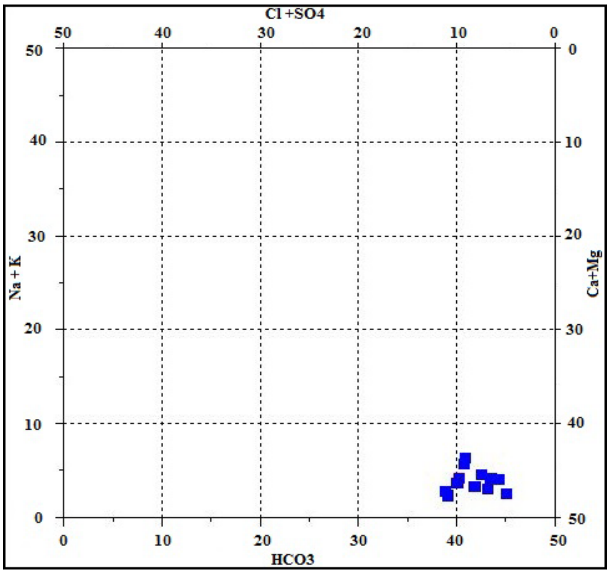

Figure 5: Langelier-Ludwig diagram [28].

Chemical Constituents	WHO (2006)	BIS (2012)	Samples (%) exceed safety limits
pH	7-8.5	6.5-8.5	Within the range
TDS (mg/L)	500	500	Within the range
TH (mg/L)	100	200	Within the range
Ca (mg/L)	75	75	Within the range
Mg (mg/L)	30	30	Within the range
Na (mg/L)	200	-	Within the range
K (mg/L)	12	-	Within the range
HCO_3 (mg/L)	-	200	Within the range
SO_4 (mg/L)	200	200	Within the range
Cl (mg/L)	200	250	Within the range
NO_3 (mg/L)	45	45	Within the range
F^- (mg/L)	1.5	1.5	Within the range
As (ppb)	50	10	Within the range
Cd (ppb)	5	3	Within the range
Cr (ppb)	50	50	Within the range
Cu (ppb)	50	50	Within the range
Fe (ppb)	300	300	66.6%
Pb (ppb)	50	10	Within the range
Mn (ppb)	100	100	Within the range
Ni (ppb)	-	20	Within the range
Zn (ppb)	5000	5000	Within the range

Table 2: Compliance of quality of water samples (%) to drinking standards.

TDS mg/l	Remarks on Quality	No. of Samples	%age of Samples
Up to 500	Desirable for Drinking	12	100
500-1000	Permissible for Drinking	----	----
Up to 3000	Useful for Agricultural	----	----
>3000	Unfit for Drinking and Irrigation	----	----

Table 3: Water quality for drinking and agricultural purposes (after Davis and De Wiest).

TH as $CaCO_3$ (mg/l)	Water Classes	No. of samples	%age of Samples
<75	Soft	2	16.66
75 - 150	Moderately Hard	6	50
150-300	Hard	4	33.33
>300	Very hard	----	----

Table 4: Hardness classes of water (after Sawyer and McCarthy).

Magnesium content of the water samples ranged from 12.5 to 50 meq/L and is thus suitable for irrigation. Sodium percent is another important parameter to study the sodium hazard. Higher concentration of sodium in irrigation water leads to its adsorption by clay particles, displacing magnesium and calcium ions. This exchange process of sodium reduces the permeability of the soil and eventually results in poor internal drainage of the soil [32]. Based on percent sodium, irrigation water has been classified into two categories with percent sodium greater than sixty percent as unsafe and the water with percent sodium less than sixty as safe [33]. The water samples are well below sodium percent less than sixty, are safe for irrigation purposes. Wilcox diagram with percentage Na plotted against specific conductance [33] is used in evaluating irrigation waters. An appraisal of the Wilcox diagram (Figure 6) shows that most of the samples from the study area fall under excellent to good fields of the diagram indicating that water samples from the study area are suitable for the irrigation purpose for majority of crops and most of the soils. A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity (Figure 7) data on the US Salinity Laboratory (USSL) diagram [34]. Accordingly, 7 samples fall in the category of C1S1 (58.3%), indicating a low salinity/low sodium type and the remaining 5 samples (41.7%), belong to C2S1 category. The permeability of the soil is affected by the long term use of water influenced by Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^-. As per the Doneen's chart [35-37], water can are 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. An appraisal of the Figure 8 shows that the samples fall in class I and class II field of the Doneen's Chart except

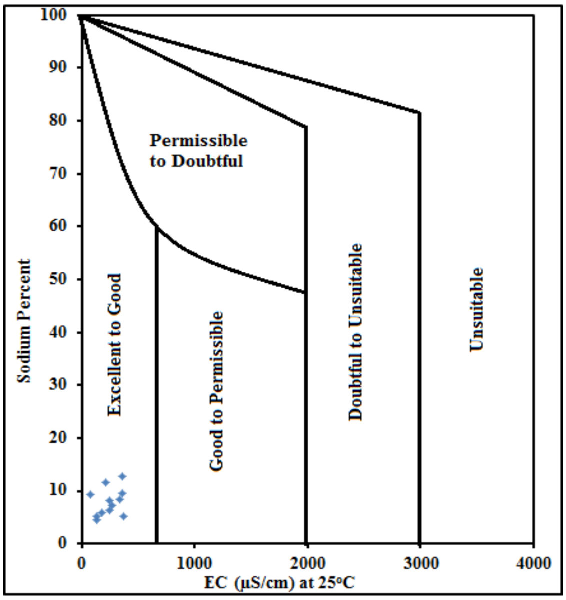

Figure 6: Wilcox diagram [33].

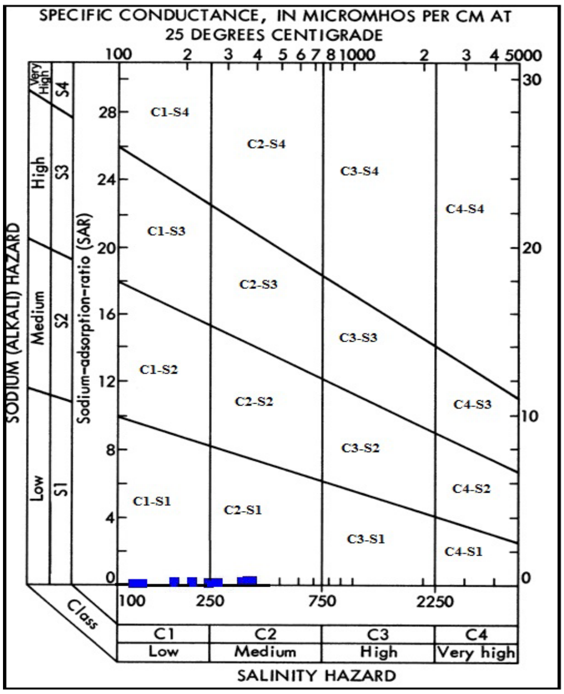

Figure 7: USSL salinity hazard diagram [34].

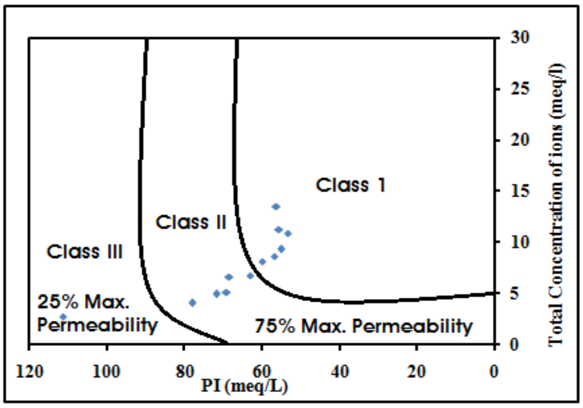

Figure 8: Doneen's chart of permeability index [35].

one sample falling in class III field. The maximum permeability is more than 75% which indicates that the water is excellent for the irrigation purpose.

Conclusion

The surface water of the study area is neutral to slightly alkaline. The order of cations is Ca > Mg > Na > K and anions is HCO_3 > Cl > SO_4 > NO_3. Carbonate weathering is the dominant weathering process in the study area; however, silicate weathering processes are also responsible for the supply of some ionic species to the surface water. As per the Gibb's diagram, Piper trilinear plot and Langelier-Ludwig diagram, the major ion chemistry of surface water is controlled by rock-water interaction and are characterized by Ca-Mg-HCO_3 trend i.e., carbonate weathering in the drainage system. The major ions in the water samples are well below standards prescribed by WHO and BIS for drinking purposes. The suitability of water for irrigation was evaluated based on the quality parameters and plots of water like EC and TDS classification, hardness classification, Magnesium Content, Sodium Percent, Wilcox diagram, USA Salinity hazard plot and Doneen's plot. According to the values of these parameters the surface water of the study area was found fresh, suitable for drinking purposes and can be used for irrigating most of the crops and majority of the soils.

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