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Water Quality Assessment Using Multivariate Statistical Techniques: A Case Study of Devika Stream of Udhampur District in Lower Shivalik Region

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Abstract: Our knowledge of the water quality of small mountainous water streams (rivulets) is based on very limited data; therefore, the current study has been carried out to assess the impact of human activities on the water quality of ‘Devika’ stream, a rivulet flowing through Udhampur district of Jammu and Kashmir by following physico-chemical parameters, such as temperature, pH, EC, hardness, major anions and major cations. The Piper diagram showed that 30% of water samples belonged to the Ca^{2+} type, whereas 70% of the remaining samples were in no dominant cation facies. Similarly, for anions, 50% of samples were categorised into Cl^- type, 30% in no dominant type, 20% HCO_3^- type, therefore, facies classification indicated that maximum samples were $CaCl_2$ type. The indices Na%, sodium adsorption ratio (SAR), permeability index (PI), magnesium hazard (MH) and residual sodium carbonate (RSC) were applied to check the appropriateness of water for the irrigation purpose and their average value was found to be 24.19, 0.75, 47, 48.06, and 1.12 meq/L, respectively. These values revealed that despite various human activities, all the water samples were found suitable for irrigation purposes.

Key words: Hydro-geochemistry, irrigational suitability, streams, water quality.

Introduction

Rivers are very important in integrating and structuring the landscape and designing the ecosystem of the basin. They are the main players in regulating the global hydrological cycle, they are known to be the most dynamic agents of nutrient and sediment transport (Palmer and Ruhi, 2019). Considering the present way and rate of consumption of water, there is no denial of the fact that the quality and quantity of water would continue to compromise with the population explosion, including the associated social, political, and environmental implications (Cosgrove and Loucks, 2015). In the recent past, various anthropogenic activities have put tremendous pressure on rivers worldwide, despite their wide-ranging role. Regular monitoring and identification of point and non-point sources of river pollution furnish useful data on the

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eco-hydrologic state of a river basin. Such kind of information provides a thorough understanding of spatial and temporal variation in quantity and quality of water and is considered a significant measure of the health of water resources (Gautam et al., 2018; Nemčić-Jurec et al., 2019).

The quality of the river water is of great importance and are commonly used for various purposes, for instance, domestic and household water supplies, hydroelectric power plants and for several other human or economic use. The quality of irrigation water is of great concern to preserve the fertility of the soil and improve the agricultural yield (Gautam et al., 2018; Rawat et al., 2018). Along with major Indian rivers, the role of Indian rivulets could not be overlooked as it sustains a healthy ecosystem, e.g. these rivulets are responsible for maintaining a proper drainage system (inflow-outflow balance). Unfortunately, studies related to the water quality of these small streams (rivulets) for domestic and agricultural suitability are surprisingly low.

There are various mountainous small water streams (rivulets) that flows through the Udhampur city, Jammu region and are considered as life-supporting system for the city dwellers by sustaining their important activities such as drinking water supply, agriculture, and religion. Devika, a third-order stream of the Ravi River, runs through the entire town of Udhampur and is believed to be originated from 'SudhMahadev' near Chennai. The stream has immense religious significance in this region and is also known as Gupt Ganga for the reason of flowing underground at several places and again appearing on the surface at Purumandal of Sambha district in the Jammu region, eventually it meets with the Ravi River and flows into Pakistan**.** In Udhampur, the Devika stream is fed by several natural springs (Bowlis), due to unplanned developmental activities and the discharge of untreated sewage and solid waste directly into the stream, which has transformed it into 'nallahs' or 'sewers'. Thus, it is pertinent to assess the water quality of the Devika stream for domestic and irrigation purposes (Dutta, 2014). Therefore, the current study was carried out to assess the impact of urbanisation on the water quality of the 'Devika' stream, by using various physico-chemical parameters, geochemical plots and irrigation suitability Indices,

Study Area

The present study was carried out in Udhampur district which is located in the Jammu division of Jammu & Kashmir state between 32° 34' and 39° 30' North latitude and 74°16' and 75° 38' East longitude and has a total area of 2380 km^2 (Figure 1). The majestic and mighty Himalayan range in the surrounding Udhampur district is responsible for its very small portion of cultivable land (only 17% of the total reporting area). The district is blessed to drain not only by perennial rivers but also by having few transient streams. These streams render them a part of the Indus major basin and Chenab sub-basin. These streams follow the path from northern mountainous regions to the southwestern direction (Kumar et al., 2018). Physiography of the study area mirrors that it is covered by three major divisions spreading throughout the district. Udhampur district falls in northeastern part of the Siwalik formation. The elevation of the study area ranges between 600 and 2900 m above mean sea level. The temperature varies between 1°C (minimum) and 42°C (maximum) and the average rainfall usually recorded is 155.1 cm (Bhatia et al., 2014).

Geology

The north-eastern section of Udhampur district is considerably the Siwalik formations which belong to the 60 to 70 million years old tertiary rock deposits of the outer Himalayas. These tertiary systems of rocks are predominantly of sandstone and conglomerate rock formations, which are the solidified debris to the north of the tremendous mountain range. The North southern Murree formation unit, generally consists of clay, siltstone, sandstone, and conglomerates. Its deposition took place as sand-rich fluvial system (Kumar et al., 2018).

Material and Methods

One time water sampling was done in February 2015 from 10 different sampling sites i.e. Housing colony near Command hospital, Shiv mandir complex, Bowli, and Tap water of Shiv mandir complex, Doodh Ganga at confluence point, after confluence, before confluence with Devika stream, Moda mod, Brihhannallah, and Dhoodarnallah. All water samples were collected in plastic bottles of 250 ml capacity, pre-washed with distilled water before use. pH, temperature, EC and TDS were measured at the site, and for the remaining parameters, water samples were carried in the laboratory and samples were stored at 4 °C to prevent any further microbial activities in water samples. To study physico-chemical parameters of water, sampling was done in the month of February. After measuring the initial parameters, the water samples were analysed for major cations and anions as per APHA (1998). All the parameters were measured in mg L^{-1} except pH and EC. Phosphate was measured using the ascorbic acid method. The hardness of water was determined by the EDTA method. Sodium and Potassium were determined by the flame photometric method. In addition to this, sodium adsorption ratio (SAR), percentage sodium (%Na), Residual sodium carbonate (RSC), Magnesium hazards (MH) and Permeability Index (PI) were also calculated to check the suitability of water for the irrigation purpose.

Results and Discussion

General Observation

The results of in situ measurements (temperature and pH) are shown in Table 1. The Devika stream was found to be neutral with a narrow range of pH from 6 to 7.85; whereas, the average values of electrical conductivity (EC) and total dissolved solids (TDS) were found to be 527 µS/cm^{-1} and 450 mg/L, respectively. EC of a water reservoir depends upon the concentration of ions, its trophic (nutrient) status and dissolved impurities (Verma et al., 2012). In the present study, a higher value of EC and TDS was found in water samples taken from the mandir premises and Moda mod. Being located in the center of the city, maximum human activities (worshiping, bathing and washing and domestic sewage) are performed at these sampling sites. The decreasing order of average concentration of major anion was found as HCO_3^- (164 mg/L) > Cl^- (127 mg/L) > SO_4^{2-} (34 mg/L) > NO_3^- (3.19 mg/L) > PO_4^{3-} (2.39 mg/L) (Table 1). Whereas, the decreasing order of average concentration of major cation was observed as Ca^{2+} (50 mg/L) > Mg^{2+} (30 mg/L > Na^+ (27 mg/L) > K^+ (16 mg/L), and total hardness was reported as 246.24 mg/L (Table 1).

Evaluation of Water Suitability for Irrigation

To check crop productivity EC is considered one of the most important parameters. In the present study, the general criteria of water salinity hazard were measured by employing EC (Ahmad et al., 2015) and

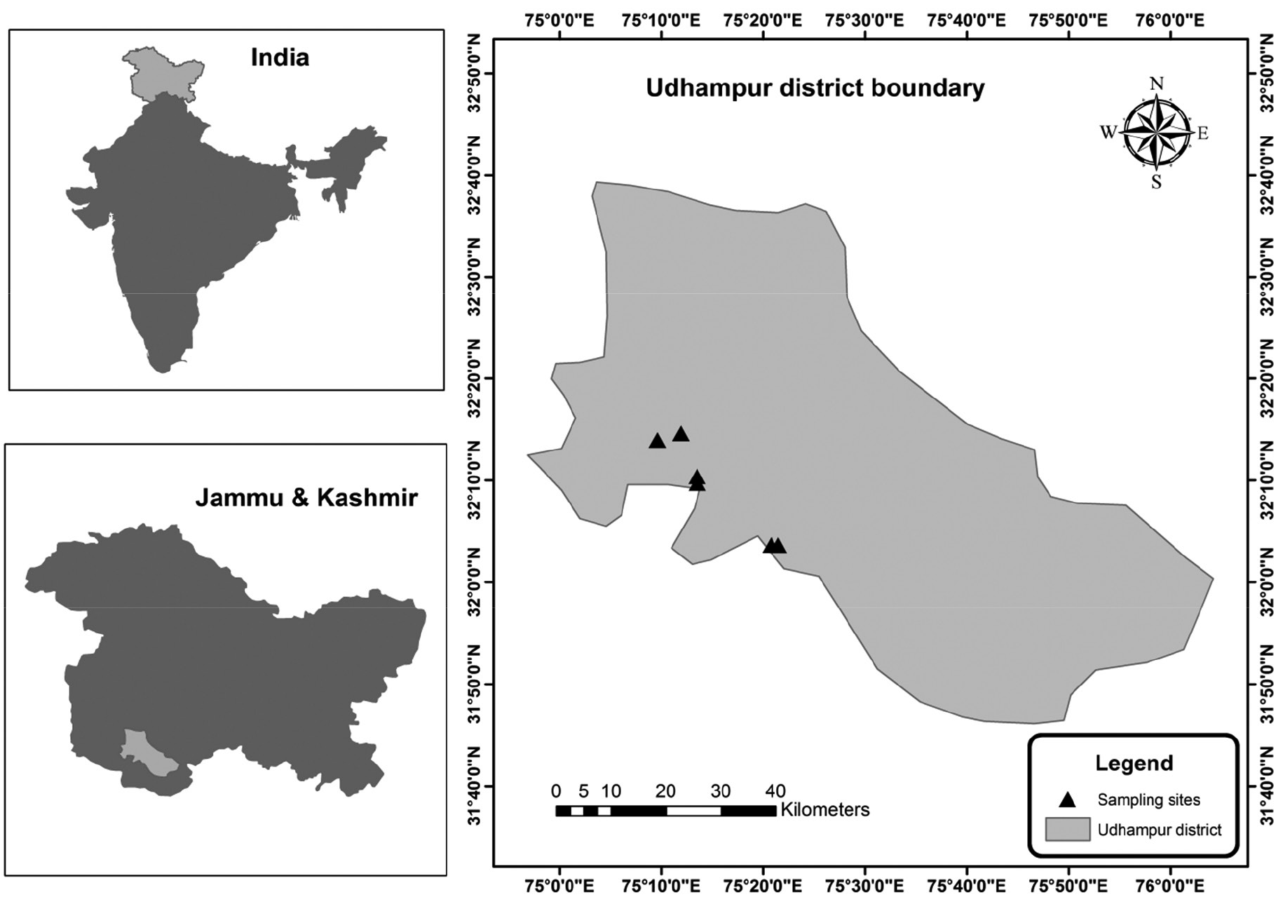

Figure 1: Udhampur district boundary map with sampling locations.

Table 1: Physico-chemical and irrigation suitability parameter

S.N.	*Location*	*pH*	*EC*	*TDS*	*Cl^-*	*HCO_3^-*	*SO_4^{2-}*	*NO_3^-*	*Ca^{++}*	*Mg^{++}*	*Na^+*	*K^+*	*% charge diff*	*Hardness*	*%Na*	*SAR*	*PI*	*MH*	*RSC*
1	Housing colony	6.95	603	439	102	168	40	0.26	46	36	33	14	3.92	261.71	25.32	0.87	46.27	56.60	0.12
2	Mandir premises	7	701	503	159	176	33	0.28	55	24	35	19	-8.86	236.64	30.01	1.00	51.62	41.75	0.51
3	Bowli	6	417	391	132	115	31	6.76	59	18	18	11	-7.38	221.98	19.29	0.52	41.28	33.39	-0.34
4	Mandir tap water	6.5	422	387	129	125	23	6.11	43	16	31	14	-9.71	172.51	33.17	1.04	58.17	38.19	0.32
5	Doodh Ganga confluence point	7.2	593	543	182	176	34	0.31	49	48	35	18	-1.98	319.78	23.84	0.86	40.78	61.76	-0.33
6	After confluence	6.8	580	473	142	173	32	1.81	65	19	21	19	-9.57	240.59	22.64	0.59	45.37	32.52	0.41
7	Before confluence	7.27	508	482	129	193	32	1.45	39	36	34	19	-4.36	244.96	28.56	0.93	50.92	60.47	0.69
8	Moda mod	7.25	630	547	149	152	78	11.15	53	54	25	25	1.82	354.19	19.64	0.58	32.68	62.73	-1.07
9	Brihannalla	7.6	450	414	80	207	23	1.83	52	22	16	13	-5.95	221.17	18.84	0.47	49.62	40.95	1.17
10	Dhoodarnalla	7.85	362	324	66	152	21	1.97	36	24	21	2	-0.64	188.89	20.57	0.67	53.29	52.29	0.59
	Average	7.04	527	450	127	164	34	3.19	50	30	27	16	-4.27	246.24	24.19	0.75	47.00	48.06	0.21
	Min.	6	362	324	66	115	21	0.26	36	16	16	2	-9.71	172.51	18.84	0.47	32.68	32.52	-1.07
	Max.	7.85	701	547	182	207	78	11.15	65	54	35	25	3.92	354.19	33.17	1.04	58.17	62.73	1.17

other important indices e.g. SAR, %Na, RSC, MH and Permeability Index PI, (Tables 1 & 2) were also estimated to determine the usefulness of Devika stream for agricultural purposes.

Electrical Conductivity (EC)

The high value of EC of water, is responsible for the lesser availability of water to plants, even though the soil may appear wet on the surface. Based on total concentration of soluble salts, the irrigation water can be classified as excellent (EC = < 250 µS/cm), good (250–750 µS/cm), permissible (750–2,000 µS/cm), doubtful (2,000–3,000 µS/cm) and unsuitable (> 3,000 µS/cm) (Richards, 1954). In addition to this, we plotted SAR and electrical conductivity (EC) diagram using the U.S. Salinity Laboratory (USSL) diagram (Figure 2). The plots exhibited that all the water samples were found to be suitable for irrigation.

Sodium Adsorption Ratio (SAR)

The percentage or capacity of exchangeable sodium in water samples is expressed by the sodium adsorption ratio (SAR) which can be calculated by using the following equation:

$$\text{SAR} = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \qquad (1)$$

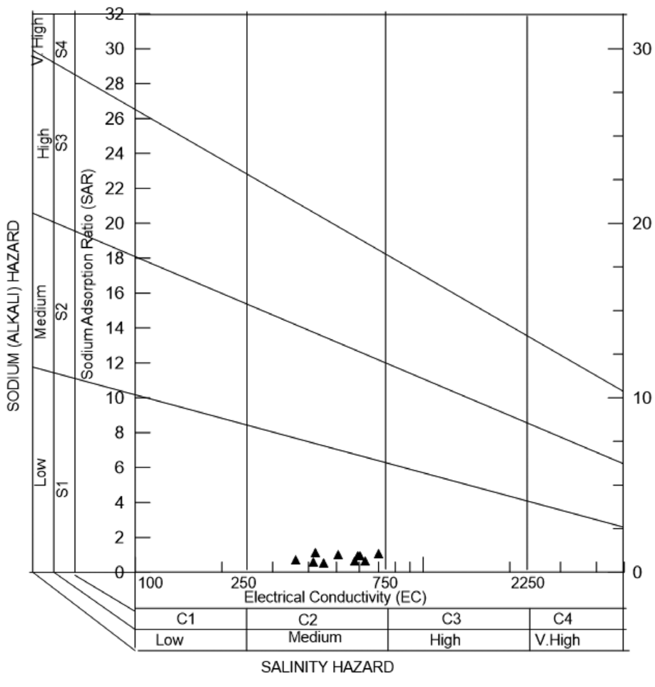

Figure 2: Irrigation water quality assessments of Devika stream based on United States Salinity Laboratory (USSL, 1954; Richards, 1954).

where cationic concentrations are in milliequivalents per litre (meq/L).

The higher values of SAR in the water indicate a greater risk of Na^+ which eventually results in the development of alkaline soil (Todd, 1980). Based on this submission, the water of the Devika stream is suitable for irrigation. The calculated value of SAR in the Devika stream was found to range between 0.47 and 1.04 (Table 1), which is excellent for irrigation (Table 2). The plot of the US salinity diagram (Figure 2) has shown that all the water samples fell in the category C2S1 region (Figure 2), i.e. medium salinity and low alkalinity.

Percentage Sodium (%Na)

An excessive amount of sodium in water creates undesirable effects in terms of changing soil properties and lessening soil permeability (Rawat et al., 2018; Wilcox, 1955). The Na^+ in irrigation water is generally expressed as % Na and can be estimated by using the formula where the concentrations are expressed in meq/L as follows:

Table 2: Classification of water quality based on suitability of water for irrigation purposes

Parameters	*Range*	*Class*	*No. of water samples*	*% of samples*
EC	<250	Excellent	Nil	Nil
	250-750	Good	10	100
	750-2,000	Permissible	Nil	Nil
	2,000-3,000	Doubtful	Nil	Nil
	>3,000	Unsuitable	Nil	Nil
Na%	<20	Excellent	3	30
	20-40	Good	7	70
	40-60	Permissible	Nil	Nil
	60-80	Doubtful	Nil	Nil
	>80	Unsuitable	Nil	Nil
RSC	<1.25	Safe	10	100
	1.25-2.5	Marginally safe	Nil	Nil
	>2.5	Unsuitable	Nil	Nil
PI	>75	Safe	Nil	Nil
	25-75	Marginally safe	10	100
	<25	Unsafe	Nil	Nil
MH	<50	Safe	5	50
	>50	Unsafe	5	50

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

The %Na in the study area was found to range between 18.84% and 33.17%, with an average of 24.19% (Table 1). It was observed that 70% of water samples fell within the category of good (20-40%) and a few 30% samples fell under excellent (< 20%) as per the Indian standards (BIS, 2003), a maximum Na content of 60% is recommended for irrigation water. All water samples of the Devika stream in the Wilcox diagram (Figure 3) were found in the categories of excellent to good for irrigation purposes (Table 2).

Residual Sodium Carbonate (RSC)

The surplus amount of bicarbonate and carbonate of alkaline earth (Ca+Mg) also affects the suitability of water for irrigation purposes (Gautam et al., 2018). When the sum total concentration of carbonates and bicarbonates ions are found in excess of calcium and magnesium ions, there are chances of complete precipitation of Ca and Mg (Gautam et al., 2018). Therefore, in the present study, to quantify the effects of carbonate and bicarbonate, RSC has been calculated using the following equation:

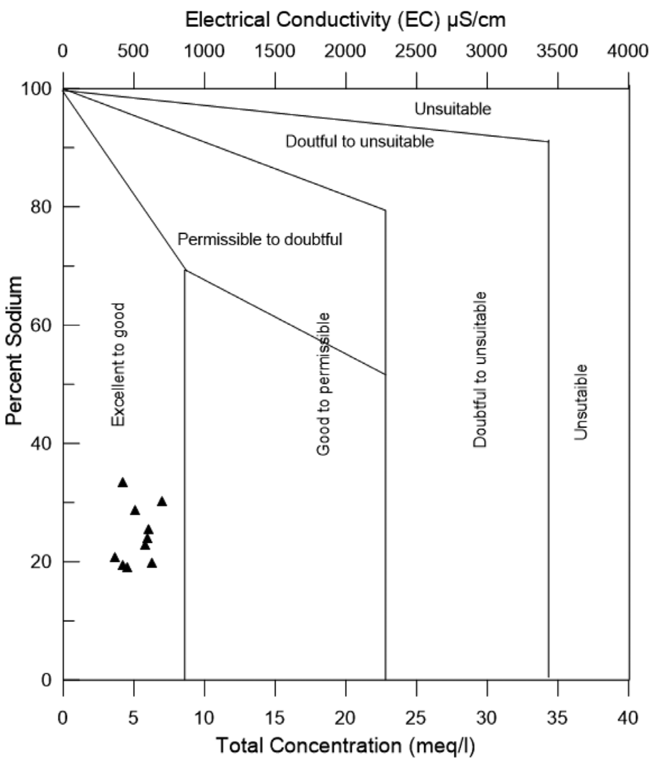

Figure 3: Wilcox diagram showing percent sodium (%Na).

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \text{ in meq/L} \quad (3)$$

If the value of RSC is found to be elevated in water, then it causes an increase in the adsorption of sodium in soil (Eaton, 1950). The water samples with RSC values greater than 5 meq/L are considered to be harmful to plant growth, while waters with RSC values above 2.5 meq/L are not treated as suitable for irrigation purposes. The river water samples in the present study showed RSC values ranging from -1.07 to 1.17 meq/L (Table 1). According to RSC classification, all water samples of the study area are in the safe region (RSC < 1.25 meq/L) to be used for irrigation (Table 2).

Magnesium Hazard (MH)

Usually, Ca^{2+} and Mg^{2+} ions in water maintain a state of equilibrium in it. A higher amount of Mg^{2+} ions present in water affects the quality of soil by changing it into alkaline and eventually dropping the crop yield. Szabolcs and Darab (1964) proposed the indices for irrigation water as MH value which is estimated by using the following formula (where the concentrations are expressed in meq/L):

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \quad (4)$$

As per Szaboles and Darab (1964), if the MH < 50, then it is considered safe and an MH value > 50 is considered unsafe for irrigation purposes. In the water samples of the present study, the MH ranged from 32.52 to 62.73 with an average of 48.06 (Table 1). According to MH, it is indicated that 50% of the samples are suitable and the remaining 50% are not suitable for irrigation purposes (Table 2).

Permeability Index (PI)

Doneen (1964) proposed a criterion for assessing the appropriateness of groundwater for irrigation based on the PI as the permeability of soil is affected by the long term application of irrigation water because it is influenced by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- ions present in the soil. The formula for estimating the permeability index is as follows, where concentrations are in meq/L:

$$PI = \frac{\left(Na^+ + \sqrt{HCO_3^-}\right)}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \quad (5)$$

The PI is categorised in class I (> 75%), class II (25–75%) and class III (< 25%) orders. Class I and class II waters are considered as good for irrigation with 75% or more of maximum permeability. Class

III waters are not considered fit for irrigation with 25% of maximum permeability. In the present study, The PI ranged between 32.68% to 58.17% with an average of 47% (Table 1), which were placed under class I and II (Table 2). The PI value of water samples showed that 60% of water samples fell in class-I (PI > 75, safe), and the remaining 40% in class-II (PI = 25-75, marginally safe) in Doneen's chart (Figure 4) (Domenico and Schwartz, 1990). Thus, the maximum water samples were meeting the suitability criteria for irrigation purposes.

Statistical Analysis and Geochemical Plots

Principal Component Analysis

The purpose of the factor analysis is to explain observed relations between numerous variables in terms of simpler relations (Cattel, 1965). The variables of water samples from the Devika stream are governed by the following four factors (Table 3):

Factor 1: All the variables present in this category except for pH, HCO_3^- and Ca^{2+} which indicated that factor 1 is mainly attributed to weathering and anthropogenic activity.

Factor 2: In this category, the main variables were pH, HCO_3^- NO_3^- and Ca^{2+} which indicated weathering is the major factor and the presence of nitrate indicated agricultural activities to some extent.

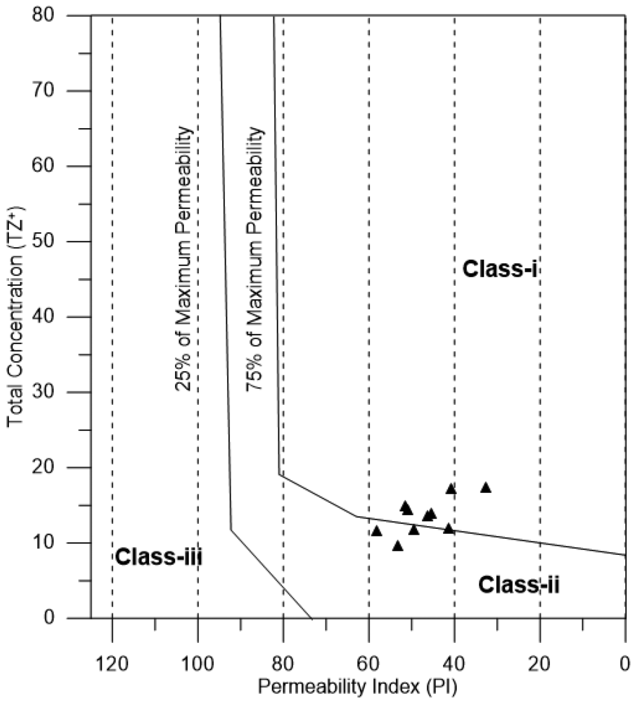

Figure 4: Doneen's chart showing permeability index (PI).

Table 3: Component matrix of principal component analysis

	Component			
	1	*2*	*3*	*4*
TDS	.979	.118	-.049	.079
K	.931	-.095	-.041	.118
EC	.885	.160	-.231	.087
Cl	.810	-.245	-.334	-.237
SO_4	.747	-.249	.565	.106
Mg	.722	.275	.540	-.120
HCO_3	.233	.811	-.141	.464
pH	-.074	.804	.454	.266
NO_3	.156	-.744	.607	.001
Na	.523	.390	-.227	-.707
Ca	.367	-.543	-.439	.596

Factor 3: Variables found in this category attributed to domestic sewage and agricultural runoff.

Factor 4: Na^+ and Mg^{2+} showed that this factor is mainly governed by weathering.

Piper Diagram

Piper diagram is one way of comparing the results of chemical analyses of water (Piper et al., 1944). This classification system showed the anion and cation facies in terms of major-ion percentages.

The Piper diagram in the present study showed that 30% of water samples fell into the Ca^{2+} type, whereas, 70% of the remaining samples were in no dominant cation facies. Similarly, for anions, 50% of samples fell into Cl^- type, 30% in no dominant type, 20% HCO_3^- type, therefore, facies classification indicated that maximum samples were $CaCl_2$ type except for samples of Moda mod which is slightly sulphate type (Figure 5).

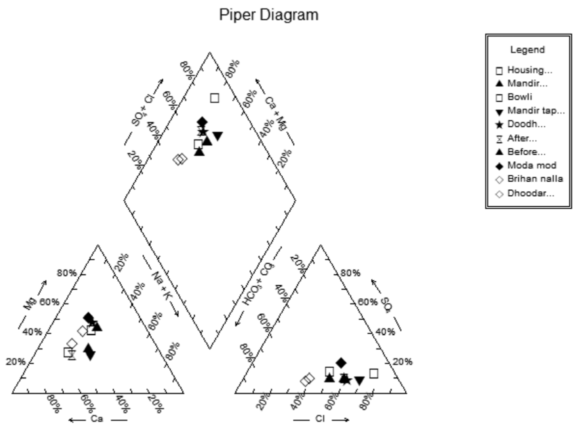

Figure 5: Piper diagram of water samples of Devika stream in Udhampur district.

Gibbs Diagram

The ratio Na/(Na+Ca), in mass units, plotted against TDS gives characteristics boomerang-shaped plot depicting the major factors operating behind the water chemistry of the major aquatic system of the world (Gibbs, 1970). This plot (Figure 6) places the water samples in the weathering region which indicated weathering is the key factor controlling the water quality.

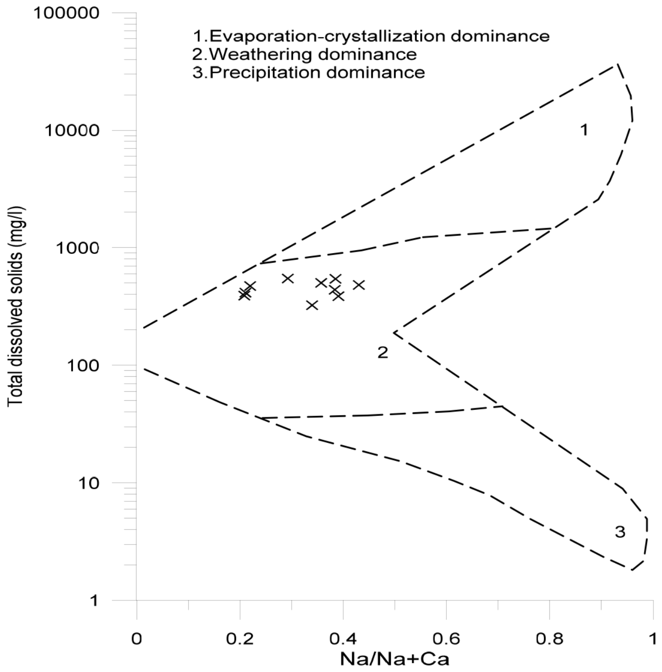

Figure 6: Gibbs diagram for water samples of Devika stream in Udhampur district.

Conclusion

The analysis of water samples showed that the pH ranged from neutral to slightly acidic. The low to moderate EC value of river samples indicated that the concentration of free ions was not much high. The dominant anion i.e. bicarbonate (HCO_3^-) and the dominant cations calcium (Ca^{2+}) indicated carbonate and silicate weathering taking place in the area. Factor analysis and Gibbs diagram also indicated weathering as the major and anthropogenic activity and precipitation as other controlling factors for water quality. Geochemical diagrams (piper diagrams) indicated the importance of weathering process taking place in the area which was inferred by the dominance of sodium, calcium and bicarbonate ions. Irrigation suitability parameters or indices, such as %Na, SAR, RSC, MH and PI indicated that most of the water samples were found to be good for irrigation purpose.

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