Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25428

185 (2020) 384–394
May

Hydrochemical evolution and quality assessments of streams water in Alaknanda basin, Garhwal Himalaya, India

Mohammad Mulhim*, Sarfaraz Ahmad

Department of Geology, Aligarh Muslim University, Aligarh, India, emails: mulhim.m@gmail.com (M. Mulhim), sarf71@gmail.com (S. Ahmad)

Received 20 July 2019; Accepted 30 December 2019

ABSTRACT

A hydrochemical study of the stream's water in the Alaknanda basin has been carried out for the samples collected in 2016–2017 during high and low flow. The hydrochemical facies is Ca^{2+}– HCO_3^- types for most of the samples. Gibbs ratio and Cl^-/[sum anion] ratio shows that the rock weathering is the primary source of solute in stream water. Apportioning of the weathering indicated that silicate, carbonate and mixed type of weathering are dominated by 52%, 19%, and 29% respectively in the watersheds. Base ion exchange index (IBI CaI1, IBII CaI2) suggested that stream chemistry is influenced by ion exchange and stream water also has deeper sources of water through joints and fissures in the watersheds. A comparison between ion concentrations in the samples suggested that few samples had magnesium and fluoride more than permissible limits. Based on dissolved ions in stream water, the water quality index indicates 80%, 14%, and 6% falls into the excellent to good, poor and unsuitable category respectively. High Kelly index and permeability index for some samples indicated the impact of rock type on water quality that may affect local agricultural productivity.

Keywords: Hydrochemical; Alaknanda River basin; WQI; Kelly ratio; Base ion-exchange index

1. Introduction

Stream water is one of the major sources to satisfy the necessity of daily basic needs in the mountain region due to the absence of sample groundwater storage. The quality and quantity of water from mountain streams are vulnerable because of regional controlling geology and hydro-meteorological conditions. Therefore, the large population in the mountain region depends on these streams that are highly impacted by variations in climate. This is recorded in history as migration events from these regions to adjacent plains in search of food, fodder and other economic benefits. The impact of the regional geological environment also makes the soil and water of some areas vulnerable to quality. It has been found that some quality-related reporting is available in the literature. In some cases, heavy metals as micronutrients are deficient in streams and groundwater along the Himalayan watersheds. The concentration of dissolved aluminium and iron was found in excess in the dissolved form at Gomukh, Gangotri while aluminium and lead in excess in the Alaknanda River due to high silicate sediment loading of certain elements in small watersheds [1,2].

Stream water hydrochemistry has also regularly been utilized as an apparatus to clarify the complex weathering forms happening in the glacial environment [3–6]. The amount and quality of surface water nourished through high altitude glaciers are changed by various natural and man-made activities and, in particular, the effects of climate change may have severe implications for local and regional sustenance and, for that region environmental and water sustainability require careful attention [7–9]. The Alaknanda

* Corresponding author.

River basin earlier had less interference of human activities nowadays it is modified due to the construction of large structures like dams, which in turn influences water quality and ecological condition of the basin. [10–12]. Apart from that, it is also considered as a holy river, so various ritual activities are performed on the bank of the river, its streams and its tributaries which creates massive immigration of people round the year that creates enormous pressure on natural resources in the basin. To meet the necessities of the indigenous people, terraced agriculture onto steeper hill-slopes is practiced on a large scale, the use of organic and inorganic fertilizers could also contaminate the water quality in the basin. In the present study, an effort has been constituted to assess the geochemical characteristics of streams water and water quality index (WQI) in the Alaknanda basin.

2. Study area

The study has been carried out in the streams of the Alaknanda River. The Alaknanda River originates from the snout of the Satopanth and the Bhagirathi Kharak glaciers, at a lower elevation, it joins with the Bhagirathi River at Devprayag and named as River Ganga. The area occupied by the Alaknanda River basin is 11.8 × 10^3 km^2 that is greater than its fellow River Bhagirathi [13,14]. The geology of the Alaknanda River basin is very complex; it divides into three successions, namely Tethyan Himalaya, Higher Himalayan crystalline, and Lesser Himalaya. The perennial river makes its way through the Higher Himalayan crystalline and consists of gneiss, schist with granite associated with migmatite types of rocks. After passing through the central crystalline zone, it enters into a formation called Tejam and berinag of Lesser Himalaya having marble, limestone and quartzitic types of rocks. Before it joins with Bhagirathi, thereafter it crosses Chandpur formation composed of phyllite and greywacke. Not only Alaknanda River flows in varied lithology, but its tributaries also [15–17]. The South Tibetan detachment system (STDS), Vaikrita thrust, Munsairi thrust, and North Almora thrust (NAT) are the main East West (EW) tectonics boundaries found in the Alaknanda basin (Fig. 1).

3. Methodology

Twenty-one samples of high and low flow periods were collected from the stream of the Alaknanda basin before meeting with the main Alaknanda channel, in the year 2016–2017 (see Fig. 1). The latitude and longitude of the sampling points were taken with a handheld GPS (Table 1). The streams water sample was collected in a 1 L plastic bottle thoroughly washed with concentrated HNO_3 and later washed with distilled water, and then the particular bottle was cleaned with the water from where the

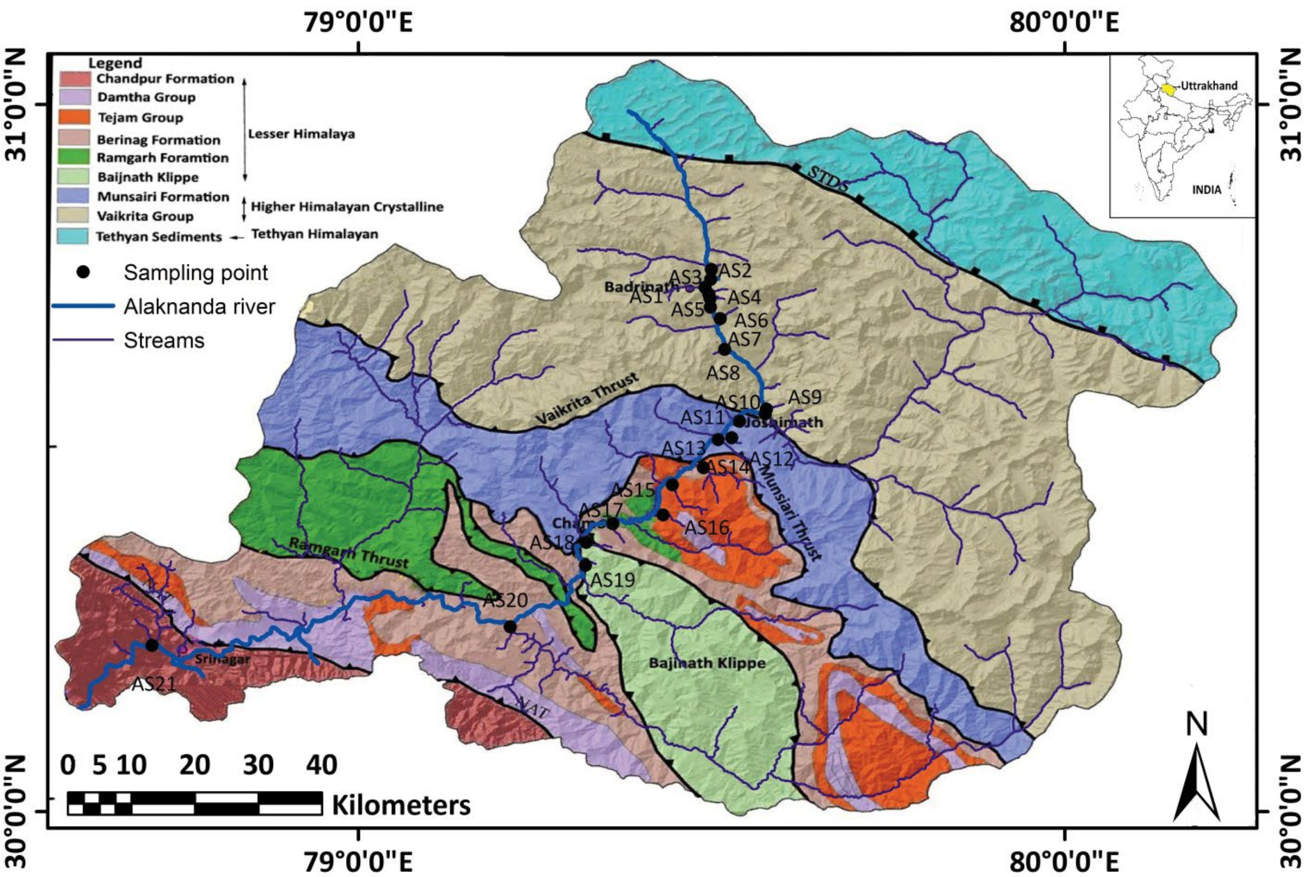

Fig. 1. Location map [inset], detailed geology along with sample location point, after Celerier [18] Ray and Srivastava [19] of the study area. The STDS, Vaikrita thrust, Munsairi thrust, NAT are the main EW tectonic boundaries.

sample was collected. The pH of the sample taken during the sample collection with handheld Digital pH meter and major ions were analyzed in the geochemical laboratory as per the standard method given by APHA [21]. The data thus obtained after geochemical analysis; an average of both high and low flow periods was calculated, and then various parameters were obtained.

4. Results and discussion

The major ion chemistry of streams water of Alaknanda basin was statistically analyzed, and the results compiled by minimum, maximum and average (Table 2). Among the major cations, calcium is the most dominant ion (0.28–1.72 meq/L) with an average value of 0.96 followed by magnesium (0.12–2.88 meq/L), sodium (0.02–0.30 meq/L) and potassium (0.03–0.19 meq/L) with a mean value of 0.85, 0.12, and 0.10 respectively. Furthermore, among the major anions bicarbonate ion is most dominated, value ranges from 0.43–3.62 meq/L with a mean value of 1.60 followed by sulphate, chloride and fluoride and their values lie between 0.06–2.25 meq/L, 0.28–0.52 meq/L, and 0.00–0.18 meq/L with an average value of 0.46, 0.08, and 0.04 meq/L, respectively.

The suitability of the stream's water is evaluated for drinking and irrigation point of view [21]. Comparative hydro-chemical data shows a high degree of magnesium in the sample no AS 14 and AS 15, and undesirable high bicarbonate is also found in sample no. AS 14, AS 16, and AS 21 (as shown in Table 3). Based on Indian Standard Specification for Drinking Water [22], the results indicated that all the samples are within the range of the prescribed limit. The sources of solute in the stream's water have been analyzed based on the formula r2 $[Na^+ + K^+]–Cl^-/SO_4^{2-}$ indicating that most of the water in streams got its source from the subsurface viz. joints, fractures and fault zones in the watershed (Table 4).

4.1. Hydrochemical facies

The hydrochemical facies of Alaknanda River streams has been obtained by Piper trilinear diagram [23]. Whereby major ion chemistry of the stream's water of the Alaknanda River shows the dominance of Ca^{+2} and HCO_3^- ions. It suggests that Ca^{2+}, Mg^{2+} is higher than Na^+, K^+ and carbonic acid (HCO_3^-) is exceeding than the strong acids (Cl^-, SO_4^{2-}). From the piper trilinear plot of the streams water samples in Alaknanda basin predominantly of $Ca^{+2}–HCO_3^-$ facies type (Fig. 2).

4.2. Sources of solute

A number of ratios of chemical species and models are utilized in deciding the sources of solute in streams water. In order to visualize the comparative characteristics of surface water chemical compositions, Gibb's [24] give a boomerang envelope model to recognize the kinetics of surface water chemical compositions and classify the controlling factors into three division's viz. precipitation, rock weathering, and evaporation. The weight proportion $Cl^-/[Cl^- + HCO_3^-]$ and $Na^+/[Na^+ + Ca^{2+}]$ as a function of total dissolved solids (TDS) has been plotted, and it has been inferred that rock weathering is a dominated factor controlling the chemistry of water in the streams (Fig. 3). Gibbs ratio I values vary from 0.09

Table 1
Latitude and longitude of the sample location point

Sample I.D.	Location	Latitude	Longitude
AS 1	Badrinath	E79.49083	N30.74123
AS 2	Mana 1	E79.49984	N30.76661
AS 3	Mana 2	E79.49874	N30.75266
AS 4	Ekadashi Gufa	E79.49640	N30.73143
AS 5	Bindukhatta	E79.49788	N30.72564
AS 6	Near Bheem pul	E79.49818	N30.71315
AS 7	Hanuman Chatti	E79.51221	N30.69707
AS 8	Lambagarh	E79.51868	N30.65351
AS 9	New Govindghat	E79.57764	N30.56913
AS 10	Vishnuprayag Confluence	E79.57594	N30.56240
AS 11	Joshimath	E79.53970	N30.55192
AS 12	Paini Village	E79.52861	N30.52842
AS 13	Hailong Bridge	E79.50949	N30.52596
AS 14	Langsi	E79.48866	N30.48620
AS 15	Dhauliganga River Confluence	E79.44458	N30.46198
AS 16	Bridge Beraanganaa	E79.43136	N30.41957
AS 17	Bhimtal	E79.36034	N30.40717
AS 18	Balkhila	E79.32269	N30.38079
AS 19	Nandprayag Confluence	E79.32164	N30.34841
AS 20	Pindar River	E79.21490	N30.26120
AS 21	Jayalgarh	E78.70780	N30.23490

Table 2
Minimum, maximum and average value of different chemical parameters in stream water samples of the study area

S. No	Chemical parameters	Min.	Max.	Avg.
1	Calcium (meq/L)	0.28	1.72	0.96
2	Magnesium (meq/L)	0.12	2.88	0.85
3	Sodium (meq/L)	0.02	0.30	0.12
4	Potassium (meq/L)	0.03	0.19	0.10
5	Bicarbonate (meq/L)	0.43	3.62	1.60
6	Sulphate (meq/L)	0.06	2.25	0.37
7	Chloride (meq/L)	0.28	0.52	0.42
8	Fluoride (meq/L)	0.00	0.18	0.03
9	pH	7.00	8.60	7.79
10	EC (μmhoscm^{-1})	23.44	210.94	100.63
11	TDS (ppm)	79.77	347.07	195.09
12	Hardness (ppm)	52.30	196.00	89.52
13	Sodium absorption ratio (SAR)	2.54	20.58	11.87
14	Sodium percentage (SP)	0.02	0.28	0.13
15	Potential salinity (PS) (meq/L)	0.42	1.56	0.61
16	Permeability index (PI) %	44.52	130.88	79.20
17	Kelly's ratio	0.23	2.91	0.99
18	IBE CaI1 (Indices of base exchange)	–6.96	–0.09	–1.87
19	IBE CaI2 (Indices of base exchange)	–6.93	0.02	–1.77
20	Mg hazard	12.64	267.48	95.78
21	Gibbs ratio I	0.09	0.53	0.26
22	Gibbs ratio II	0.09	0.36	0.19
23	Total WQI	17.94	262.77	49.98
24	$Na^+ + K^+/Cl^-$	0.12	1.24	0.54
25	$(Ca^{2+} + Mg^{2+})$ vs. Tz^+	0.77	0.98	0.89
26	$(Ca^{2+} + Mg^{2+})/(Na^+ + K^+)$	3.41	39.19	11.47

Table 3
Indian Standard (IS 2000) guidelines for various parameters

Parameters	Indian Standards	Number of sample
Total hardness	300	None
Bicarbonate	200	AS14, AS16, AS21
Chloride	250	None
Fluoride	1	None
Calcium	75	None
Magnesium	30	AS14, AS15
Sodium	20	None
Potassium	10	None
Nitrate	45	None
Sulphate	200	None
TDS	500	None

All the concentrations in ppm

to 0.53 with a base value of 0.26 while Gibbs ratio II ranges from 0.09 to 0.36 with an average value of 0.19 (see Table 2).

Furthermore, sources of dissolved ions in the streams have been evaluated using scatter diagrams and associations of various dissolved ions (Figs. 4a–d). The scattered plot $(Ca^{2+} + Mg^{2+})$ vs. Tz^+ for the streams falling above the 1:1 line with an average ratio of 0.89. The Ca^{2+} + Mg ions contribution is relatively high to the total cations and the high average ratio of $(Ca^{2+} + Mg^{2+})/(Na^+ + K^+)$, that is, 11.47 showing carbonate weathering. The plot of $Na^+ + K^+/Tz^+$ falls below the 1:1 line indicating minor contribution compared to $Ca^{2+} + Mg^{2+}$ for chemical weathering. The plot of $(Ca^{+2} + Mg^{+2})$ vs. $(HCO_3^- + SO_4^{2-})$ is almost falling on the 1:1 line. It suggests the contribution from SO_4^{2-} and HCO_3^- in mobilizing the Ca^{2+} and Mg^{2+} as major cations for the geochemical weathering in the study area. The scattered plot between $(Na^+ + K^+)$ vs. Cl^- shows that the concentration of $Na^+ + K^+$ is comparatively lower than chloride (Cl^-). The lower concentration of Na^+, K^+ reflects the minerals that contain Na^+ and K^+ are weathered in a minor amount resulting in low $Na^+ + K^+/Cl^-$ a ratio of 0.54. Relatively high concentration and abundance of Ca^{2+}, Mg^{2+} and HCO_3^- and less contribution of Na^+ and K^+ indicate that the carbonate weathering is the primary source of the solute in the water of the streams. A correlation matrix has been determined for an average of the measured parameters is given in (Table 5). The alliances of the parameters indicating a close relationship of the most dominant cation (Ca^{2+}–HCO_3^- (r^2 = 0.6), Ca^{2+}–SiO_2 (r^2 = 0.5) and Mg^{2+} with HCO_3^- (r^2 = 0.8) in streams water reflecting the major part of solute release by silicate and carbonate weathering.

The sources of solute from carbonate, silicate and mixed type weathering contributions are also determined using the Hounslow [25] scheme based on ratios of dissolved ionic species. In the study area, 52% of the samples are showing the domination of silicate weathering; 19% of the samples are showing carbonate types of weathering and 29% come under the mixed case of weathering. The stream's water with HCO_3^-/SiO_2 ratios >5 to <10 along with $Mg^{2+}/[Ca^{2+} + Mg^{2+}]$ ratio >0.5 indicates the ferromagnesium silicate weathering under the mixed weathering category. which is further verified by using a mixing diagram between (HCO_3^-/Na^+) vs. (Ca^{2+}/Na^+) and (Mg^{2+}/Na^+) vs. (Ca^{2+}/Na^+) adapted from [26] as shown in (Fig. 5a and b) suggesting a mixed type of weathering.

Dissolution and control of the unwanted matters in water are inconceivable during the subsurface overflow, yet it is crucial to find the progressions experienced by the water during its courses [27,28]. With the help of chloro-alkaline indices, the transfer of ions among groundwater and its interacting environment either during flow or stagnant can be easily understood [29,30] and suggests two chloro-alkaline indices of base exchange (IBE) CaI1 and CaI2. The value of IBE is positive which signifies the exchange of sodium (Na^+) and potassium (K^+) from the water with magnesium (Mg^{2+}) and calcium (Ca^{2+}) of the rocks 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 rocks. The result is shown in (Table 2) and reveals that IBE CAI 1 value is ranging from –6.96 to –0.09 with a mean value of –1.87 and CAI 2 value extent from –6.93 to maximum 0.02 with a mean of –1.77. The result implies that in the study area there is an exchange of Mg^{2+} and Ca^{2+} of the water with Na^+ and K^+ of the rocks/soil. The ionic exchange between dissolved ions in water and bedrock of the catchment has also been deciphered by the Durov diagram [31]. In the present study, the location of samples is mostly lying in the ions exchange field and a minor contribution from the dissolution or mixing (Fig. 6).

5. Water quality standard for drinking

WQI gives a broad explanation of the characteristic of the subsurface and surface water and its appropriateness for drinking purposes. The objective of WQI is to simplify water quality information in reasonable and practical data so that ordinary individuals can understand water quality in a distinct area [32–35]. The weighted arithmetic index method is used to calculate WQI using eleven aspects like pH, total hardness, TDS, alkalinity, chloride, calcium, magnesium, sulphate, and fluoride, which exhibit the maximal fluctuation in a specific period and also show fluctuation at the various sampling points by using the following equation:

$$\text{WQI} = \left(\frac{C_i}{S_i}\right) \times 100 \tag{1}$$

For WQI, initially, the S_i is determined for each parameter, and then equation (Eq. (2)) is used for the calculation of WQI as:

$$S_i = W_i \times Q_i \tag{2}$$

From Eq. (3) unit weight (W_i) for each water quality norm is calculated:

$$W_i = \frac{k}{S_i} \tag{3}$$

where k is constant, and S_i is the standard admissible value of the i^{th} parameter. The quality rating (Q_i) is calculated as:

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{4}$$

where C_i stands for an approximate concentration of the i^{th} parameter in the examined water samples. The standard rating of water quality according to WQI summarized in Table 6 and the calculated WQI for the streams water samples suitability for drinking purpose given in Table 7. A detail distribution of WQI suggests 80% fall in excellent to good category, 14% fall under the poor quality and 6% of the total water samples were found in the unsuitable category.

5.1. Water quality standard for irrigation

The stream's water is also being used for irrigation. In this perspective, four criteria have been determined viz. sodium adsorption ratio (SAR), magnesium hazards (MH), sodium percent (Na %), Kelly's ratio (KI), permeability index (PI) to check their suitability for irrigational needs of the local native of the area.

5.1.1. Sodium adsorption ratio

Based on Richards [37], 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. With continuing usage, water having a surplus SAR level can prompt an expansion in sodium concentration with time, which thus can severely influence the soil characteristic. Under such conditions, certain corrective measures might be needed to keep up the soil below high SAR value. Soil having exchangeable calcium and magnesium, which are present in sample quantity will balance the effect of sodium and keep exceptional soil values [37]. Likewise, harmful SAR levels also lead to poor germination of seedling, aeration, soil crusting in some high cases [38]. The SAR value is calculated using the formula:

$$\text{SAR} = \frac{\text{Na}^+}{\left\{\dfrac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}\right\}^{1/2}} \tag{5}$$

where all the concentrations of ions in meq/L.

The SAR for all the samples is determined using the above formula, and the results were found to be within the range 0.02–3.79 with a mean value of 0.79 and signify excellent quality for irrigational uses. A scatter diagram between SAR and electrical conductivity (EC) suggests that all samples

Table 4
Stream water classification, based on Soltan [23]

Parameters	Ranges	Type of water	No. of samples
TDS	<1,000 mg/L	Fresh	All sample
	>1,000 mg/L	Brackish	None
Cl^-	<15 meq/L	Normal Cl^-	All sample
	>15 meq/L		None
SO_4^{2-}	<6 meq/L	Normal SO_4	All sample
	>6 meq/L		None
HCO_3^-	2–7 meq/L	Normal HCO_3	6[AS12, AS14, AS15, AS16, AS19, AS21]
	>7 meq/L		None
r1[Na^+–Cl^-]/SO_4^{2-}	<1	Na–HCO_3	All
	>1	Na–SO_4	None
r2[Na^+ + K^+]–Cl^-/SO_4^{2-}	<1	Subsurface water	All
	>1	Shallow meteoric water	None

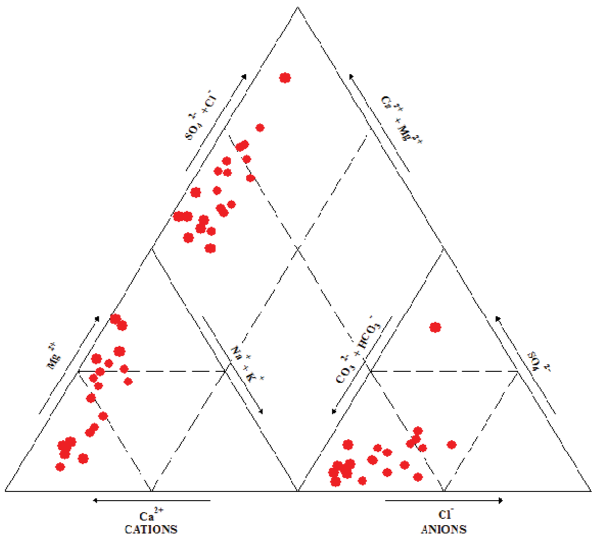

Fig. 2. Piper trilinear plot of the study area.

belong to excellent water quality, that is, low salinity/low sodium hazard (C1S1), while only one sample is found under medium salinity (C2S1) category (Fig. 7).

5.1.2. Magnesium hazards

Szabolcs and Darab [40] give the parameter called MH to check the quality of water for irrigation purposes given as:

$$MH = \frac{Mg^{+2}}{\left(Ca^{+2} + Mg^{2+}\right)} \quad (6)$$

The value of MH is greater than 50 is destructive for plant health. From Table 2, MH vary from 12.64 to 267.48 with an average value of 95.78. In the study area, 62% of the samples are considered unsafe for irrigational uses however the high value in the study area indicates magnesium and calcium got its source from carbonate rocks having calcite and dolomites, with a little quantity of source from calcium silicate minerals.

5.1.3. Sodium percentage

Sodium percentage (SP) is also used to examine water quality for the irrigational application. The Surplus of Na^+ in water reacts with soil, which not only ruins soil permeability but also influences plant growth [40]. The following equation calculates the Na^+ % in a water sample:

$$Na\% = \frac{Na^+ + K^+}{\left(Ca^{2+} + Mg^{2+} + K^+ + Na^+\right)} \times 100 \quad (7)$$

All the units in meq/L.

The SP of stream water ranges from 2.54% to 20.58% with an average of 11.87%. The calculated Na % showed that 100% stream water samples fall within the excellent category (Fig. 8).

5.1.4. Kelly's ratio

The suitability of water quality for irrigation purpose also determines by Kelly [42] as for sodium and magnesium by the following formula.

$$KI = \frac{Na^+}{\left(Ca^{2+} + Mg^{2+}\right)} \quad (8)$$

KI of more than one shows an excess of sodium in the water that makes it unfit for irrigation uses, as water with KI of less than one is fit for irrigation purposes. (Table 2) KI varies from 0.23 to 2.91, with an average value of 0.9. In the study area, 24% of the samples are considered unsuitable for irrigation purposes.

5.1.5. Permeability index

The permeability of the soil is damaged by the continuing use of irrigation water, which in turn gets altered by the

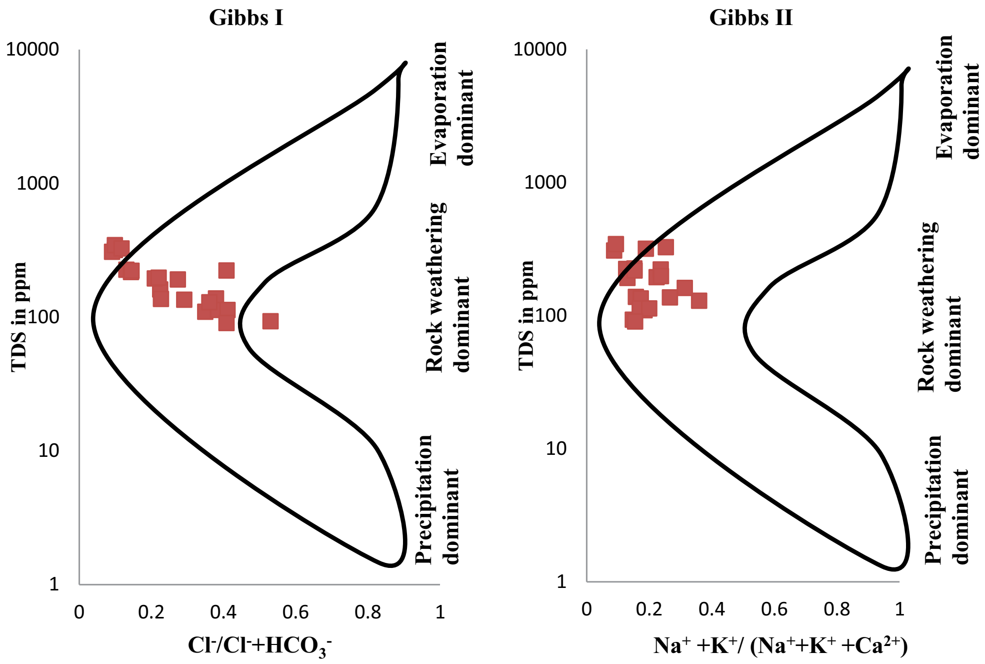

Fig. 3. Changes of weight proportion of $Cl^-/(Cl^- + HCO_3^-)$ and $Na^+ + K^+/(Na^+ + K^+ + Ca^{2+})$ as a component of TDS.

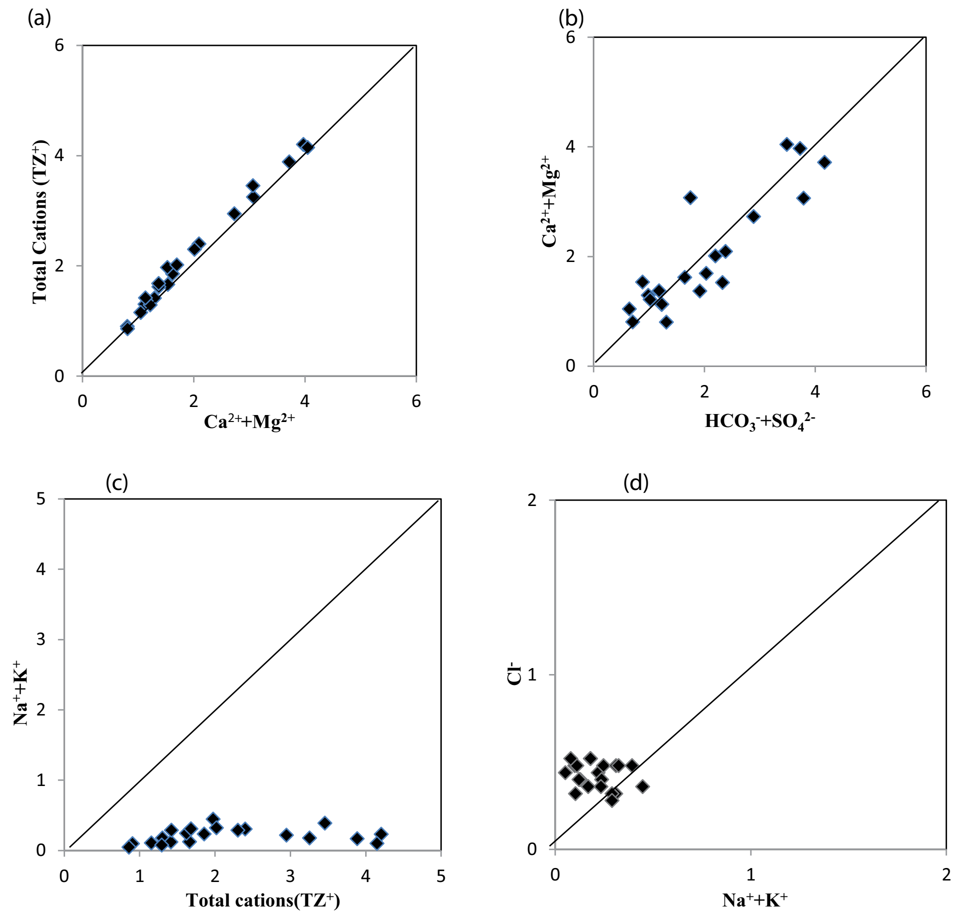

Fig. 4. Scatter plot between (a) $Ca^{2+} + Mg^{2+}$ vs. total cations (TZ+), (b) $HCO_3^- + SO_4^{2-}$ vs. $Ca^{2+} + Mg^{2+}$, (c) $Na^+ + K^+$ vs. total cations (Tz^+) and (d) $Na^+ + K^+$ vs. Cl^- (all ions in meq/L).

Table 5
Average correlation matrix of chemical parameters in the Alakananda River streams

	Ph	TDS	EC	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	F^-	SiO_2
Ph	1.0												
TDS	0.5	1.0											
EC	0.8	0.6	1.0										
Ca^{2+}	0.6	0.3	0.6	1.0									
Mg^{2+}	0.7	0.6	0.8	0.2	1.0								
Na^+	0.3	0.0	0.2	0.4	–0.1	1.0							
K^+	0.6	0.1	0.4	0.6	0.1	0.4	1.0						
HCO_3^-	0.9	0.6	0.9	0.6	0.8	0.3	0.4	1.0					
SO_4^{2-}	0.0	0.0	0.0	0.4	0.1	–0.1	0.1	–0.1	1.0				
NO_3^-	–0.2	–0.2	–0.1	–0.2	0.0	0.0	–0.1	–0.1	0.1	1.0			
Cl^-	–0.5	–0.3	–0.4	–0.4	–0.2	0.1	–0.5	–0.3	0.0	0.4	1.0		
F^-	0.1	0.1	0.2	0.4	–0.1	0.1	0.4	0.1	0.0	–0.1	–0.2	1.0	
SiO_2	0.5	0.2	0.5	0.5	0.3	–0.1	0.3	0.4	0.1	0.1	–0.3	0.2	1.0

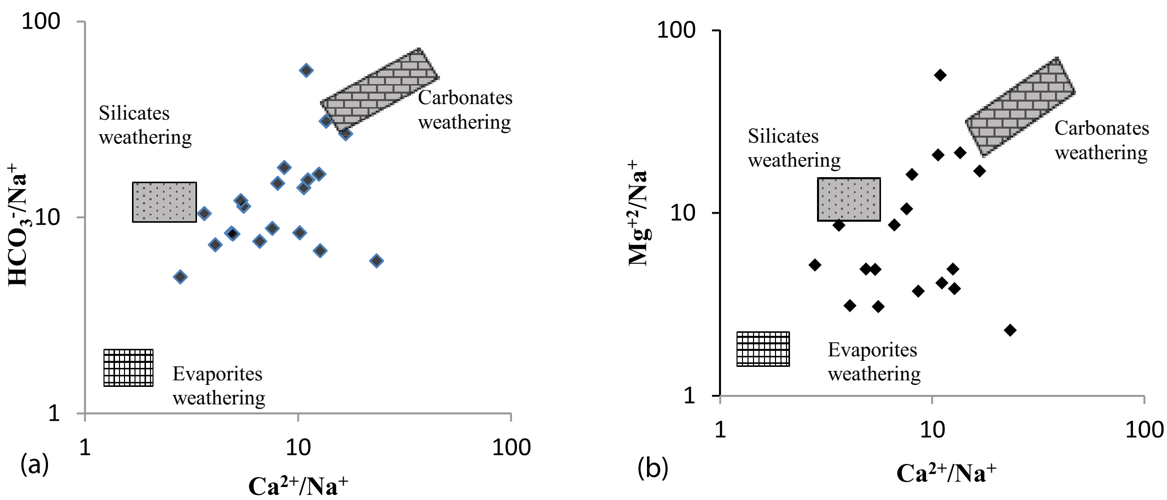

Fig. 5. Plot of (a) HCO_3^-/Na^+ vs. Ca^{2+}/Na^+ and (b) Mg^{2+}/Na^+ vs. Ca^{2+}/Na^+ signify mixing between silicates and carbonates end members.

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 [42].

$$PI = \frac{Na\sqrt{HCO_3}}{Ca + Mg + Na} \times 100 \quad (9)$$

The value of the PI less than 60 is considered good for irrigation, and its value more than 60 shows not suitable for irrigation. Given that, the PI is classified as class I (>75%), class II (25–75%) and class III. Class, I and II water are grouped as good for irrigation with a maximum permeability of 75% or more, whereas class III water is considered bad with maximum permeability 25%. In the study area, the PI value varies from 44.52% to 130.88% with an average value of 79.20% (Table 2). It was found that high PI of the stream water is due to the calcium and magnesium-rich bedrock, that is, limestone/ dolomite in the watershed. The excess quantity of calcium and magnesium in the soil increases the pore spaces and pH of the soil. The continuing practice of agricultural activities in these soil using high PI water for irrigation may lead to soil dryness and hence reduces the crop productivity In the case of Ca, Mg and high pH the absorption of the trace metal by the plant roots becomes difficult. Because under high pH conditions mobilization of trace elements in soil solution becomes difficult due to the absence of free hydrogen ions [43]. However, only 23% of the stream water sample is suitable for irrigation in the study area (Fig. 9).

6. Conclusions

This paper argued that the geology of the watershed facilitates the subsurface water contribution in the streams. Hence, bedrock geology affects the hydrochemistry at a regional scale. The WQI of the water samples for drinking purposes suggested that 80%, 14% and 6% of samples fall under excellent to good, poor and unsuitable categories respectively. The poor and unsuitability of the samples for the drinking purposes is due to the high concentration of Mg^{2+}, Ca^{2+}, HCO_3^- and F^- in a few streams water that evolves through geochemical weathering of basement rocks. It is also found that few samples are unsuitable for irrigation purposes due to the geology of the area that supplies excess amounts of calcium and magnesium in the soil and leads to a high PI in some areas. In these areas, suitable agriculture practices must be adopted to prevent crop failure due to the deficiency of trace elements.

Hydrochemical species are dominantly Ca^{+2}–HCO_3^- type for the water samples in the region and evolved through geochemical weathering and ion base exchange. The ionic ratios of anions and cations suggested that silicate, carbonate and mixed weathering are dominating in 52%, 19% and 29% of the watersheds. High dissolved silica and Mg^{2+} concentration in 29% of the samples suggests the ferromagnesium silicates weathering under the mixed weathering category.

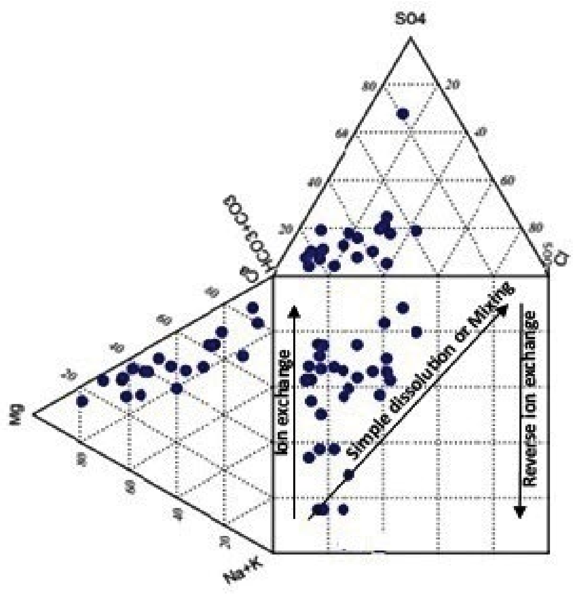

Fig. 6. Durov diagram of the study area.

Acknowledgment

The authors would like to express their sincere thanks to the Chairman, Department of Geology, Aligarh Muslim University for providing the laboratory and seminar facilities. The authors would like to appreciate the financial assistance provided by University Grant Commission (UGC), Ministry of Human Resource Development (MHRD), Govt.

Table 6
Indian Standards, weight and relative weight of various parameters

Parameters	Indian Standards	Weight [wi]	Relative weight [Wi]
Ph	7.5	4	0.1081
Total hardness	300	2	0.054
Alkalinity	200	3	0.081
Chloride	250	3	0.081
Fluoride	1	4	0.1081
Calcium	75	2	0.054
Magnesium	30	2	0.054
Sodium	20	2	0.054
Potassium	10	3	0.081
Nitrate	45	4	0.1081
Sulphate	200	4	0.1081
TDS	500	4	0.1081

Table 7
Standard water quality rating as per WQI

WQI scale	Water qualitative level	Rating (WQR)	Letter grade	Sample No.
0–25	Excellent	9	A	2 (AS 7, AS 10)
26–50	Good	71	B	15 (AS 1, AS 2, AS 3, AS 4, AS 5, AS 6, AS 8, AS 11, AS 12, AS 14, AS 15, AS 17, AS 18, AS 19, AS 21)
51–75	Poor	14	C	3 (AS 9, AS 16, AS 20)
76–100	Very poor	0	D	None
>100	Unsuitable	6	E	1 (AS 13)

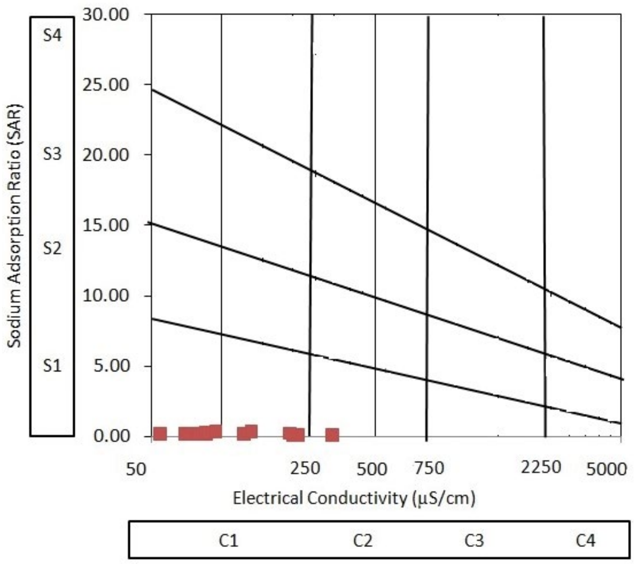

Fig. 7. Salinity classification of stream water samples of the study area by (Richards [37]).

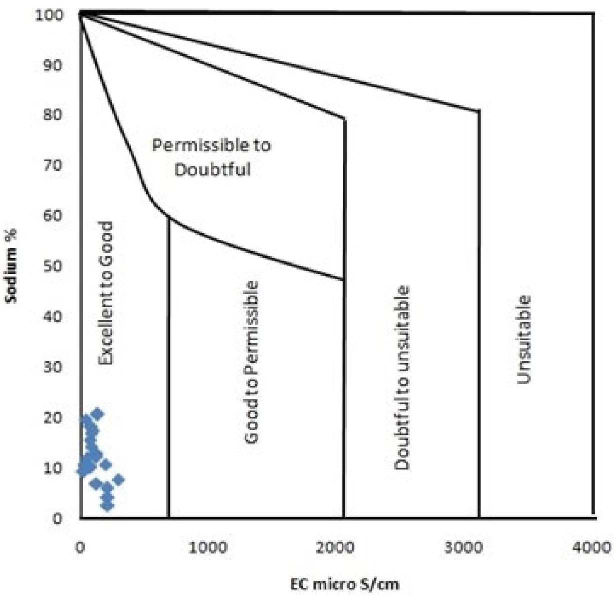

Fig. 8. Wilcox [41] classification of stream water in the study area.

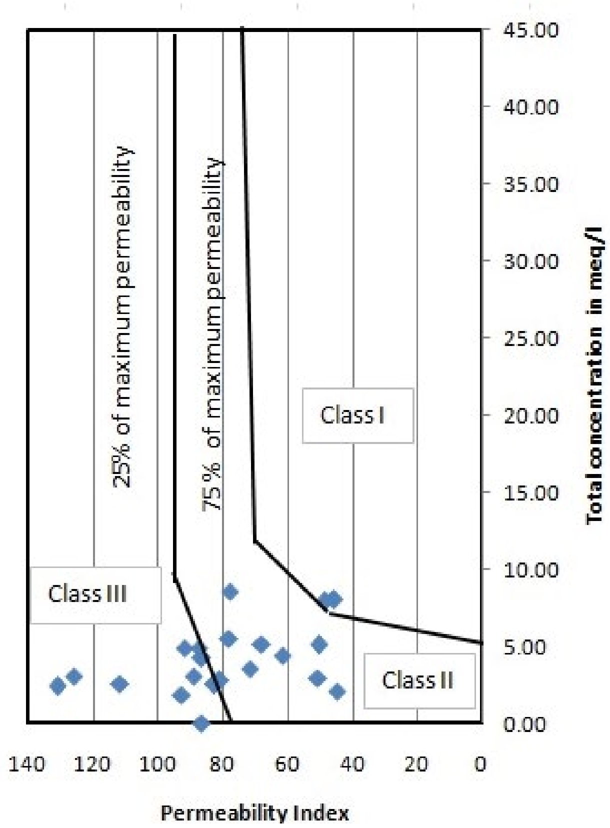

Fig. 9. Permeability index against the total concentration of ions.

of India, under Departmental Research Support II (Special Assistance Programme-1) program.

References

[1] NMCGNEERI, Assessment of Water Quality and Sediment to Understand the Special Properties of River Ganga, 2014. Available at: http://nmcg.nic.in/writereaddata/fileupload/NMCGNEERI%20Ganga%20Report.pdf
[2] N. Semwal, P. Akolkar, Water quality assessment of sacred Himalayan Rivers of Uttarakhand, Curr. Sci., 91 (2006) 486–496.
[3] P. Sharma, A.L. Ramanathan, J.G. Pottakkal, Study of solute sources and evolution of hydrogeochemical processes of the Chhota Shigri Glacier meltwaters, Himachal Himalaya, India, Hydrol. Sci. J., 58 (2013) 1128–1143.
[4] V.B. Singh, A.L. Ramanathan, P. Sharma, J.G. Pottakkal, Dissolved ion chemistry and suspended sediment characteristics of meltwater draining from Chhota Shigri Glacier, western Himalaya, India, Arabian J. Geosci., 8 (2015) 281–293.
[5] V.B. Singh, A.L. Ramanathan, P. Sharma, Major ion chemistry and assessment of weathering processes of the Patsio Glacier meltwater, western Himalaya, India, Environ. Earth Sci., 73 (2015) 387–397.
[6] V.B. Singh, A.L. Ramanathan, Assessment of solute and suspended sediments acquisition processes in the Bara Shigri glacier meltwater (Western Himalaya, India), Environ. Earth Sci.,74 (2015) 2009–2018.
[7] T.P. Barnett, J.C. Adam, D.P. Lettenmaier, Potential impacts of a warming climate on water availability in snow-dominated regions, Nature, 438 (2005) 303–309.
[8] T. Yao, L. Thompson, W. Yang, W. Yu, Y. Gao, X. Guo, X. Yang, K. Duan, H. Zhao, B. Xu, Different glacier status with atmospheric circulations in Tibetan Plateau and surroundings, Nat. Clim. Change, 2 (2012) 663–667.
[9] F. Zhang, G.-T. Yeh, J.C. Parker, H. Zhang, X. Shi, C. Wang, R. Gu, A reaction-based river/stream water quality model: reaction network decomposition and model application, Terr. Atmos. Oceanic Sci., 23 (2012) 605–620.
[10] P.W. Moorehead, D.E. Walling, The particle size characteristics of fluvial suspended sediment: an overview, Hydrobiologia, 176 (1989) 125–149.
[11] K.H. Liao, From flood control to flood adaptation: a case study on the Lower Green River Valley and the City of Kent in King County, Washington, Nat. Hazards, 71 (2014) 723–750.
[12] Q. Zhang, C. Xu, S. Becker, T. Jian, Sediment and runoff changes in the Yangtze River basin during the past 50 years, J. Hydrol, 331 (2006) 511–523.

[13] A.K. Singh, S.I. Hasnain, Major ion chemistry and weathering control in a high altitude basin: Alaknanda River, Garhwal Himalaya, India, Hydrol. Sci. J., 436 (1998) 825–843.
[14] G.J. Chakrapani, R.K. Saini, Temporal and spatial variations in water discharge and sediment load in the Alaknanda and Bhagirathi Rivers in Himalaya, India, J. Asian Earth Sci., 35 (2009) 545–553.
[15] K.S. Valdiya, Geology of Kumaun Lesser Himalaya, Wadia Institute of Himalayan Geology, Dehradun, 1980, p. 29.
[16] M.M. Sarin, S. Krishnaswami, J.R. Trivedi, K.K. Sharma, Major ion chemistry of the Ganga source waters: weathering in the high altitude Himalaya, Proc. Indian Acad. Sci. – Earth Planet Sci., 101 (1992) 89–98.
[17] M.M. Sarin, S. Krishnaswami, K.K. Sharma, J.R. Trivedi, Uranium isotopes and radium in the Alaknanda-Bhagirathi River system: evidence for high uranium mobilization in the Himalaya, Curr. Sci., 62 (1992) 801–805.
[18] J. Celerier, M.T. Harrison, A.A.G. Webb, A. Yin, The Kumaun and Garwhal Lesser Himalaya, India: part 1. Structure and stratigraphy, Geol. Soc. Am. Bull., 121 (2009) 1262–1280.
[19] Y. Ray, P. Srivastava, Widespread aggradations in the mountainous catchment of the Alaknanda–Ganga River System: timescales and implications to Hinterland–foreland relationships, Quat. Sci. Rev., 29 (2010) 2238–2260.
[20] APHA, Standard Methods for the Examination of Water and Wastewater, American Public Health Association/American Water Works Association/Water Environment Federation, USA, 1998.
[21] ISI, Indian Standard Specification for Drinking Water, IS: 10500, Indian Standard Institute, India, 2000.
[22] M.E. Soltan, Evaluation of groundwater quality in Dakhla Oasis [Egyptian Western Desert], Environ. Monit. Assess., 57 (1999) 157–168.
[23] A.M. Piper, A graphic procedure in the geochemical interpretation of water analysis, Am. Geophys. Union Trans., 25 (1994) 914–928.
[24] R.J. Gibbs, Mechanisms controlling world water chemistry, Science, 170 (1970) 1081–1090.
[25] H.W. Arthur, Water Quality Data – Analysis and Interpretation, Lewis Publishers, CRC Press, USA, 1995, 416p.
[26] J. Gaillardet, B. Dupre, P. Louvat, C.J. Allegre, Global silicate weathering and CO_2 consumption rates deduced from the chemistry of large rivers, Chem. Geol., 159 (1999) 3–30.
[27] R.B. Pojasek, Drinking Water Quality Enhancement Through Protection, Ann Arbor Science Publications, Inc., Ann Arbor Michigan, 1977, 614p.
[28] C.C. Johnson, Land application of waste-an accident waiting to happen, Groundwater, 17 (1979) 69–72.
[29] H. Schoeller, Qualitative Evaluation of Groundwater Resources, In: Methods and Techniques of Groundwater Investigation and Development, Water Res. UNESCO, 33 (1967) 44–52.
[30] H. Schoeller, Geochemistry of Groundwater, In: Groundwater Studies–An International Guide for Research and Practice, UNESCO, Paris, 15 (1977) 1–18.
[31] S.A. Durov, Classification of natural waters and graphical representation of their composition, Dokl. Akad. Nauk, USSR, 59 (1948) 87–90.
[32] I.S. Akoteyon, O. Soladoye, Groundwater quality assessment in Eti-Osa, Lagos-Nigeria using multivariate analysis, J. Appl. Sci. Environ. Manage., 15 (2011) 121–125.
[33] M. Vasanthavigar, K. Srinivasamoorthy, K. Vijayaragavan, R.R. Ganthi, S. Chidambaram, P. Anandhan, S. Vasudevan, Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India, Environ. Monit. Assess., 171 (2010) 595–609.
[34] I.N. Balan, M. Shivakumar, P.D. Madan Kumar, An assessment of groundwater quality using water quality index in Chennai Tamil Nadu, India, Chron. Young Sci., 3 (2012) 146–150.
[35] S. Ahmed, S. Khurshid, F. Qureshi, A. Hussain, A. Bhattacharya, Heavy metals and geo-accumulation index development for groundwater of mathura city, Uttar Pradesh, Desal. Water Treat., 138 (2019) 291–300.
[36] L.A. Richards, Ed., Diagnosis and Improvement of Saline and Alkali Soils, USDA Handbook, No. 60, 1954, p. 160.
[37] G. Fipps, Irrigation Water Quality Standards and Salinity Management Strategies, Texas A&M University System, College Station, Texas, 2003, 20pp.
[38] S.M. Lesch, D.L. Suarez, A Short Note on Calculating the Adjusted SAR Index, American Society of Agricultural and Biological Engineers ISSN 0001-2351, 52 (2009) 493–496.
[39] I. Szabolcs, C. Darab, The Influence of Irrigation Water of High Sodium Carbonate Content of Soils, In: Proceedings of an 8th International Congress of ISSS, Trans., 2 (1964) 802–812.
[40] L.V. Wilcox, Classification and Use of Irrigation Water, US Department of Agriculture, Washington, Circular No. 969, 1955, p. 19.
[41] W.P. Kelly, Permissible Composition and Concentration of Irrigated Waters, In: Proceedings of the A.S.C.F, 66 (1940) 607–613.
[42] L.D. Doneen, Water Quality for Agriculture, Department of Irrigation, University of California, Davis, 1964, 48 p.
[43] Neal Kinsey, 1973, Available at: http://www.kinseyag.com/index.html