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Hydrogeochemical Evolution and Quality Assessments of Streams Water in the Bhagirathi Basin, Garhwal Himalaya, Uttarakhand

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Abstract: Hydrogeochemical studies were carried out to assess the quality and evolutions of the streams in the Bhagirathi basin during high and low flow of water in the given environment. The hydrochemical characteristics of the streams water indicated that silicate and mixed type of weathering dominated in the Bhagirathi watersheds. The stream's water chemistry is mostly influenced by deeper sources of water through joints and fissures in the stream watersheds. A comparison between ion concentrations in the samples suggested that few samples have high sodium and fluoride exceeding the permissible limits. Based on dissolved ions in stream water, the water quality index falls into the excellent/good category (80%), poor quality (14%) and unsuitable class (6%), respectively. Kelly and Permeability index results suggest the impact of rock type on water quality that may affect local agricultural productivity.

Key words: Hydrochemical, Bhagirathi river basin, water quality index, Kelly ratio, base ion exchange index.

Introduction

Stream water is one of the major water sources that fulfil the necessity of daily basic needs in the mountain region due to the absence of large groundwater storage. The quality and quantity of water from mountain streams is vulnerable as a result of local controlling factors like geology and hydro-meteorological conditions. Therefore, large population depends on these streams in the mountain regions, which is influenced by environmental variations. The impact of the local geological environment also makes the soil and water of some area vulnerable to quality in the localized area. In some cases, heavy metal as micronutrients is deficient in streams and groundwater along the Himalayan watersheds. The concentrations of dissolved Al and Fe were found to be in excess in dissolved form at Gomukh, Gangotri while Al and Pb were found to be in excess in the Bhagirathi river due to high silicate sediment loading of certain elements in small watersheds (NEERI, 2014; Semwal and Akolkar, 2006).

The amount and quality of surface water nourished through high altitude glaciers have changed with the disturbance caused by various natural and man-made activities and in particular, the effects of climate change may have severe implications for local and regional sustenance (Barnett et al., 2005; Yao et al., 2012; Zhang et al., 2012). The Bhagirathi river basin earlier had less interference of human activities (Liao, 2014; Walling and Moorehead, 1989; Zhang et al., 2006). Apart from that, it is also considered as a holy river, so the various ritual activities performed on the bank

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of rivers, streams, and their tributaries which in turn brings massive immigration of people round the year that creates enormous pressure on natural resources in the basin. To meet the necessities of the local people, terraced agriculture practices on steeper hill-slopes at a large scale, use of organic and inorganic fertilizers could also contaminate the water quality in the basin. So increase in anthropogenic activities on upper altitude could influence somehow the stream chemistry at a lower altitude. In the present study, an effort was constituted to assess the geochemical characteristic of streams water and water quality index in the various watersheds in Bhagirathi basin.

Study Area

The Bhagirathi River is one of the important tributaries of the Ganga fluvial system. It originates from the Gangotri glacier at Gomukh in Uttarakashi district of Uttarakhand. Geographically the total catchment is bounded by 30°10′ to 30°30′ N latitudes and 78°10′ to 79°15′ E longitudes. Climatologically, the Bhagirathi river and its tributaries are dependent predominantly on glacier, snowmelt, and precipitation. The Bhagirathi river basin experiences strong climatic seasonal variations in stream flows. Most of the Garhwal Himalayan streams carry 69–83% of their annual flow during the summer monsoonal months (Bruijnzeel et al., 1989). Geologically, the Bhagirathi river and its tributaries drain largely through the rocks of the lower and central crystalline consisting of schists, micaceous quartzite, calc-silicates, amphibolites, gneisses, granites, slates and phyllites (Figure 1).

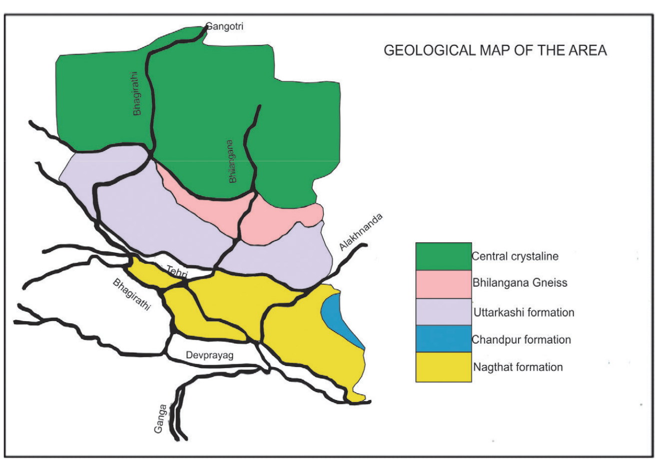

Figure 1: Geological map of the Bhagirathi river basin (Modified after Pandey et al., 1999).

Methodology

Thirty-two streams water samples of high and low flow period were collected from the Bhagirathi basin before meeting with the main Bhagirathi channel, in the year 2016-2017 presented in Figure 2. The stream water sample was collected in a 1-L plastic bottle thoroughly washed with concentrated HNO_3 and later washed with distilled water, and further respective bottle was clean with the water from where the sample was to be collected. The electrical conductivity and pH of the samples were measured using a conductivity meter and pH meter. Bicarbonate was analysed by the potentiometric titration method keeping 4.5 pH as an end point. Sulphate concentration was determined by the turbidimetric method, absorbance was measured at 420 nm by using a UV/VIS spectrophotometer. Chlorine was determined by the titration method. Dissolved silica was determined by the molybdo silicate method at 812 nm using a UV/VIS spectrophotometer. The concentrations of Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} in melt water were determined by one of the American Public Health Association (APHA, 2005) method. The cationic and anionic charge balance (<10%) were checked for each water sample for precision.

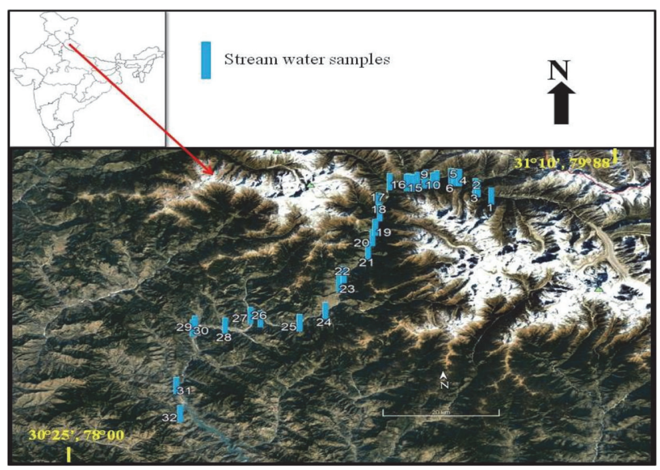

Figure 2: Google image of study area along with sample location.

Results and Discussion

The major ion chemistry of stream water in Bhagirathi basin was statistically analysed and presented in Table 1. Among the major cations, calcium is the most dominant cation followed by sodium, magnesium, and potassium, respectively. Furthermore, bicarbonate is the dominant anions followed by sulphate, chloride and fluoride, respectively.

Table 1: Minimum, maximum and average value of different chemical parameters in stream water samples of the study area

S. No.	*Chemical parameters*	*Minimum*	*Maximum*	*Average*	*STD*
1	Calcium (Ca^{2+})	0.38	3.02	1.34	0.65
2	Magnesium (Mg^{2+})	0.13	1.17	0.55	0.25
3	Sodium (Na^{+})	0.24	3.52	1.20	0.86
4	Potassium (K^{+})	0.18	0.93	0.48	0.23
5	Bicarbonate (HCO_3^-)	0.16	2.21	0.82	0.48
6	Sulphate (SO_4^{2-})	0.07	3.24	0.55	0.55
7	Chloride (Cl^-)	0.39	0.70	0.54	0.08
8	Fluoride (F^-)	0.00	0.08	0.02	0.02
9	pH	5.40	7.50	6.90	0.41
10	EC (umhoscm^{-1})	49.40	225.00	121.29	45.12
11	TDS	29.00	133.00	71.97	27.33
12	Hardness	16.40	77.30	39.15	14.80
13	Sodium Absorption Ratio (SAR)	0.30	3.79	1.22	0.78
14	Sodium percentage (SP) %	29.11	71.49	45.89	10.09
15	Potential salinity (PS) (meql^{-1})	0.51	2.16	0.81	0.29
16	Permeability index (PI) %	48.40	89.21	68.02	10.08
17	Kelly's ratio	0.39	3.26	1.47	0.60
18	Indices of base exchange (IBE) CaI1	-6.74	2.67	-0.44	1.69
19	Indices of base exchange (IBE) CaI2	-6.55	3.10	0.04	1.81
20	Gibbs ratio I	0.36	0.77	0.55	0.10
21	Gibbs ratio II	0.21	0.75	0.44	0.13
22	Mg hazard (MH)	9.44	91.81	45.38	18.72
23	Total WQI	16.93	127.83	52.42	28.38

The suitability of the stream water was evaluated for drinking and irrigation purposes (ISI, 2000). Comparative hydrochemical data is showing a high degree of sodium and potassium in most of the streams samples, and some of undesirable high fluoride was also found in some samples as presented in (Table 2). Based on the study by Soltan et al., (1999), the results also indicated that most of the samples are within the range of the prescribed limits except high fluoride in some samples (AS1, AS12 and AS3). The sources of stream water have been analysed using the formula (Na^++K^+)-Cl^-/SO_4^{2-} and it indicates that most of the water in streams was derived from the subsurface sources from joints, fractures and fault zones in the watershed as given in Table 3.

Table 2: Indian Standard (ISI, 2000) guidelines for various parameters

Parameters	*Indian standards*	*Number of sample*
Total hardness	300	None
Bicarbonate	200	None
Chloride	250	None
Fluoride	1	1,2,3
Calcium	75	None
Magnesium	30	None
Sodium	20	None12,3,4,11,12,23,28,29, 30,31,32
Potassium	10	All except (4,5,8,9, 10,27,32)
Nitrate	45	None
Sulphate	200	None
TDS	500	None

Hydrochemical Facies

Major ion chemistry of the streams water was obtained using Piper (1994) plots and it shows the dominance of HCO_3^- as the major anion and Na^+ as the major cation

Table 3: Stream water classification, based on the study by Soltan (1999)

Parameters	*Ranges*	*Type of water*	*No. of samples*
r1(Na^+-Cl^-)/SO_4^{2-}	< 1	Na^+-HCO_3^-	All
	> 1	Na^+-SO_4^{2-}	None
r2(Na^++K^+) - Cl^-/ SO_4^{2-}	< 1	Subsurface water	All
	> 1	Shallow Meteoric water	None

present in streamwater samples. It also suggests that most of the water samples have mixed type water-facies with a little excess of bicarbonate, sodium and calcium (Figure 3).

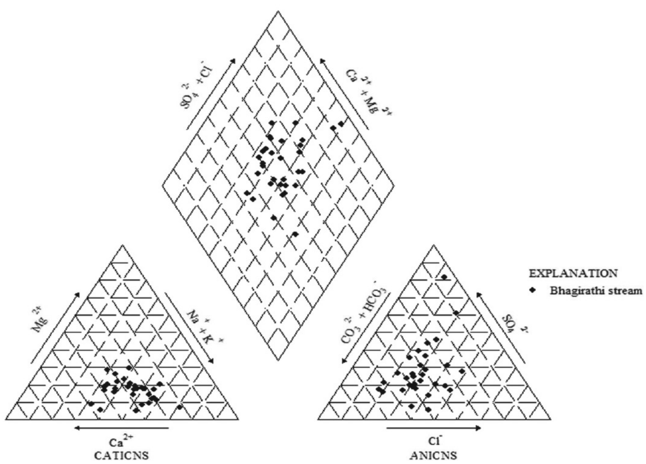

Figure 3: Piper trilinear plot for the stream water samples.

Sources of Solute

The sources of solute from carbonate, silicate and ferromagnesium weathering contribution were determined by Gibbs (1970) diagram and the result suggested that most of the samples were from fall in rock weathering dominated region as shown in Figure 4.

The sources of solute from carbonate, silicate and ferromagnesium weathering contribution were also determined by using the method used by Hounslow (1995). The result indicates that 90% of the samples are showing the domination of silicate weathering and 10% of the samples are showing mixed type of weathering. The streams water with HCO_3^-/SiO_2 ratios >5 to <10 along with $Mg^{2+}/(Ca^{2+}+Mg^{2+})$ ratio > 0.5 indicate that weathering of granite is dominant.

With the help of chloro-alkaline indices the transfer of ions between the groundwater and its interacting environment, either during flow or stagnant can

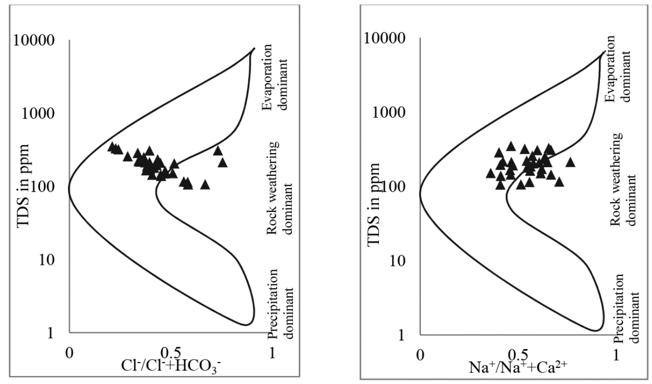

Figure 4: Changes of weight proportion of $Cl^-/(Cl^-+HCO_3^-)$ and $Na^+/(Na^++Ca^{2+})$ as a component of TDS (after Gibbs, 1970).

easily be understood. Schoeller (1977) suggested two chloro-alkaline indices CaI1 and CaI2 to identify the direction of trade towards the aquifer during the path of groundwater. The positive value of indices of base exchange (IBE) signifies the exchange of sodium (Na^+) and potassium (K^+) from the water with magnesium (Mg^{2+}) and (Ca^{2+}) whereas it becomes negative when there is an exchange of magnesium (Mg^{2+}) and calcium(Ca^{2+}) of the water with sodium (Na^+) and potassium (K^+) of the bedrocks/aquifer. The result shown in Table 1 revealed that IBE CaI1 value ranging from -6.74 to 2.67 has a mean value of -0.44 and CaI2 value ranging from -6.55 to maximum 0.04 has a mean of -1.81. The result implies that in the study area there is exchange of Mg^{2+} and Ca^{2+} present in water with Na^+ and K^+ present in the rock/soil.

Water quality standard for drinking

Water quality index gives a broad explanation of the characteristic for the subsurface and surface water and its suitability for drinking purpose. A weighted arithmetic index method is used to calculate water quality index, which exhibit maximal fluctuation in specific periods as well as fluctuation at the various sampling point, by using the following equation.

$$WQI = (C_i/S_i)*100$$

where C_i stands for approximate concentration of the i_{th} parameter and S_i is the standard admissible value of the i^{th} parameter in the examined water samples. The calculated WQI for the streams water samples suitability for drinking purpose is given in Table 4. A detailed distribution of WQI suggests that 80% fall in excellent and good category, 14% fall under the poor quality and 6% fall in the unsuitable category.

Table 4: Standard water quality rating as per WQI

WQI scale	*Water qualitative level*	*Rating (WQR)*	*Letter grade*	*Sample No.*
0–25	Excellent	9	A	(27,23,9,14,8)
26–50	Good	71	B	32,7,26,25,,17,29,22,28,31,30,5,6,,18,13,12,16)
51–75	Poor	14	C	24,11,15,10,4
76–100	Very poor	0	D	21,19,3
>100	Unsuitable	6	E	20,1,2

Water Quality Standard for Irrigation

The stream water is also used for the purpose of irrigation in the mountain land area. In this perspective, five criteria were determined viz. SAR, magnesium hazards, sodium percent (Na%), Kelly's ratio (KR), and permeability index (PI) to check their suitability for irrigation needs in the surrounding area.

(a) Sodium Adsorption Ratio (SAR)

Based on the study by Richards (1954), SAR is used to classify the excess of common cations, Na^+ along with Ca^{2+} and Mg^{2+}. In general, a high amount of sodium in water renders it incompatible for irrigation. The SAR value is calculated using the formula

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na^+}{\left\{\frac{Ca^{2+} + Mg^{2+}}{2}\right\}^{1/2}}$$

(All the values in $meql^{-1}$)

The SAR for all samples was determined from the above formula, and the results obtained were within the range of 0.30-3.79 with a mean value of 0.78. A scatter diagram between SAR and electrical conductivity (Figure 5) suggests that all samples belong to an excellent water quality, i.e., low salinity/low sodium hazard (C1S1).

(b) Magnesium Hazards

Szabolcs and Darab (1964) gave the parameter called magnesium hazard to check the quality of water for irrigation purposes using formula

$$\text{Magnesium Hazards } MH = \frac{Mg^{+2}}{(Ca^{+2} + Mg^{2+})} *100$$

*100 (All the values in $meql^{-1}$)

If the value of magnesium hazards is greater than 50, it will be destructive for plant health. Magnesium hazards of the samples varies from 9.44 to 91.81 with an average value of 45.38 as presented in Table 1. In the study area, 63% of the samples are considered as safe for irrigation uses as shown in Table 5. However, some of the high MH values in the study area indicate that sodium and potassium derived from silicate rocks have granite and gneiss, with a little quantity from carbonate minerals.

Table 5: Mg hazard categories of streams water samples

Mg hazard category	*Suitability*	*Number of the sample %*
0-50	Safe	20 (63%) 1,2,9.10,11,13,14,15,16,17,19,20,21,23,26,28,29,30,31,32
50-70	Moderate	9 (28%) 3,4,5,6,7,8,12,18,22
>70	Unsuitable	3 (3%) 24,25,27

(c) Sodium percentage

Sodium percentage is also used to examine water quality pertaining to irrigation use. The surplus of Na^+ in water reacts with soil, which not only ruins soil permeability, but also influences plant growth (Wilcox, 1955). The

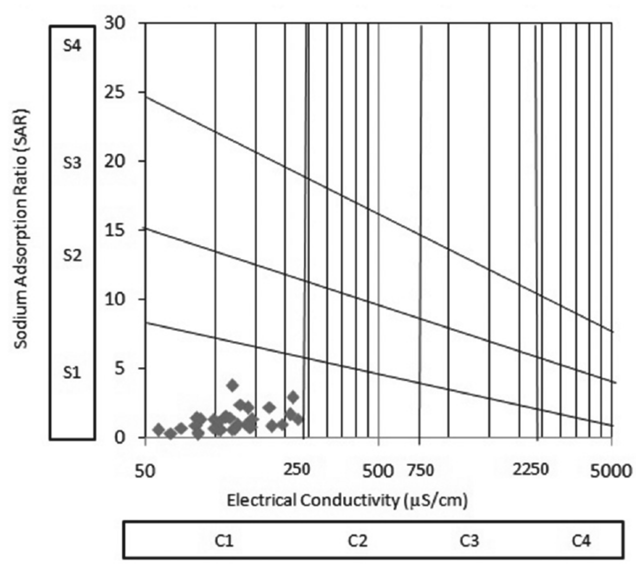

Figure 5: Salinity classification of stream water samples of the study area by (Richards 1954).

following equation is used to analyse the Na^+ % in water samples.

$$Na\% = \frac{Na^+ + K^+}{(Ca^{2+} + Mg^{2+} + K^+ + Na^+)} * 100$$

(All the values in $meql^{-1}$)

The sodium percentage of stream water ranges from 29% to 71% with an average of 45.89%. The calculated results show that 46% fall in the excellent and 50% samples fall in the moderate category (Table 6) and (Figure 6).

Table 6: Na^{+2} hazard categories of streams water samples

Na^+ hazard category	*Suitability*	*Number of the sample %*
0-40	Safe	15 (46%) 5,7,14,16,17,19,21, 22,23,24,25,26,27,28,29
40-60	Moderate	16 (50%) 1,2,3,4,6,6,8,9,10,1 1,12,13,15,18,20,30,31
>60	Unsuitable	1 (4%) 2

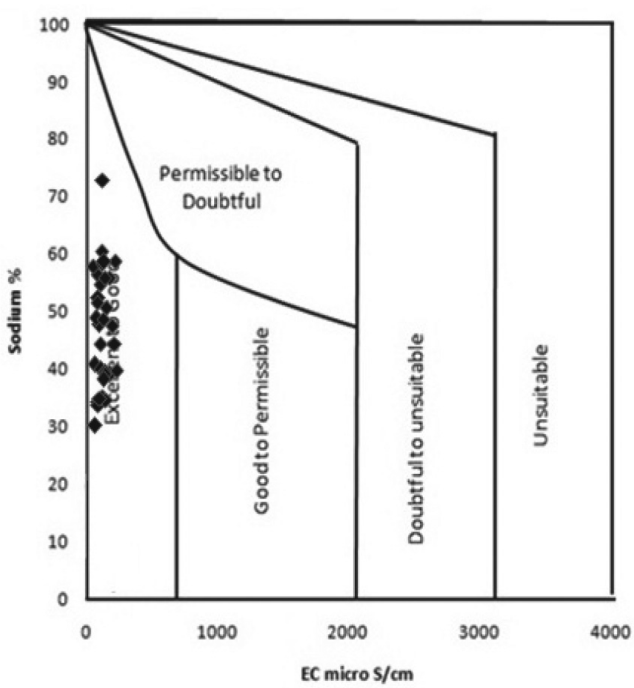

Figure 6: Wilcox classification of stream water of the study area.

(d) Kelly's Ratio

The suitability of water quality for irrigation purposes also determined by Kelly (1940) as for sodium and magnesium by using the formula

$$KI = \frac{Na^+}{(Ca^{2+} + Mg^{2+})}$$

(All the values in $meql^{-1}$)

Kelly's ratio more than one shows an excess of sodium in water that makes it unfit for irrigational uses, as water with Kelly's ratio of less than one is fit for irrigational purposes. As shown in Table 7, Kelly's ratio varies from 0.39 to 3.26 with an average value of 1.47. In the study area, 3% of the samples are considered as unsuitable for irrigation purpose.

Table 7: Kelly hazard categories of streams water samples

Kelly hazard category	*Suitability*	*Number of the sample %*
0-1	Safe	9 (28%) 5,7,14,16,17,19,21,22,23
1-3	Doubtful	22 (69%) 1,3,4,6,6,8,9,1 0,11,12,13,15,18,19, 22, 24,25,26,28,29,30,31, 32
>3	Unsuitable	1 (3%) 2

(e) Permeability Index (PI)

The permeability of the soil is damaged by continuous use of unfavourable irrigation water, which in turns is altered by the soil content of ions like sodium, calcium, magnesium and bicarbonate. The PI values tell about the suitability and unsuitability of stream water for irrigation. It is calculated by the following formula as given by Doneen (1964).

$$\text{Permeability Index } (PI) = \frac{Na\sqrt{HCO_3}}{\mathrm{Ca + Mg + Na}} * 100$$

(All the values in $meql^{-1}$)

The value of Permeability Index less than 60% is considered good for irrigation and more than 60% is not good for irrigation. The permeability index is classified under class I (>75%), class II (25-75%) and class III. Water from Class I and II is grouped as good for irrigation with a maximum permeability of 75% or more, whereas water from Class III is considered bad with maximum permeability 25%. In the study area, PI value varies from 48 to 89 % with an average value of 68% and standard deviation of 9.6%. It is found that high PI of the stream water is due to the presence of sodium and potassium-rich bedrock i.e. schists, amphibolite, granite, biotite gneiss, slates and

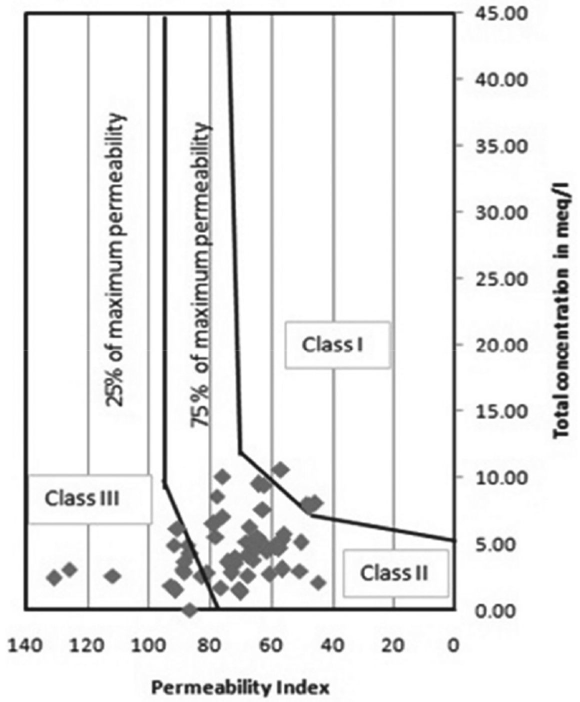

Figure 7: Permeability index against the total concentration of ions.

phyllites in some of the watersheds. However, only 23% of stream water sample is suitable for irrigation as presented in Figure 7.

Conclusions

The complex tectonic structure in watershed facilitates the subsurface water contribution in the streams. Hence, bedrock geology affects the hydrochemistry at a local scale. The WQI of the water samples suggested that 80%, 14% and 6% of samples fall under excellent, good, poor and unsuitable categories, respectively. Poorness and unsuitability of the water samples is due to high concentration of Na^+, K^+, HCO_3^- and F in few streams. The ionic ratios of anions and cations suggested that silicate and mixed weathering are dominating. Permeability Index of the stream water indicates that due to the calcium and magnesium-rich bedrock i.e. schists, granite and biotite gneiss in the watersheds, only 23% of stream water sample is suitable for irrigation purposes.

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