



A hydrogeochemical approach to evaluate groundwater quality in the vicinity of three tributaries of the Beas River, North-West India

Jasdeep Singh¹ · Simerpreet Kaur Sehgal¹ · Kuldip Singh² · Didar Singh¹

Received: 8 June 2021 / Accepted: 15 November 2021 / Published online: 29 November 2021
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Abstract

The present study focused on the seasonal investigation of hydro-geochemical characteristics of groundwater samples collected from the vicinity of three tributaries of the Beas River, Punjab, India. Total 45 samples were analyzed during the pre- and post-monsoon season for physico-chemical parameters and heavy metals along with health risk assessment. Results revealed that the majority of samples were below the permissible limits set by the BIS and WHO. The relative abundance of major cations was $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$, while that of the major anions was $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{CO}_3^{2-}$ in the pre- and post-monsoon season, respectively. Groundwater was alkaline and hard in nature at most of the sites. Bicarbonate content exceeded the desirable limit having an average concentration of 337.26 mg/L and 391.48 mg/L, respectively, during the pre- and post-monsoon season. Tukey's multiple comparison test was applied for finding significant differences among samples at $p < 0.05$. The dominant hydrochemical face of water was Ca–Mg– HCO_3 type. US salinity (USSL) diagram indicated that during the pre-monsoon, 48.9% samples were C2S1 type and remaining 51.1% were C3S1 type while during the post-monsoon all samples were C3S1 type. It indicates that groundwater of the study area is at risk of salinity hazards in future and is not to be ignored. Such monitoring studies are recommended to design future safety plans to combat soil and human health risks.

Keywords Hydro-geochemical · Groundwater · Cations · Bicarbonate · Heavy metals · Irrigation

Introduction

Groundwater is the most important source for drinking and irrigation purpose but due to intensive farming, industrial discharge, pollution of rivers, its quality is deteriorating in North-West regions of Punjab, India for survival (Talabi and Kayode 2019; Adimalla et al. 2020). The Beas River, falling in the Northwest of Punjab, India and its tributaries adjoining agricultural fields loaded with contaminants like heavy metals, bicarbonates, chlorides, sulfates etc. due to inefficient agricultural practices (Kumar et al. 2017; Srivastava et al. 2019; Setia et al. 2020). Use of groundwater is very high in India, particularly for irrigation purposes (Singh et al. 2020). Indiscreet consumption and speedy rise of this

contamination in groundwater is threat to supply of good quality water (Kumar and Shah 2006; Gupta et al. 2018; Jain and Mujawar 2019). Groundwater contamination is difficult to assess than that of surface water. It needs regular monitoring as contamination will remain for decades in the subsurface environment (Jha et al. 2020). India is the biggest consumer of groundwater in the world, with an estimated groundwater use of around 230 km³/year (CGWB 2017). The higher use has resulted in depletion of groundwater more prominently in the Punjab state (Krishan et al. 2014). Groundwater is intimately linked to surface water present in the rivers and water received as rainfall also contributes to groundwater reserves. So, pollution of surface water also affects the quality of groundwater (Srivastava et al. 2019).

About 80% of diseases in human beings are directly linked to consumption of polluted water (Ganiyu et al. 2018; Ali and Ahmad 2019). The heavy metals are also one of the major contaminants of water. Exposure to contaminants in groundwater via drinking water and cooked food had led to direct or indirect accumulation in human body resulting in health hazards like respiratory diseases (Jaishankar et al.

✉ Simerpreet Kaur Sehgal
sehgalenv@gmail.com

¹ Department of Soil Science and Agricultural Chemistry, Khalsa College, Amritsar, Punjab 143005, India

² Principal Soil Chemist, Punjab Agricultural University, Ludhiana 141027, India

2014), osteoporosis (Rodriguez and Mandalunis 2018), hypertension (Scheelbeek et al. 2017), dermal problems (Sharma and Bhattacharya 2017), neurological (Bondy and Campbell 2017) and reproductive disorders (Agrawal et al. 2010), etc. According to the data compiled by the Central Groundwater Board (CGWB 2017), the total 2420 number of villages had been found to be affected by heavy metal contamination in India, out of which 2139 had fallen in Punjab (Sharma et al. 2019). The present study was therefore undertaken to investigate the quality of groundwater by determining the various hydro-geochemical characteristics of groundwater in the vicinity of the three tributaries of Beas River falling in Bist-Doab region, namely Pong left main canal, Odhra rivulet and Kali bein and determining the suitability of groundwater for drinking and irrigation purpose.

Materials and methods

Sampling and sample pretreatment

An array of 15 villages (5 villages/tributary) distributed across the study area was selected which are close to confluence of the selected tributaries of the Beas river,

Punjab, India (Fig. 1). Total 90 groundwater samples (45 samples through each season) were collected from tubewells located in these villages (3 sampling sites i.e., $45 \times 3 = 90$) in June 2019 (pre-monsoon) and October 2019 (post-monsoon) from same locations to evaluate the seasonal variations. Samples were collected in clean pre-washed polyethylene bottles around 3–4 times with same groundwater to be collected. Samples were collected after pumping the tubewells for about 10 min so that water previously stored in pipes can be removed (Singh et al. 2013). For estimation of heavy metals such as manganese (Mn), lead (Pb), molybdenum (Mo), nickel (Ni), selenium (Se), aluminum (Al), arsenic (As), copper (Cu), cadmium (Cd), iron (Fe), cobalt (Co) and zinc (Zn), a portion of water sample was acidified with conc. HNO_3 ($\text{pH} < 2$) and rest of the portion were used to analyze different physico-chemical parameters like pH, electrical conductivity (EC), total dissolved solids (TDS) and contents of anions and cations. The groundwater samples were transported in cooled ice box and stored in refrigerator at 5°C until analysis.

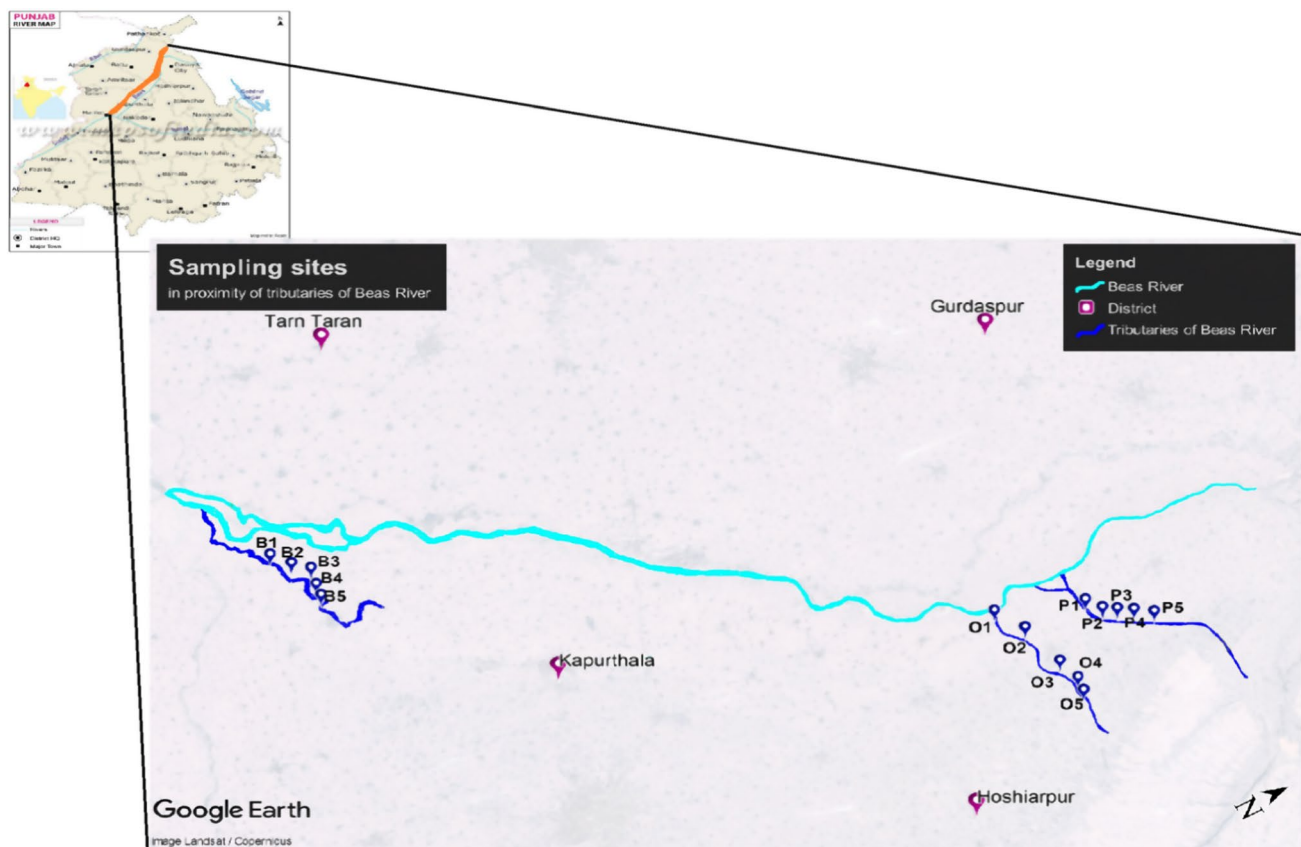


Fig. 1 Location map of sampling sites in the proximity of tributaries of Beas River, India

Physico-chemical analysis of groundwater samples

Physico-chemical parameters of collected groundwater samples were analyzed by following the standard methods (Trivedy et al. 1987; APHA (2017)); The portable kit was used for measuring pH and TDS at sampling sites. Carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and chloride (Cl^-) ions were determined by the titrimetric method while calcium (Ca^{2+}) and magnesium (Mg^{2+}) were quantified using ver-senate method.

First letter in name of each site represents the name of tributary and number represents the code of village as P₁: Sadarpur, P₂: Lamipur, P₃: Jamalpur, P₄: Bhagran, P₅: Sunderpur, O₁: Bhushan, O₂: Pandori Aryian, O₃: Odhra, O₄: Takipur, O₅: Sajjan, B₁: Sarupwal, B₂: Alluwal, B₃: Bussowal, B₄: Miani Bahadur, B₅: Tarf Hazi

Sulfate (SO_4^{2-}) was determined by turbidimetric method (Sheen et al. 1935) using colorimeter (make: Systronics; model: 115) at a wavelength of 420 nm with a blue filter. Na^+ and K^+ contents in samples were analyzed using flame photometer (make: Systronics; model: 130).

Heavy metal analysis of groundwater samples

Heavy metals were determined in water samples by following standard method used by Oyekanmi et al. 2018 using microwave plasma-atomic emission spectrometer (make: Agilent; model- 4200). Before determination of concentration of heavy metals, water samples were filtered using Whatman filter paper no. 42 (Sharma et al. 2019).

Reagents and quality control

The chemicals and reagents used for analyzing physico-chemical parameters and heavy metal contents in present study were of analytical grade. Stock standard solutions (Agilent technologies, USA) were used to draw calibration curves for determination of heavy metal content in samples. Double distilled water was used at regular intervals to run instrument for washing to avoid the deposition of any analyst inside it.

Water quality assessment

Groundwater samples were categorized into various classes for irrigation and drinking purposes on the basis of physico-chemical parameters such as total dissolved solids (TDS) and total hardness (TH) etc. The hardness of water is due to dissolution of salts of Ca^{2+} and Mg^{2+} .

So, to determine TH, we have estimated Ca^{2+} and Mg^{2+} contents in water samples.

Hem (1989) had given following formula for calculating TH of water:

$$\text{TH (as CaCO}_3\text{) mg/L} = (\text{Ca}^{2+} + \text{Mg}^{2+}) \text{ meq/L} \times 50 \quad (1)$$

Groundwater samples can also be classified on the basis of indices such as electrical conductivity (EC), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), Kelly's ratio (KR), magnesium ratio (MR), permeability index (PI), corrosivity ratio (CR) and sodium percentage (Na%). Suitability of groundwater samples for drinking and irrigation purposes was determined by keeping in consideration the standard limits given by WHO (2011) and BIS (2012).

Sodium adsorption ratio (SAR) is used for estimating sodium hazard to crops and to classify groundwater to check its suitability for irrigating crop fields (Gholami and Sri-kantaswamy 2009). SAR values of all groundwater samples were estimated by using the equation given by Richards 1954 as:

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

Todd (1995) had given following equation to calculate sodium percentage (Na%) in water:

$$\text{Na\%} = \frac{(\text{Na}^+ + \text{K}^+) \times 100}{\text{Ca}^+ + \text{Mg}^+ + \text{Na}^+ + \text{K}^+} \quad (3)$$

Magnesium ratio (MR) was evaluated using following formula (Palliwai 1972):

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

Kelly's ratio (KR) was calculated by using equation given by Kelley (1946) which is expressed as follows:

$$\text{KR} = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+}} \quad (5)$$

Residual sodium carbonate (RSC) is the measure of excessive amount of sodium bicarbonate and carbonate over Ca^{2+} and Mg^{2+} which has affect on physical properties like pH, EC and SAR of the soil by dissolution of organic matter (Naseem et al. 2010). It has been evaluated using the following equation (Ragunath 1987):

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (6)$$

Corrosivity ratio (CR) is used to check the corrosiveness of water. It was evaluated using following equation (Raman 1985):

$$CR = \frac{\left[\frac{Cl^-}{35.5} + 2 \left(\frac{SO_4^{2-}}{96} \right) \right]}{2 \frac{(HCO_3^- + CO_3^{2-})}{100}} \quad (7)$$

Permeability index (PI) is a qualitative measure of rate of vertical movement of water from the ground surface through unsaturated zone to the subsurface layers of the soil (Kumar 2016; Rawat et al. 2018). It is given as:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (8)$$

Health risk assessment

Health risk assessment is essential to check the suitability of groundwater for drinking purposes. The US Environmental Protection Agency (USEPA 2004) had given following two equations to measure the exposure dose (E) through ingestion and potential non-carcinogenic risk of Hazard Quotient (HQ):

$$E = \frac{CPW \times IR \times ED \times EF}{ABW \times AET} \quad (9)$$

$$HQ = \frac{E}{RfD} \quad (10)$$

where E: chronic daily intake (mg/kg/day), CPW: concentration of contaminant (mg/L), IR: human ingestion rate (L/day: 0.78 L/day for children and 2.5 L/day for adults), ED: exposure duration (years: 12 and 64 for children and adults, respectively), EF: exposure frequency (days/years: 365 days for children and adults), ABW: average body weight (Kg: 18.7 and 57.5 for children and adults, respectively), AET: average time (days: 4380 and 23360 for children and adults, respectively), HQ: Hazard quotient, RfD: reference dose of pollutant (Adimalla and Qian 2019).

Statistical analysis

Analysis of variance (ANOVA) was applied on physico-chemical parameters and heavy metal content to assess variation among location and season of sampling site at $p < 0.05$ using SPSS 16.0 software. Further, Tukey's multiple comparison test was used to confirm significant differences among samples at $p < 0.05$.

Results and discussion

Physico-chemical analysis

All the tributaries were in the Bist-Doab region where groundwater level falls systematically in various regions over the last two decades. The pH of the studied samples was within the maximum permissible limits given by WHO and BIS during both the pre- and post-monsoon season (Kamble and Saxena 2016). All the groundwater samples of both seasons were alkaline (average of 7.80 and 7.96) in nature. Dissolution of primary CO_3^- and silicate minerals after monsoon had led to increase in concentration of Ca^{2+} , Na^+ , Mg^{2+} and HCO_3^- which had raised the value of pH (Rouabhia et al. 2011). During each season, values of EC remained higher than the permissible value of 250 $\mu S/cm$ (WHO 2011). All samples have shown higher EC ($\mu S/cm$) values than permissible limits, i.e., 750.80 (pre-monsoon) and 891 (post-monsoon). TDS in mg/L of all the samples was observed to be less than the permissible limits set by WHO (2011) and BIS (2012) with average value of 316.09 (pre-monsoon) and 406.18 (post-monsoon). It was noticed a small increase in EC and TDS in the post-monsoon season than in pre-monsoon season.

It has been reported that leaching and dissolution or mixing of salts due to geochemical or anthropogenic activities was responsible for this variation in the study area (Sharma et al. 2017; Subba Rao et al. 2017a; et al. 2017). During summer, the water present in the interspaces of soil get evaporated and salts were accumulated in upper layer of the soil which were leached back again during monsoon period had resulted high EC and TDS values (Singh et al. 2013).

Total hardness (TH) of all the samples in the pre-monsoon was below the permissible limit but in the post-monsoon season, 31 samples of groundwater have high TH values than desirable value of 200 mg/L as per BIS (2012). It was probably due to increase in Ca^{2+} and Mg^{2+} ions in the studied samples. The pre-monsoon value (mg/L) of Ca^{2+} were ranged from 24.67 to 31.33 having average value 27.56 while in post-monsoon season it was from 31.33 to 41.33 having average value of 36.58. The Mg^{2+} concentration (mg/L) in the post-monsoon ranged from 19.60 to 28.40 having average value of 24.00 while in the post-monsoon it was from 22.80 to 29.20 with mean concentration of 26.27. The CO_3^{2-} content was negligible in both the seasons of the study area while HCO_3^- was found beyond desirable limit in all the 45 samples having average concentration (mg/L) of 337.26 and 391.48 in the pre- and post-monsoon season, respectively. The carbonic acid helps in initiating acid-base reactions and

fastens the weathering of rocks like limestone (CaCO_3) and dolomite [$\text{CaMg}(\text{CO}_3)_2$] present in the study areas and similar results had been reported by Singh et al. 2013; Humbarde et al. 2014; Dev and Bali 2018. Due to this weathering process, the concentration of Ca^{2+} and Mg^{2+} were also increased after the monsoon (Sharma and Chhipa 2016; Sharma et al. 2019). The abundance of major cations was in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$, respectively, in the pre- and post-monsoon season. On the other hand, abundance of major anions was in the order of $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{CO}_3^{2-}$ in both the pre- and post-monsoon seasons as similarly reported by Humbarde et al. 2014; Thakur et al. 2016. The mean concentration of chloride (Cl^-) in the study area was found to be 42.08 and 54.21 (mg/L) in the pre- and post-monsoon season, respectively. The high concentration of Cl^- could be due to the addition of sewage effluents directly into the tributary water and utilizing that water for irrigation (Saraswat et al. 2019). Leaching of salts along with rainwater was also reported as one of the main reasons behind high chloride concentration (Purushothaman et al. 2012; Pathak et al. 2014). Both the K^+ and Na^+ ions were found in concentrations (mg/L) lower than permissible limits having mean value of 11.80 and 12.20 for K^+ and 24.22 and 26.88 for Na^+ in the pre- and post-monsoon season, respectively. High concentration of K^+ was noticed in the post-monsoon season may be due to weathering of saltpetre during the rainy season (Kumar et al. 2013). The average value (mg/L) of SO_4^{2-} was 68.90 in the pre- and 78.85 during the post-monsoon, was lower than the permissible limit. The presence of high SO_4^{2-} ion during the post-monsoon may be due to leaching, breakdown of organic matter in soil, excess use of fertilizers and anthropogenic activities. Similar findings were documented by Ganiyu et al. 2018 and Hejaz et al. 2020 in their studies.

Heavy metal analysis

The heavy metal content in samples of study areas during both the pre- and post-monsoon season is represented in Table 1. The average concentration of Fe, Al, Mn, Cu, As and Se in samples to be 0.30 mg/L, 0.02 mg/L, 0.02 mg/L, 0.03 mg/L, 0.19 $\mu\text{g/L}$ and 0.78 $\mu\text{g/L}$, respectively during pre-monsoon and 0.33 mg/L, 0.03 mg/L, 0.03 mg/L, 0.03 mg/L, 0.25 $\mu\text{g/L}$ and 0.84 $\mu\text{g/L}$, respectively, during the post-monsoon. Main sources of heavy metals in the present study area were due to indiscriminate use of agrochemicals and leaching of heavy metals along with the rainwater as reported by Sharma et al. 2019 and Virk 2019. Selenium was found in more concentration mainly at sites near Kali Bein, for the unknown reason but had predicted to be due to Se rich soil in that area (Bajaj et al. 2011). It has also been reported in groundwater due to weathering, leaching

and oxidation of soluble selenium compounds (Virk 2018). Though, selenium has an essential role in human health but at the same time toxicity had been reported at higher concentrations (Dhillon and Dhillon 2003) in Punjab. There was no reason behind occurrence of As contamination in Punjab (Virk 2019). The aluminum was reported naturally as oxides, hydroxides and silicates or as a complex with organic matter. The samples with negligible concentrations of Zn, Cd, Co, Pb, Mo and Ni in both the seasons were observed in the present study.

3.3 Statistical analysis

One-way ANOVA is used for assessment of variation during the pre- and post-monsoon season in physico-chemical parameters as well as for the heavy metal content. It is necessary to evaluate the level of difference over change in sampling sites for both the seasons (pre- and post-monsoon) and their interaction. The heavy metals which were below detection limits were not used for statistical analysis. Results had shown statistically significant difference for most of the parameters at $p < 0.05$ (Tables 2, 3 and 4) (Kumar et al. 2016). The significant difference was observed due to different sampling locations, leaching of agrochemicals, influence of river and tributary water, inputs via industrial and domestic waste in groundwater.

Groundwater quality for drinking purpose

The water samples have been evaluated for suitability for drinking purpose based on the guidelines given by WHO (2011). It was noticed that values of water quality parameter and number of samples exceeding desirable limits (DL) and maximum permissible limits (MPL) set by the WHO (2011) and their health implications are given in Table 5. The suitability of studied water samples for drinking was examined from its TDS, TH and ionic concentration which is explained under following headings:

Total dissolved solids (TDS)

Total dissolved solids are regarded as one of the major determinants for studying suitability of drinking water. As per WHO, TDS value higher than 1000 mg/L along with high pH value resulted in unpleasant taste. Groundwater samples were classified into six classes on the basis of TDS (Singh et al. 2013) as: excellent, good, fair, poor and unacceptable. TDS value (mg/L) ranged from 272.33 to 378.33 with an average value of 316.09 and from 320.00 to 475.00 with an average value of 406.18 for the pre- and post-monsoon samples, respectively. Out of the total 45 samples collected during the each season, 15 samples were under excellent class while remaining 30 samples were under good class for the pre-monsoon while in the post-monsoon season, all samples were under good class (Table 6). Similar findings were observed by Krishan et al. 2014 and Rao et al. 2017.

Table 1 Physico-chemical parameters of groundwater samples collected from the proximity of tributaries of Beas River, India

Parameter	Pre-monsoon					Post-monsoon								
	Max desirable limit	Maximum permissible limit	Max	Min	Mean	Std dev	No. of sample > than desirable limit (BIS)	No. of samples > than permissible limit (BIS)	Max	Min	Mean	Std. dev	No. of samples > than desirable limit (BIS)	No. of samples > than permissible limit (BIS)
pH	6.5–8.5	–	8.13	7.53	7.81	0.06	–	–	8.23	7.70	7.96	0.06	–	–
EC	–	–	937.67	615.67	750.80	21.23	45	45	1072.67	785.67	891.00	18.89	45	45
TDS	500	2000	378.33	272.33	316.09	11.99	0	0	475.00	320.00	406.18	11.35	0	0
TH	200	600	190.00	145.00	168.89	3.96	0	0	211.67	180.00	200.89	5.53	31	0
CO ₃ ²⁻	75	200	Nil	Nil	Nil	Nil	0	0	Nil	Nil	Nil	Nil	–	–
HCO ₃ ⁻	30	500	422.93	260.27	337.26	14.09	45	0	471.73	325.33	391.48	11.27	45	0
Ca ²⁺	75	200	31.33	24.67	27.56	1.34	0	0	41.33	31.33	36.58	2.06	0	0
Mg ²⁺	30	100	28.40	19.60	24.00	0.75	0	0	29.20	22.80	26.27	1.70	3	0
Cl ⁻	250	1000	53.67	26.83	42.08	2.16	0	0	65.33	44.33	54.21	1.89	0	0
SO ₄ ²⁻	200	400	101.50	35.25	68.90	6.20	0	0	114.13	46.50	78.85	3.68	0	0
Na ⁺	–	200	28.47	16.20	24.22	1.05	–	0	30.26	19.50	26.88	1.09	–	0
K ⁺	–	–	14.80	9.15	11.80	0.55	0	0	15.25	9.44	12.20	0.50	–	–
Fe	0.3	–	0.44	0.11	0.30	0.02	23	–	0.52	0.16	0.33	0.02	26	–
Al	0.03	0.2	0.05	0.01	0.02	0.00	9	0	0.06	0.02	0.03	0.00	19	0
Se	10	–	1.38	0.44	0.78	0.04	0	0	1.43	0.49	0.84	0.04	0	0
As	10	50	0.44	0.00	0.19	0.01	0	0	0.57	0.01	0.25	0.01	0	0
Cu	0.05	1.5	0.04	0.01	0.03	0.00	0	0	0.04	0.02	0.03	0.00	0	0
Mn	0.1	0.3	0.04	0.01	0.02	0.00	0	0	0.05	0.01	0.03	0.00	0	0
Zn	5	15	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–
Cd	0.003	–	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–
Co	–	1.5	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–
Pb	0.01	–	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–
Mo	0.07	–	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–
Ni	0.02	–	Nil	Nil	Nil	Nil	–	–	Nil	Nil	Nil	Nil	–	–

All values in mg/L except pH (unitless), EC (µS/cm), As (µg/L) and Se (µg/L)

Table 2 One-way ANOVA and Tukey’s multiple comparison tests for water quality parameters of samples collected from the proximity of tributaries of Beas River, India for pre-monsoon period (June, 2019)

Parameters	Tributaries			F-ratio ($p < 0.05$)	LSD ($p < 0.05$)
	Pong left main canal Mean \pm SD	Odhra rivulet Mean \pm SD	Kali Bein Mean \pm SD		
pH	7.71 ^c \pm 0.06	7.91 ^a \pm 0.06	7.81 ^b \pm 0.07	112.50*	0.03
EC	781.27 ^a \pm 13.24	712.33 ^c \pm 22.92	758.80 ^b \pm 27.54	32.32*	21.43
TDS	345.93 ^a \pm 10.42	300.40 ^b \pm 12.42	301.93 ^b \pm 13.13	48.69*	12.82
HCO ₃ ⁻	341.60 ^b \pm 14.09	359.49 ^a \pm 14.09	310.69 ^c \pm 14.09	345.50*	4.60
Cl ⁻	35.70 ^c \pm 2.02	47.83 ^a \pm 2.02	42.70 ^b \pm 2.42	204.40*	1.47
SO ₄ ²⁻	59.28 ^b \pm 5.37	87.35 ^a \pm 7.82	60.08 ^b \pm 5.41	83.98*	6.03
Ca ²⁺	26.93 ^a \pm 1.15	27.87 ^a \pm 1.09	27.87 ^a \pm 1.77	1.26	NS
Mg ²⁺	22.40 ^b \pm 0.79	26.48 ^a \pm 0.79	23.12 ^b \pm 0.66	74.10*	0.88
Na ⁺	20.67 ^c \pm 1.01	26.59 ^a \pm 1.02	25.40 ^b \pm 1.12	182.53*	0.80
K ⁺	10.51 ^c \pm 0.84	12.89 ^a \pm 0.42	11.99 ^b \pm 0.40	36.65*	0.69
TH	160.67 ^c \pm 3.73	180.00 ^a \pm 3.31	166.00 ^b \pm 4.84	62.60*	4.37
RSC	2.39 ^a \pm 0.22	2.29 ^a \pm 0.22	1.77 ^b \pm 0.27	98.29*	0.12
Mg ratio	57.96 ^b \pm 1.62	61.28 ^a \pm 1.44	58.05 ^b \pm 1.59	10.81*	1.96
SAR	0.71 ^b \pm 0.03	0.86 ^a \pm 0.03	0.86 ^a \pm 0.04	129.27*	0.03
Fe	0.39 ^a \pm 0.03	0.33 ^b \pm 0.02	0.16 ^c \pm 0.02	134*	0.03
Al	0.02 ^b \pm 0.01	0.03 ^a \pm 0.00	0.02 ^b \pm 0.00	299*	0.01
Se	0.57 ^b \pm 0.02	0.59 ^b \pm 0.03	1.23 ^a \pm 0.06	1773*	0.03
Cu	0.02 ^c \pm 0.00	0.03 ^b \pm 0.00	0.07 ^a \pm 0.00	2590*	0.01
As	0.17 ^b \pm 0.00	0.35 ^a \pm 0.02	0.01 ^c \pm 0.00	2448*	0.01
Mn	0.02 ^b \pm 0.00	0.03 ^a \pm 0.00	0.01 ^c \pm 0.00	707*	0.01

All values in mg/L except pH (unitless), EC(μ S/cm), RSC (meq/L), Mg ratio (meq/L), SAR (meq/L), As (μ g/L) and Se (μ g/L)

Similar alphabets in a row indicates no significant difference between the means at $p < 0.05$

NS, not significant at $p < 0.05$,

*Indicates significant at $p < 0.05$

Total hardness (TH)

Total hardness (mg/L) ranged from 145 to 190 for pre-monsoon and from 180.00 to 211.67 for the post-monsoon season. The TH of samples were observed as: post-monsoon season > pre-monsoon. Further, the classification of samples based on TH (Sawyer and McCarty 1967) has shown that 4 samples were under moderately hard class and 41 samples were under hard class during pre-monsoon while in the post-monsoon season all the 45 samples fall under hard class (Table 7).

Health risk assessment

Health risk assessment characterizes the adverse health effects caused by exposure of pollutants on children and adults (Adimalla and Qian 2019). Drinking is the most prominent factor of ingestion of the heavy metals through contaminated groundwater (Chen et al. 2016). In the present study, Fe exceeded the desirable limits (DL) (WHO 2011). Fe concentration was more than DL in 23 water samples

and 26 samples, collected, respectively, in the pre-monsoon and post-monsoon season. On the other hand, concentration of As and Se was found lower than DL during both seasons. The health risk assessment of these heavy metals was determined by calculating the hazard quotient (HQ). The calculations were done on the basis of standards given by USEPA (2004). The results of the health risk assessment are shown in Table 8. The HQ values for As during the pre-monsoon were ranged from 0 (B₃) to 6.12E-02 (O₅) for children and 0 (B₃) to 6.38E-02 (O₅) for adults while in the post-monsoon, it was ranged from 1.39E-03 (B₃) to 7.93E-2 (O₅) for children and from 1.45E-03 (B₃) to 8.26E-02 (O₅) for adults. On the other hand, results had shown that the HQ values for Fe during the post-monsoon ranged from 6.36E-03 (B₁) to 2.64E-02 (P₃) for children and from 6.63E-03 (B₁) to 2.75E-02 (P₃) for adults while it ranged from 9.53E-03 (B₂) to 3.10E-02 (P₃) for children and from 9.94E-03 (B₂) to 3.23E-02 (P₃) for adults during the pre-monsoon. While in case of Se, the HQ values ranged from 3.67E-03 (O₁) to 1.15E-02 (B₅) for children and from 3.83E-03 (O₁) to 1.20E-02 (B₅) for adults during the pre-monsoon while during the

Table 3 One way- ANOVA and Tukey's multiple comparison tests for water quality parameters of samples collected from the proximity of tributaries of Beas River, India for the post-monsoon period (October, 2019)

Parameters	Tributaries			F-ratio ($p < 0.05$)	LSD ($p < 0.05$)
	Pong left main canal Mean \pm SD	Odhra rivulet Mean \pm SD	Kali Bein Mean \pm SD		
pH	7.87 ^c \pm 0.05	8.06 ^a \pm 0.06	7.94 ^b \pm 0.07	31.79*	0.06
EC	916.87 ^a \pm 19.16	866.60 ^c \pm 13.15	889.53 ^b \pm 24.35	33.72*	15.00
TDS	450.07 ^a \pm 14.45	403.40 ^b \pm 10.67	365.07 ^c \pm 8.94	141.83*	12.37
HCO ₃ ⁻	383.89 ^b \pm 11.27	411.55 ^a \pm 14.09	379.01 ^b \pm 8.45	58.17*	7.96
Cl ⁻	50.87 ^c \pm 2.02	58.57 ^a \pm 2.02	53.20 ^b \pm 1.62	50.53*	1.92
SO ₄ ²⁻	68.88 ^b \pm 5.50	98.13 ^a \pm 4.16	69.55 ^b \pm 1.39	147.61*	4.76
Ca ²⁺	35.73 ^a \pm 2.77	36.27 ^a \pm 1.55	37.73 ^a \pm 1.85	1.44	NS
Mg ²⁺	26.16 ^{ab} \pm 1.84	27.52 ^a \pm 1.67	25.12 ^b \pm 1.57	5.30*	1.81
Na ⁺	24.13 ^b \pm 0.82	28.38 ^a \pm 1.33	28.14 ^a \pm 1.13	107.66*	0.80
K ⁺	10.88 ^c \pm 0.72	13.32 ^a \pm 0.42	12.41 ^b \pm 0.37	51.04*	0.60
TH	198.33 ^a \pm 5.84	205.33 ^a \pm 4.84	199.00 ^a \pm 5.92	3.22	NS
RSC	2.33 ^b \pm 0.21	2.64 ^a \pm 0.22	2.23 ^b \pm 0.22	17.71*	0.18
Mg ratio	54.89 ^a \pm 3.35	55.82 ^a \pm 2.42	52.66 ^a \pm 2.11	3.15	NS
SAR	0.75 ^b \pm 0.03	0.86 ^a \pm 0.04	0.87 ^a \pm 0.03	210.17*	0.02
Fe	0.42 ^a \pm 0.02	0.36 ^b \pm 0.03	0.21 ^c \pm 0.01	415*	0.02
Al	0.02 ^c \pm 0.00	0.04 ^a \pm 0.00	0.03 ^b \pm 0.00	107*	0.01
Se	0.62 ^b \pm 0.02	0.66 ^b \pm 0.05	1.31 ^a \pm 0.04	657*	0.05
Cu	0.03 ^a \pm 0.00	0.02 ^a \pm 0.00	0.03 ^a \pm 0.00	268*	NS
As	0.24 ^b \pm 0.01	0.44 ^a \pm 0.03	0.03 ^c \pm 0.00	1396*	0.02
Mn	0.02 ^b \pm 0.00	0.04 ^a \pm 0.00	0.02 ^b \pm 0.00	27.1*	0.01

All values in mg/L except pH (unitless), EC (μ S/cm), RSC (meq/L), Mg ratio (meq/L), SAR (meq/L), As (μ g/L) and Se (μ g/L)

Similar alphabets in a row indicates no significant difference between the means at $p < 0.05$

NS, not significant at $p < 0.05$

*indicates significant at $p < 0.05$

post-monsoon, it was ranged from 4.09E-03 (O_1) to 1.19E-02 (B_5) for children and from 4.26E-03 (O_1) to 1.24E-02 (B_5) for adults. It is a scientific fact that the $HQ < 1$ indicates no certain non-carcinogenic risk (USEPA 2004; Koki et al. 2015; Vetrimerugan et al. 2017; Victor et al. 2018). It was noticed that the HQ value for As, Fe and Se was found less than 1 in all the samples which showed that the contamination was below risk level in the study area for both the adults and children.

Groundwater quality for irrigation purpose

The quality of the groundwater for the irrigation purposes has been given by the different experts. However, the most important parameters to determine suitability of the water samples were EC, SAR, Na%, RSC, MR, CR, PI and KR (Tripathi et al. 2012). The classification of groundwater samples for their suitability for irrigation purpose is given in Table 9.

In addition, the suitability of the water samples for irrigation purpose was determined by plotting data on various

scientific diagrams which included USSL diagram, Wilcox diagram and Piper Diagram which are explained in the following discussion.

Salinity hazard (EC)

Wilcox (1955) had given classification of the groundwater on the basis of salinity hazard (EC) to check its suitability for irrigation purposes. He had classified the groundwater samples into five classes. After analyzing, it was observed that 22 groundwater samples were under good class and 23 samples were in permissible class during the pre-monsoon while during the post-monsoon all the samples collected from the study area were found in permissible class. Thus, results have shown that salinity get increased after the monsoon season which might had been due to the leaching of salts from upper layer of the soil into the groundwater table (Vinod et al. 2009; Ahamed et al. 2015). Value of the EC had been reported to rise with increase in TDS of groundwater (Adimalla and Venkatayogi 2018).

Table 4 Two-way ANOVA for water quality parameters of samples collected in the proximity of tributaries of Beas River, India

Parameters	F- ratios			LSD ($p < 0.05$)
	Sites	Seasons	Sites \times season	
pH	41.91*	126.18*	0.62	0.10
EC	75.03*	824.76*	1.63	37.85
TDS	49.59*	1182.59*	10.87*	20.31
HCO ₃ ⁻	61.90*	359.36*	2.44*	22.18
Cl ⁻	54.21*	749.99*	5.01*	3.43
SO ₄ ²⁻	53.15*	60.39*	0.97	9.91
Ca ²⁺	8.73*	566.65*	2.80*	2.94
Mg ²⁺	13.10*	54.15*	2.69*	2.39
Na ⁺	48.25*	106.75*	1.22	2.00
K ⁺	40.30*	9.16*	0.05	1.05
TH	28.79*	885.31*	4.81*	8.34
RSC	47.93*	24.98*	3.49*	0.39
Mg ratio	5.99*	82.64*	2.08*	3.96
SAR	53.55*	2.86	1.87*	0.06
Fe	133.38*	48.90*	3.60*	0.04
Al	193.97*	173.10*	16.14*	3.19
Se	295.40*	40.67*	0.47	0.08
Cu	859.65*	686.71*	1098.43*	2.93
As	446.56*	189.46*	6.73*	0.03
Mn	139.95*	250.35*	1.13	3.07

Similar alphabets in a row indicates no significant difference between the means at $p < 0.05$

NS, not significant at $p < 0.05$

*Indicates significant at $p < 0.05$

Alkalinity hazard (SAR)

High concentration of Na⁺ relative to Ca²⁺ and Mg²⁺ had been reported to reduce water supply to crop by decreasing soil permeability and the soil texture. SAR values in study the area were observed to be less than 10 in both seasons. So, the water samples collected in the both the seasons were under excellent category. Table 9 represents that the groundwater in study area was suitable for the irrigation purpose in the both the pre-monsoon and the post-monsoon season.

Sodium percentage (Na%)

It was reported that sodium reduces the permeability of soil by reacting with the ions (Ca²⁺ and Mg²⁺) present in the soil (Selvakumar et al. 2014). Na⁺ ion was absorbed by the clay particles and destroyed the structure of the soil (Singh et al. 2015). So, classification of the water on the basis of the sodium percentage is an important parameter to check its suitability for irrigation purposes.

Wilcox (1955) had classified the water samples into five classes on the basis of Na% to evaluate their suitability for

the irrigation purpose (Table 9). After analyzing samples, it was observed that all the water samples collected during both the seasons were under good class and suitable for irrigation use.

Magnesium ratio (MR)

Groundwater was classified into suitable (>50%) and unsuitable class (<50%) based on MR value (Khodapanah et al. 2009). Mostly Mg²⁺ and Ca²⁺ are present in equilibrium concentration with respect to each other. But if Mg²⁺ content is higher in water then it was observed that soil becomes alkaline and adversely affected the crop yield (Nagaraju et al. 2014; Kumar et al. 2017). After analysis, it was noticed that all the 45 samples collected from study area during the pre-monsoon were found suitable but during the post-monsoon season, 42 samples fall in the suitable class and remaining 3 samples fall in the unsuitable class (Table 9). The high amounts of Mg²⁺ ion at few places were due to the high dissolution of dolomite mineral after monsoon as reported in earlier study (Singh et al. 2020).

Kelly's ratio (KR)

The Kelly's ratio more than 1 is an indication of alkali hazard (Karanth 1987; Bhat et al. 2018). It was observed that all the samples collected during both the seasons were in the suitable category (Table 9). So, according to classification based on KR, the water of study area was found to be suitable for irrigation. Further it was observed that presence of low sodium content was good for permeability and structure of the soil (Ramesh and Elango 2012; Patel and Vadodaria 2013).

Residual sodium carbonate (RSC)

The presence of RSC in water had resulted darkening of upper soil surface, burning of foliage which had resulted in reduce crop yield (Toumi et al. 2015). It was observed that out of total 45 samples, 29 samples were fit and 16 samples were marginal during the pre-monsoon while during the post-monsoon season, 23 samples were fit and 22 samples fell in marginal class (Table 9). Results have indicated that HCO₃⁻ content gets increased with respect to Ca²⁺ and Mg²⁺ after the rainy season which could be due to excessive leaching of HCO₃⁻ ions from upper layer to lower layers of soil. Nishanthiny et al. (2010) and Bhat et al. (2018) also had evinced similar results in their studies.

Corrosivity ratio (CR)

Water is considered safe if its CR value is less than 1 while the value more than 1 denotes corrosive nature of

Table 5 Guideline values (WHO 2011) for drinking water along with number of samples exceeding maximum permissible limit (MPL) and desirable limit (DL) and health implications

Parameter	WHO standard (2011)		Number of samples > DL		Number of samples > MPL		Health implications if present beyond MPL	References
	Desirable limit (DL)	Maximum permissible limit (MPL)	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon		
pH	6.5–8.5	–	0	0	–	–	Objectionable taste and affect mucus membrane permeability	Sharma and Bhattacharya 2017
TH	75	150	45	45	41	45	Formation of scales, calcification of arteries, urinary concretions and stomach disorder	Sharma et al. 2017
TDS	500	1500	0	0	0	0	Gastrointestinal problems in human and decrease in palatability	Adimalla and Qian 2019
Ca ²⁺	75	200	0	0	0	0	Concretions in kidney, irritation in urinary system, severe rickets	Magesh and Chandrasekar 2013
Mg ²⁺	30	150	0	0	0	0	Laxative, cathartic and diuretic effects	Baaij et al. 2015
Fe	0.3	1	23	26	0	0	Promotes bacterial growth in body and affects enzyme system	Engwa et al. 2019
As	10	–	0	0	–	–	Cancer of lungs, kidney, urinary bladder, skin and also cause hyperkeratosis	Fowler et al. 2015
Cu	–	2	0	0	0	0	Intake of copper in excess can cause vomiting, diarrhea, stomach cramps, etc	Taylor et al. 2020
Mn	–	0.1	0	0	0	0	Adversely affects enzymatic activity	Kshetrimayum and Hegeu 2016
Se	10	40	0	0	0	0	Chronic or acute selenosis	Bajaj et al. 2011
Al	0.03	–	9	19	–	–	Neurodegenerative effects, especially Alzheimer disease	Virk 2018

All standard limits in mg/L except pH (unitless), As ($\mu\text{g/L}$) and Se ($\mu\text{g/L}$)

Table 6 Classification of groundwater samples WHO (2011) collected from the proximity of Beas River, India

TDS (mg/L)	Water class	Number of samples	
		Pre-monsoon	Post-monsoon
<300	Excellent	15	0
300–600	Good	30	45
600–900	Fair	0	0
900–1200	Poor	0	0
>1200	Unacceptable	0	0

Table 7 Classification of groundwater samples collected from the proximity of Beas River, India

Total hardness (TH) (mg/L)	Water class	Number of samples	
		Pre-monsoon	Post-monsoon
<75	Soft	0	0
75–150	Moderately hard	4	0
150–300	Hard	41	45
>300	Very hard	0	0

water as per Tripathi et al. 2012. The CR value indicated non-corrosive nature of all the 45 water samples collected during both the seasons as represented in Table 9. As a result of CR value, groundwater of this area is advised to be safely uplifted and transported by pipes.

US salinity diagram (USSL 1954)

US salinity diagram (USSL) was used to access the suitability of water samples for irrigation use (USSL 1954) in this studied area. It is based on EC and SAR values of water samples. On the basis of this diagram, groundwater was classified into: C1, C2, C3 and C4 types on the basis of salinity hazard (EC) and S1, S2, S3 and S4 types on the basis of sodium hazard (SAR) (Lokhande and Mujawar 2016). The groundwater data of study area were plotted using Grapher software (version: 16.2.354) which illustrates in Fig. 2 that out of total 45 samples collected in the pre-monsoon, 48.9% samples are C2S1 type and remaining 51.1% samples are C3S1 type having medium salinity—low sodium hazards and high salinity—low sodium hazards, respectively, while during the post-monsoon, all the samples were C3S1 type having high salinity—low sodium hazards. So, leaching of salts is required to eliminate salinity hazard so that all crops can be produced efficiently (Bhandari and Joshi 2013; Adimalla et al. 2018, 2020).

Wilcox diagram (Wilcox 1955)

The Wilcox (1955) had given a diagram to evaluate the suitability of water for irrigation purpose by classifying into various classes on the basis of values of EC and Na% (Singh et al. 2020). The samples had been classified into five classes: excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable. Diagrams software (version- 6.61) was used to plot the Wilcox diagram which illustrates that out of the total 45 samples collected during the pre-monsoon season, 71.1% samples are in excellent to good class and remaining 28.9% samples are in good to permissible class whereas, during the post-monsoon season, only 17.8% samples fall in excellent to good class and the remaining 82.2% samples are in good to permissible class as reported in earlier study (Singh et al. 2020). The results are represented in Fig. 3 illustrating that groundwater of the study area was good to be used for irrigation purposes during both the seasons.

Geochemical classification of groundwater (Piper diagram)

Piper (1944) had given trilinear diagram for geochemical analysis of groundwater. It has two equilateral triangle fields (i.e., cations, anions) and one central diamond-shaped field (Oki and Akana 2016). The major ion data collected was plotted in a Piper diagram using Grapher software (version- 16.4.432) which is represented in Fig. 4a, b. During both the seasons, cation triangle indicates, all the samples fall in no dominant type region but the anion triangle shows that HCO_3^- was dominant among anions and all the samples are in HCO_3^- type zone. The resultant diamond-shaped field has shown that all the samples were Ca–Mg– HCO_3 type tributaries. Thus, there was no variation in geochemical faces in water samples during both the seasons and Kaur et al. (2017) had also observed similar results. The Ca^{2+} ion was present in the form of Kankar in this region while Mg^{2+} and HCO_3^- were supposed to be present due to the influence of Beas River (Purushothaman et al. 2013). High content of Ca^{2+} had been reported due to dissolution of agrochemicals during the monsoon (Singh et al. 2013). The main source of Mg^{2+} ion had been documented due to presence of dolomite. Further, HCO_3^- ion had been found in excess due to its leaching, bacterial oxidation of organic matter through aerobic and anaerobic complex chemical reactions and dissolution of CO_3^{2-} -rich minerals (Sharma et al. 2017).

Conclusions

The interpretation of hydro-geochemical analysis of the study area in the proximity of tributaries of Beas River, Punjab has revealed that the quality of groundwater was

Table 8 Health risk assessment (HQ values) of heavy metals (As, Fe, Se) for children and adults

Sample code	Arsenic (As)				Iron (Fe)				Selenium (Se)			
	Pre		Post		Pre		Post		Pre		Post	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
P ₁	2.22E-02	2.32E-02	3.61E-02	3.77E-02	1.97E-02	2.05E-02	2.15E-02	2.24E-02	4.67E-03	4.87E-03	5.17E-03	5.39E-03
P ₂	2.50E-02	2.61E-02	4.03E-02	4.20E-02	2.26E-02	2.36E-02	2.56E-02	2.67E-02	4.00E-03	4.17E-03	4.42E-03	4.61E-03
P ₃	2.09E-02	2.17E-02	2.64E-02	2.75E-02	2.64E-02	2.75E-02	3.10E-02	3.23E-02	4.25E-03	4.43E-03	4.50E-03	4.70E-03
P ₄	2.78E-02	2.90E-02	3.20E-02	3.33E-02	2.22E-02	2.32E-02	2.44E-02	2.55E-02	5.17E-03	5.39E-03	5.51E-03	5.74E-03
P ₅	2.64E-02	2.75E-02	3.34E-02	3.48E-02	2.48E-02	2.59E-02	2.38E-02	2.48E-02	5.76E-03	6.00E-03	6.51E-03	6.78E-03
O ₁	5.14E-02	5.36E-02	5.98E-02	6.23E-02	1.13E-02	1.18E-02	1.31E-02	1.37E-02	3.67E-03	3.83E-03	4.09E-03	4.26E-03
O ₂	3.61E-02	3.77E-02	4.73E-02	4.93E-02	1.57E-02	1.64E-02	1.73E-02	1.80E-02	3.92E-03	4.09E-03	4.42E-03	4.61E-03
O ₃	4.31E-02	4.49E-02	5.42E-02	5.65E-02	2.07E-02	2.15E-02	2.56E-02	2.67E-02	4.84E-03	5.04E-03	5.59E-03	5.83E-03
O ₄	5.28E-02	5.51E-02	6.67E-02	6.96E-02	2.46E-02	2.57E-02	2.26E-02	2.36E-02	5.34E-03	5.57E-03	6.17E-03	6.43E-03
O ₅	6.12E-02	6.38E-02	7.93E-02	8.26E-02	2.60E-02	2.71E-02	2.92E-02	3.04E-02	6.76E-03	7.04E-03	7.34E-03	7.65E-03
B ₁	1.39E-03	1.45E-03	4.17E-03	4.35E-03	6.36E-03	6.63E-03	1.07E-02	1.12E-02	8.09E-03	8.43E-03	8.59E-03	8.96E-03
B ₂	2.78E-03	2.90E-03	5.56E-03	5.80E-03	8.34E-03	8.70E-03	9.53E-03	9.94E-03	1.04E-02	1.09E-02	1.15E-02	1.20E-02
B ₃	0.00E+00	0.00E+00	1.39E-03	1.45E-03	9.93E-03	1.04E-02	1.43E-02	1.49E-02	1.13E-02	1.17E-02	1.16E-02	1.21E-02
B ₄	4.17E-03	4.35E-03	5.56E-03	5.80E-03	1.09E-02	1.14E-02	1.49E-02	1.55E-02	1.06E-02	1.10E-02	1.11E-02	1.16E-02
B ₅	1.39E-03	1.45E-03	2.78E-03	2.90E-03	1.41E-02	1.47E-02	1.25E-02	1.30E-02	1.15E-02	1.20E-02	1.19E-02	1.24E-02

Table 9 Classification of groundwater samples collected from the proximity of tributaries of Beas River, India for irrigation purposes

Parameters	Range	Water class	Number of samples	
			Pre-monsoon	Post-monsoon
Salinity hazard ^a	< 250	Excellent	0	0
	250–750	Good	22	0
	750–2000	Permissible	23	45
	2000–3000	Doubtful	0	0
	> 3000	Unsuitable	0	0
Alkalinity hazard ^b	< 10	Excellent	45	45
	10–18	Good	0	0
	18–26	Doubtful	0	0
	> 26	Unsuitable	0	0
Sodium percentage (Na%) ^c	< 20	Excellent	0	0
	20–40	Good	45	45
	40–60	Permissible	0	0
	60–80	Doubtful	0	0
	> 80	Unsuitable	0	0
Magnesium ratio (MR) ^c	> 50%	Suitable	45	42
	< 50%	Unsuitable	0	3
Kelly’s ratio (KR) ^c	< 1	Suitable	45	45
	> 1	Unsuitable	0	0
Residual sodium carbonate (RSC) ^c	< 2.5	Fit	29	23
	2.5–5	Marginal	16	22
	5–7.5	Unfit	0	0
Corrosivity ratio (CR) ^c	< 1	Safe	45	45
	> 1	Unsafe	0	0

^aBased on EC (µS/cm)

^bBased on SAR

^cIonic concentrations is in meq/L

Fig. 2 Water classification according to SAR and EC values (USSL diagram)

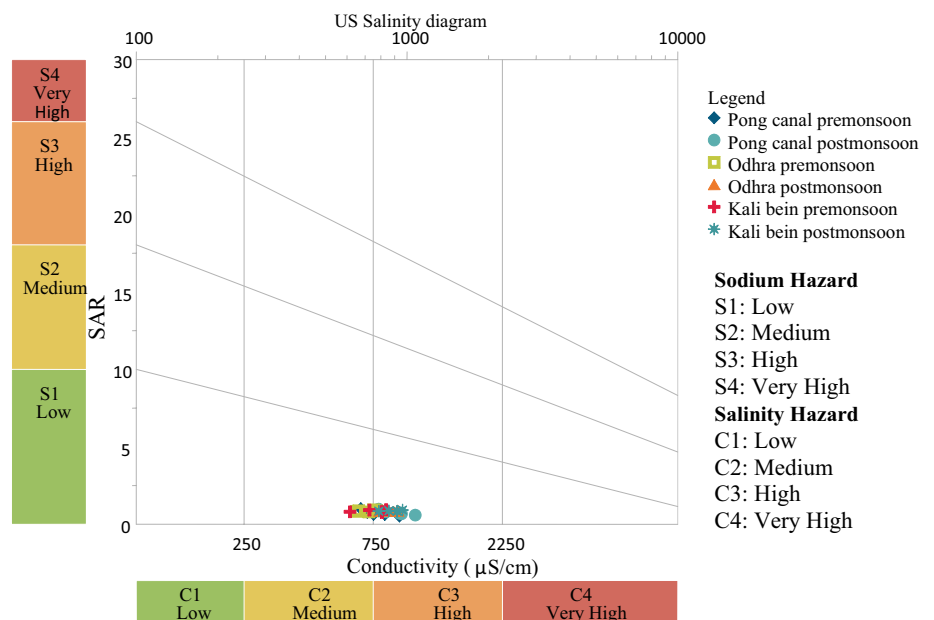


Fig. 3 Wilcox diagram for classification of groundwater samples collected from the proximity of tributaries of Beas River, India on the basis of Na% and EC

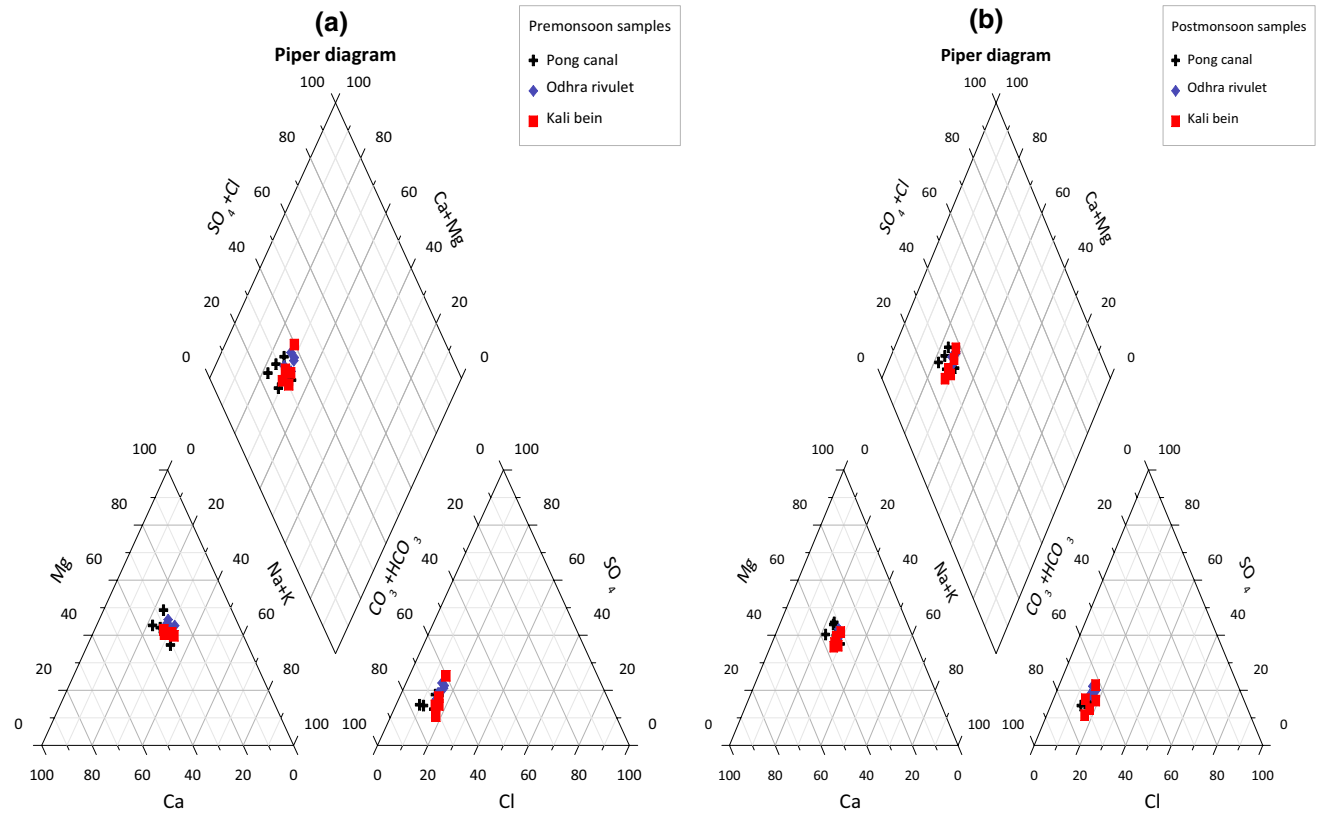
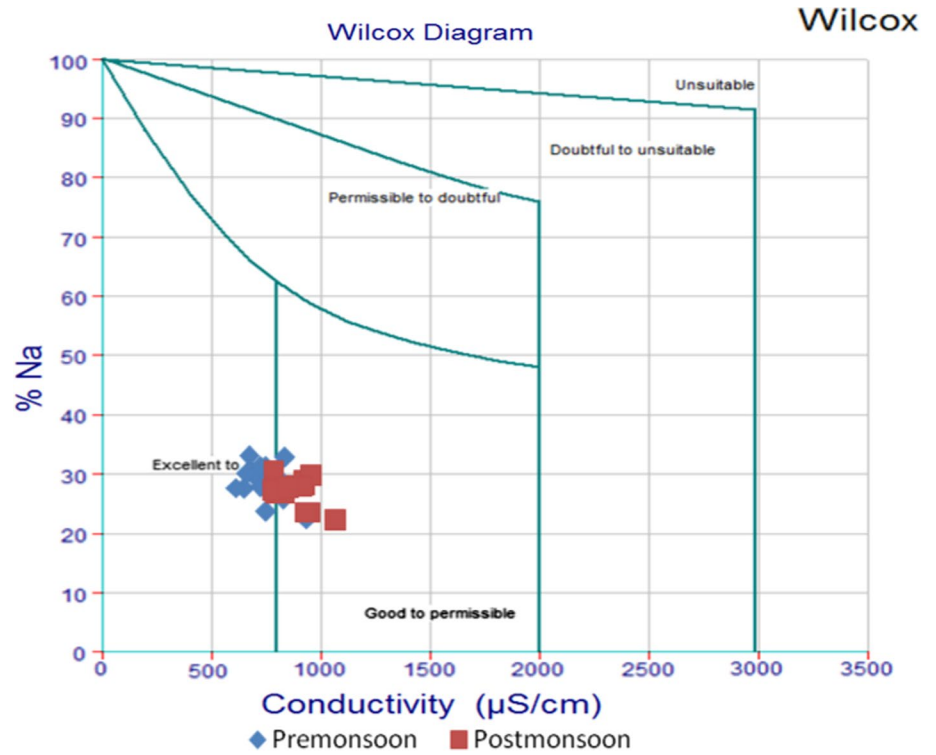


Fig. 4 a Geochemical classification of groundwater samples collected during the pre-monsoon season using Piper diagram **b** Geochemical classification of groundwater samples collected during post-monsoon season using Piper diagram

good. The bulk of samples had lower values than permissible limits prescribed by WHO and BIS. Considering TDS as a parameter, the samples were under suitable class of drinking and irrigation purposes in all the studied locations. The abundance order of major cations was $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ and $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$, respectively, in the pre-monsoon and the post-monsoon season while abundance of major anions was in the order of $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{CO}_3^{2-}$ in both the seasons. Among heavy metals, Fe, As, Al and Se were found abundant in the samples having average concentration 0.30 mg/L, 0.19 µg/L, 0.02 mg/L and 0.78 µg/L, respectively, during the pre-monsoon and 0.33 mg/L, 0.25 µg/L, 0.03 mg/L and 0.84 µg/L, respectively, during the post-monsoon. Health risk assessment of Fe, As and Se show that their concentrations were below risk level in the study area. From this study, it was concluded that the groundwater of the study area was suitable for drinking and irrigation purposes. The continuous monitoring of water in this area is recommended to cope with the rising contamination of groundwater and adverse effects on human health.

Acknowledgements Authors would like to thank Principal Khalsa College, Amritsar for providing necessary resources. Authors would also like to thank Dr. Kular Singh from post-graduation department of chemistry for analytical determinations.

Author contributions JS performed the experiments, analyzed the data, prepared figures and/or tables and approved the final draft. SKS assisted in design the experiment, statistically analyzed the data, prepared figures and/or tables, prepared manuscript and approved the final draft. KS critically reviewed the drafts of the paper and approved the final draft. DS conceived and designed the experiments, authored or reviewed drafts of the paper.

Funding The author(s) received no specific funding for this work.

Availability of data and material The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest Author's have no conflict of interest.

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