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ORIGINAL ARTICLE

Groundwater quality assessment of Shahdadkot, Qubo Saeed Khan and Sijawal Junejo Talukas of District Qambar Shahdadkot, Sindh

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Abstract

The study examines the water quality of Shahdadkot, Qubo Saeed Khan and Sijawal Junejo talukas of Qambar Shahdadkot District, less affected by industrial contamination. A total of 38 groundwater samples were collected and analysed for 28 parameters. The results indicated that 57.89% samples were not suitable for drinking purpose with total dissolved solids above than maximum permissible limit of World Health Organization (WHO) (1000 mg/L). The pH, total phosphate, orthophosphate and nitrite were within WHO limits. The concentration of essential metals more than half samples, fluoride in 60.52% and heavy metals 0–50% were contaminated higher than permissible limits of WHO. The statistical analysis of water quality parameters was also carried out to evaluate coefficient of determination among the parameters, cluster analysis and principal component analysis. Water quality determined for irrigation based on Kelly index (KI), sodium percentage (Na%), chloride–sulphate ratio, sodium adsorption ratio, permeability index (PI), chloroalkaline indices 1 (CAI-1), residual sodium carbonate and chloride bicarbonate ratio indicated that samples (55 to 100%) could be used for irrigation purposes. The consumption of water with high concentration of salts and fluoride above the permissible limits may be a cause of a number of diseases in the area.

Keywords Groundwater · High fluoride and salts · Physicochemical properties · Sindh

Introduction

Groundwater is one of the chief sources of water for the drinking, industrial and cultivation purposes. An increasing population is placing countless demand on the natural water resources (Oladipo et al. 2011). The physical and chemical impurities that harmfully affect the properties of the groundwater may arise due to land application of cultivated chemicals, infiltration from sewage treatment plants and municipal wastes (Rajappa et al. 2011). FAO (1997) defined water as the most valuable natural resources for drinking and is necessary for the maintenance of all living things. Surface water (lakes, dams and rivers) and groundwater (hand pumps, dug wells and boreholes) are the major sources for drinking purposes. Surface water is usually more contaminated than groundwater; therefore the groundwater is the chief source of drinking in rural areas (Chukwu 2008; Adekunle 2009). About 60% people in the Pakistan live in the villages, where groundwater is mostly used for drinking. The Sindh province is facing a several shortage of drinking water due to the dry weather, high evaporation rates and high temperature. The quality of groundwater depends upon geochemistry, movement of elements and also climate of the areas (Bashir et al. 2013). The ion exchange device among groundwater and arrangement of aquifer are responsible for the existence of ions in the water (Aghazadeh and Mogaddam 2010). The availability of safe drinking water is a major issue (Khan et al. 2013). The drinking of contaminated water may cause serious health concerns, including high death rates in developing countries. The many cities of world use groundwater for their daily usage, which is contaminated. Diarrhoea is common in the Pakistan; it is due to utilizing polluted water. It is expected that in future Pakistan will face drinking water challenges (Mashadi and Mohammad 2000). Many factors

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cause contamination of groundwater as well as surface including industrialization and urbanization. The quality of groundwater in Pakistan is weakening day by day (Iqbal et al. 2013). A number of problems appear due to no proper management of waste water, which is penetrating into the sediment and soil with the passage of time and become a part of groundwater (Asghar et al. 2006).

A number of studies have been carried out to examine the quality of groundwater (Ukpaka and Ukpaka 2016; Majolagbe et al. 2017; Abdulrafiu et al. 2016; MacDonald et al. 2016; Adimalla et al. 2018); including from Pakistan (Noreen et al. 2017; Baig et al. 2009), which reflects the importance of monitoring the water quality including groundwater. The interests in the determination of physico-chemical characteristics of hospital effluents (Ramdani et al. 2018), petroleum refinery waste water (Iqbal 2016), textile effluents, industrial effluents and their treatments (Iqbal and Nisar 2015; Iqbal et al. 2015) are attracting considerable attention. Iqbal et al. (2017) have also reported the ecotoxicity assessment and environmental toxicity of waste and river water. Abbas et al. (2018) reported the Vibrio fischeri bioluminescence inhibition assay for ecotoxicity assessment.

The present work investigates the physicochemical parameters including cations and anions and trace metal ions in the groundwater in the study areas and compares the results of parameters with World Health Organization (WHO). The multivariate statistical techniques are examined to certain similarity among the samples and hydrochemical composition. The work enables to make recommendations concerning the suitability and hazards of the groundwater for human consumption and irrigation.

Materials and methods

Study area

Geography

The total area of District Qambar Shahdadkot is 14.53 lakh hectare with population 13.41 lakh with population growth rate 2.8%. The district is divided into seven talukas which are Qambar, Miro Khan, Shahdadkot, Warah, Sijawal Junejo, Nasirabad and Qubo Saeed Khan; the present study examines three talukas (Shahdadkot, Sijawal Junejo and Qubo Saeed Khan) for water quality assessments. Qambar Shahdadkot shares its borders with three districts of Baluchistan on the west (Khuzdar, Jaffarabad and Jhal Magsi). It is connected with districts Dadu, Larkana and Jacobabad in Sindh province. The district has vast plains, agriculture lands, mountain range of Kirthar and a number of wetlands including Hamal, Drigh and Langh. The Kirthar extends southwards for almost 300 km from the Mula River in east-central Balochistan to Cape Muari (Monze) west of Karachi on the Arabian Sea. Kirthar range is composed of limestone hills. The Kirthar range also has a National Park which is one of the largest Wildlife Parks in the area. It is located between Karachi and Balochistan. This hilly area rises from 4000 to nearly 8000 feet and is surrounded by fossilized remnants from different times of history.

Geology

The famous Hamal Lake is present in the study area. These formations are sandy rocks composed of limestone, claystone and sandstone. During mid-Eocene, marine spread caused the growth of a CO_3 shelf in the area of Kirthar. The aquifers of hard rocks are mostly composed of partially cracked sandstone and limestone belonging to Kirthar formations. The limestone is the leading formation. The chief crops of the area are rice and wheat but some crops of sorghum sesame, maize etc, are also found here.

Climate

The climate of Qambar Shahdadkot District is mainly dry, with rainfall varying between 5 and 10 inches in a year and is one of the hottest areas of Sindh province. The reported maximum temperature is 124.88°F in July 2002. May, June and July are the hottest months of the district. About 95 per cent population depends on agriculture. It is also rich in gas reserves.

Samples collection and preservation

The 38 water samples were collected from three talukas: Shahdadkot, Qubo Saeed Khan and Sijawal Junejo, mostly used for human consumption and irrigation. The sampling scheme was designed to collect representative samples and covered the study area. The 14 samples each were collected from Shahdadkot and Qubo Saeed Khan talukas and 10 samples were collected from Sijawal Junejo. The approximate depth of pumps and wells was noted. The water samples were randomly spaced and collected in the clean 1.5-L polythene sampling bottles after allowing pumps to drain for 5 min before collection. The bottles were filled completely and kept in the dark in ice box. Two bottles were collected from each sampling site and immediately taken to the laboratory, one for physicochemical analysis and other for metal analysis. Samples were collected in the mornings between the January and May, 2016 (Table 1). The bottle for metal analysis was acidified with 1 ml of hydrochloric acid/ nitric acid.

Table 1 Name of sampling towns and villages of three talukas of district Qambar Shahdadkot

Sample ID	Villages name	Union council	Taluka	Source of water	Latitude	Longitude
1.	Khosla Market Shahdadkot	Shahdadkot	Shahdadkot	Hand pump		
2.	Qamber Road Shahdadkot	Shahdadkot	Shahdadkot	Hand pump	27° 50.35.4	67.54.14.2
3.	Koto Moto Chock Shahdadkot	Shahdadkot	Shahdadkot	Hand pump	27° 50.43.6	67.54.22.3
4.	Station Road Shahdadkot	Shahdadkot	Shahdadkot	Hand pump	27° 50.29.9	67.54.39.5
5.	Heerabad Colony Near Sijawal Road Shahdadkot	Shahdadkot	Shahdadkot	Hand pump	27° 51.00.7	67.55.16.8
6.	Kamboh Mahla Shahdadkot	Shahdadkot	Shahdadkot	Motor pump	27.50.52.85	67.54.09
7.	Khozdar Chock Shahdadkot	Shahdadkot	Shahdadkot	Hand pump		
8.	G. Girls High School Shahdadkot	Shahdadkot	Shahdadkot	Hand pump	27.50.55	67.54.19.
9.	Aitbar Khan Chandio		Shahdadkot	Hand pump	27.52.12	67.57.13
10.	Dost Ali		Shahdadkot	Hand pump		
11.	Khando Buledi		Shahdadkot	Hand pump		
12.	Khabar		Shahdadkot	Hand pump		
13.	Wada Silra 1	Silra	Shahdadkot	Hand pump	27.50.11.	67.54.48.66
14.	Wada Silra 2	Silra	Shahdadkot	Hand pump		
15.	Q.S. Khan near workshop		Q.S. Khan	Hand pump		
16.	Q.S. Khan from floor mill		Q.S. Khan	Hand pump	27° 52.14.4	067.42.40.3
17.	Masjid Quba Q.S. Khan		Q.S. Khan	Hand pump	27° 52.20.2	067.42.29.9
18.	Q.S. Khan Near Bypass Road		Q.S. Khan	Hand pump	27° 52.04.2	067.42.16.0
19.	Shahdadkot Road Q.S. Khan		Q.S. Khan	Hand pump		
20.	Kachi Pull		Q.S. Khan	Surface		
21.	Ninety-Seven Pull		Q.S. Khan	Surface		
22.	Sanaullah Magsi		Q.S. Khan	Hand pump		
23.	Sir Shahnawaz Magsi		Q.S. Khan	Hand pump		
24.	Sanaullah Chandio		Q.S. Khan	Hand pump		
25.	Mir Ali Hassan Brohi		Q.S. Khan	Hand pump		
26.	Haji Muhammad Malook		Q.S. Khan	Hand pump		
27.	Jamali Kot		Q.S. Khan	Hand pump		
28.	Muhammad Khan Mugheri		Q.S. Khan	Hand pump		
29.	Taluka Tower Sijawal	Sijawal	Sijawal	Hand pump	27° 50.29.4	068.07.00.4
30.	Sijawal Near Shahdadkot Road	Sijawal	Sijawal	Hand pump	27° 50.31.2	068.06.56.2
31.	Sijawal main chawk	Sijawal	Sijawal	Hand pump	27° 50.31.0	068.06.56.2
32.	Phulari 1	Hyder chandio	Sijawal	Hand pump		
33.	Phulari 2	Hyder chandio	Sijawal	Hand pump		
34.	Hyder Chandio	Hyder chandio	Sijawal	Hand pump		
35.	Arzi Bhutto	Arzi Bhutto	Sijawal	Hand pump	27.46.01.76	68.05.57.93
36.	Tauof Chasool	Tauof chausool	Sijawal	Hand pump		
37.	Dhingano Maheser	Dhingano maheser	Sijawal	Hand pump		
38.	Chuto Mustoi	Shuto mustoi	Sijawal	Hand pump	27.51.02.55	68.01.40.74

Reagent and chemicals

All the chemicals used were for reagent or analytical grade and were used without further purification. The standard solutions were prepared from following: sodium chloride, potassium chloride, calcium carbonate, magnesium chloride, lead nitrate, cadmium nitrate, ferrous ammonium sulphate, cobalt sulphate, sodium nitrite, sodium nitrate, hydrochloric acid (37%), silver nitrate, sodium sulphate, ethylenediaminetetracetic acid disodium (EDTA) and potassium dihydrogen phosphate (Merck, Germany).

Physicochemical procedure

The 28 physicochemical parameters were analysed in the laboratory following standard procedures (APHA 1998). The procedure was appropriately standardized before the sample analysis, including blank determination. Each of the analysis was carried out at least in triplicate.

The analysis of major cations (Na, K, Ca and Mg) in water samples was carried out after dilution of 10–20 times with deionized distilled water, whereas the samples were concentrated ten times by the evaporation of water at 80–90 °C on an electric hot plate, filtered and maintained at 4 °C till further analysis for trace elements. Chloride, alkalinity, total hardness, chemical oxygen demand, (COD), PO_4-P, SO_4, NO_3 and NO_2 were determined as reported (APHA 1998; Kazi et al. 1987; Khuhawar et al. 2018). The Orion star 5 conductivity meter (Orion Inc Boston, M.A, USA) was used to evaluate pH, electrical conductivity, total dissolved solids (TDS) and salinity. The electrodes were appropriately calibrated before analysis. The spectrophotometric measurements were taken out on Hitachi 220 UV/Visible (Hitachi (Pvt) Ltd, Tokyo, Japan), double-beam spectrophotometer with 1 cm quartz cuvettes. The elements Na, K, Ca, Mg, Pb, Co, Cr, Mn, Ni, Cd, Fe and Cu were analysed by flame atomic absorption spectrophotometer (FAAS) using a Perkin Elmer AA 800 (Perkin Elmer, Singapore) at the conditions recommended by the manufacturer. The determinations were carried out at least in triplicate ($n = 3$) with integration time 3 s and delay time 3 s. The equipment was controlled by a computer with WinLab software. Deionized double-distilled water was used for all glassware cleaning and solution preparations, stock solution of the element was prepared from pure metal salt and further solution was prepared by appropriate dilution. The blank determination (without sample) was prepared and analysed simultaneously with the samples throughout the procedures. Anions and cations balance method was used to determining the reliability of the major ions analysis of groundwater (Boyd et al. 2007) and scatter diagram plot of fluoride versus TDS was drawn using (Microsoft Excel 2013). The coefficient correlation (r) was carried out as reported (Batabyal 2014). The cluster analysis was created by ward method (Panda et al. 2006). The principal component analysis (PCA) was analysed (Simeonov et al. 2003) using SPSS statistical software version 22. Piper graph for anions and cations was created by using method (Piper 1953) by Aquachem software.

Analysis of the quality of water for irrigation

The salinity hazard of water is calculated based on of electrical conductivity using Richards method (Richards 1954).

The Na% is extensively applied for evaluating the suitability of groundwater for the irrigation using reported method (Wilcox 1955). The Na% was calculated by formulas

$$\mathrm{Na\%} = \left[\left(\mathrm{Na^+} + \mathrm{K^+}\right)/\left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^+} + \mathrm{K^+}\right)\right] \times 100.$$

The sodium adsorption ratio was determined by Todd (1980). The SAR value is determined using the following formula.

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca{+}{+}Mg{+}{+}}}{2}}}.$$

The permeability index (PI) was determined to check the quality of water for irrigation using reported method (Doneen 1964). The PI is determined by following equation.

$$\mathrm{PI} = \left[\left(\mathrm{Na^+} + \mathrm{HCO_3^-}\right)/\left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^+}\right)\right] \times 100.$$

Chloroalkaline indices were determined by using method (Schoeller 1977). The CAI-1 was calculated by the below equations.

$$(\mathrm{CAI} - 1) = \left[\mathrm{Cl^-} - \left(\mathrm{Na^+} + \mathrm{K^+}\right)\right]/\mathrm{Cl^-}.$$

Kelly index is applied to measure the suitability of water sample for the irrigation using method (Kelly 1940). KI value was determined by following equation.

$$\mathrm{KI} = \mathrm{Na^+}/\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}.$$

Residual sodium carbonate (RSC) is used to measure the harmful effect of HCO_3 in water using method (Raju 2007). RCS is calculated by following formula.

$$\mathrm{RSC} = \left(\mathrm{CO_3^-} + \mathrm{HCO_3^{2-}}\right) - \left(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}}\right).$$

The chloride–sulphate ratio is applied to measure the suitability of water for irrigation using method (Al-Harbi et al. 2009). Chloride–sulphate ratio was determined by following equation:

$$\text{Chloride sulphate} = \mathrm{Cl^-}/\mathrm{SO_4^{2-}}.$$

Chloride bicarbonate ratio is applied to measure the suitability of the water for irrigation using method (Al-Harbi et al. 2009). Chloride bicarbonate was determined by following equation:

$$\text{Chloride bicarbonate} = \mathrm{Cl}/\mathrm{HCO_3^-}.$$

The calculations of all the above equations were based on the concentration unit milli equivalent/L.

Results and discussion

The pH results of area varied from 7.0 to 8.37, it showed that pH of all samples was within limits of WHO. The − log of hydrogen ion concentration (pH) is an essential factor in water investigation and calculation of alkalinity, acidity of the any sample and the processes such as corrosion control, coagulation and disinfection (Sujatha et al. 2012). The electrical conductivity (EC) results of area varied from 373 to 18700 µS/cm; the EC of 22 (57.89%) samples was above the limits of WHO. It may be due to the geological nature of study area. EC determines the soluble salts of water in the form of the ions. There is an increase in the value of electrical conductivity due to the presence of salts in water (Trivedi and Goel 1986). The total dissolved solids (TDS) results varied from 238 to 11,968 mg/L; the TDS of 16 (42.12%) samples were within limits of WHO (1000 mg/L). The TDS in water are due to the presence of organic and inorganic salts and substances. The drinking water quality is changed by the presence of soluble salts; water comprising high TDS may have effects on human life. The total dissolved solids (TDS) may disturb the durability and strength of palatability of food cooked (Swamy 1991). The concentration of chloride (Cl) was found from 22 to 5019 mg/L, the Cl of 16 samples was within limits, and 22 samples were above the WHO limits (250 mg/L). The chloride naturally occurs in groundwater as well as surface water. High concentration of chloride (Cl) in water is known to be indicator of contamination (Sharma and Pande 1998). The higher value of chloride (Cl) may be due to the improper discarding of sewage wastes. The excess concentration of chloride causes vascular disease, steel corrosion and salty taste to water and decreases the strength of concrete. The concentration of total hardness (TH) was found between 110 and 3200 mg/L, the TH of 24 samples was within limit and 12 samples above the WHO limit (500 mg/L as $CaCO_3$). TH is defined as the amount of magnesium (Mg) and calcium (Ca) in the water (Jayalakshmi et al. 2011). High concentration of hardness may cause kidney and heart problem. The results of alkalinity were found from 100 to 530 mg/L, the alkalinity of 20 samples was within limits, and 18 samples were above the WHO limits. It is composed mostly of CO_3 and HCO_3. Very high level of alkalinity may cause operational effects, like foaming. The extremely higher causticity values may result in a form of corrosive effect of the boiler which is called ‘embrittlement’ (Patil et al. 2012). The sulphate (SO_4) ions are easily soluble in natural water. Many SO_4 ions are yielded by their minerals by oxidation process; sulphate is also present in the industrial wastes. The concentration of sulphate of study area was found from 29 to 2231 mg/L, the sulphate of 19 samples was within limits, and 19 samples above the WHO limit (250 mg/L). Chemical oxygen demand (COD) is quantity of organic pollution in natural water. COD is the quantity of oxygen required for oxidation of the organic substance in the water. It is usually used in the waste water handling but little amount is present in drinking water treatment (Milacron Marketing Co). The results of COD were found from BDL to 48 mg/L; the COD of 10 samples were above the WHO limits. The higher nitrate (NO_3) and nitrite (NO_2) levels are caused by groundwater pollution from extreme use of fertilizers, animal waste or seepage of sewage. The nitrite (NO_2) is of specific health distress in human body due to change of the haemoglobin in our blood to methaemoglobin. This situation is called methaemoglobinemia (Sabo and Christopher 2014). Nitrite NO_2 can react with the secondary amines in the human stomach to produce the extremely cancer-causing nitrosocompounds. The concentration of nitrate and nitrite was found from 0.36 to 12.11 mg/L and 0.002 to 3.52 µg/L, respectively. Nitrate of 35 samples were within limits (10 mg/L), but nitrite results of all samples were above the WHO limits (5 µg/L). The phosphates (PO_4) exist in different inorganic forms in both water and soil. The main source of phosphates (PO_4) can be anthropogenic depending on activities happening in area (American Public Health Association 1915). The phosphorus (P) is a plants nutrient and also frequently controls the aquatic plant growing in the water. Usually, groundwater comprises less phosphorus levels for the reason of less solubility of the natural phosphate ore and the capability of soils to preserve phosphate. The concentration of total phosphate and orthophosphate was found from 0.018 to 0.95 mg/L and 0.002 to 0.515 mg/L, respectively (Table 2). The total phosphate and orthophosphate of all samples were within limits of WHO.

The sodium (Na) is present in the ground as well as surface water. The presence of sodium (Na) in natural water depends upon the existence of anions in that system and the temperature of area. The high value of sodium imparts taste to the drinking water and may cause high blood pressure and cardiovascular disease (Poverty and Kopka 1995). The concentration of sodium was founded from 19 to 1442 mg/L. The sodium of 21 samples was within limits of WHO (200 mg/L), and 17 samples were above the limits. The concentration of potassium (K) of study area was found from 5 to 150 mg/L. The potassium of 14 samples was within limits, and 24 samples above the WHO limits (12 mg/L). The potassium (K) plays an essential role in the metabolism process of living organism, and it is also an essential micronutrient (animals and plants). Higher concentration may cause kidney, lungs and cardiovascular diseases. The calcium (Ca) and magnesium (Mg) are abundant in soil and rocks. They are moderately dissolved in the surface water and then enter into the groundwater. The Ca and Mg are not of health concerns, unless present in higher amount in drinking water (Kandhro et al. 2015). High concentration of Ca and Mg source of water is hardness. The concentration of calcium and magnesium was found from 17 to 947 mg/L and 15 to 801 mg/L, respectively. The results of calcium and magnesium of 20 samples were within limits of WHO (Ca and Mg 150 and 100 mg/L, respectively) (Table 3).

The residents are unprotected to lead (Pb) from food and air. The kids are mostly at risk to lead (Pb) exposure; it is permeable from blood brain barricade and has neurotoxin effects even Pb at less level of exposure (Athar and Vohora 1995). The concentration of Pb of study area was found from BDL to 37.4 µg/L; the results of Pb of 30 samples were

Table 2 Results of physicochemical parameters

S:ID	PH	EC (µs/cm)	TDS (mg/L)	Sal (ppt)	Cl (mg/L)	TH (mg/L)	Alk (mg/L)	SO_4 (mg/L)	T-PO_4 (mg/L)	O-PO_4 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	COD (mg/L)
1.	7.0	12,400	7936	7.3	3031	1400	400	1475	0.116	0.108	12.07	0.88	NA
2.	7.56	957	612	0.5	99	190	180	115	0.145	0.141	6.01	1.95	NA
3.	7.13	11,080	7091	6.5	2345	1500	430	1741	0.272	0.259	9.47	1.43	NA
4.	7.02	12,540	8025	7.4	3189	1800	530	1219	0.165	0.109	8.42	1.44	NA
5.	7.53	4060	2598	2.2	1084	600	220	325	0.95	0.092	2.84	1.39	NA
6.	7.67	3130	2003	1.7	567	400	260	475	0.167	0.158	3.116	1.43	NA
7.	7.05	9580	6131	5.6	2185	1500	500	1441	0.123	0.071	6.38	1.70	NA
8.	7.22	4560	2918	2.5	1091	560	420	430	0.86	0.172	7.06	1.29	25
9.	7.40	18,700	11,968	11.1	5019	3200	330	1507	0.018	0.012	1.73	0.002	12
10.	7.38	2968	1899	1.5	538	400	300	235	0.052	0.021	0.43	0.003	09
11.	7.97	2284	1461	1.2	308	360	310	229	0.32	0.280	0.46	0.041	33
12.	8.16	951	608	0.5	63	200	190	44	0.263	0.115	0.36	0.002	3.2
13.	7.55	14,210	9094	8.2	2963	2000	300	2231	0.223	0.115	6.32	1.39	BDL
14.	7.91	1037	663	0.5	92	210	260	32	0.040	0.006	0.98	0.14	BDL
15.	8.06	12,460	7974	7.3	2212	1500	410	1868	0.119	0.05	0.403	0.006	25
16.	8.16	2360	1510	1.3	248	480	370	292	0.46	0.013	0.60	2.91	BDL
17.	8.18	1555	995	0.8	192	250	270	80	0.23	0.011	0.97	0.003	9.6
18.	7.96	1014	648	0.5	185	170	230	38	0.12	0.10	1.70	0.04	30
19.	8.37	1370	876	0.7	127	185	220	155	0.12	0.020	0.38	0.02	24
20.	8.31	1294	828	0.6	255	180	170	69	0.25	0.003	0.61	0.050	39
21.	8.22	1292	826	0.6	257	200	180	105	0.38	0.008	0.42	0.006	16
22.	8.13	4780	3059	2.5	644	600	460	800	0.19	0.023	1.28	0.012	BDL
23.	8.30	770	492	0.4	56	180	190	30	0.12	0.002	0.38	0.021	30
24.	8.12	6800	4353	3.7	589	1060	340	1286	0.11	0.007	3.44	1.35	48
25.	7.93	9360	5990	5.2	2041	1240	490	1335	0.41	0.27	3.41	3.52	BDL
26.	7.79	3930	2515	2.1	445	550	440	416	0.31	0.173	3.34	0.002	BDL
27.	8.33	2779	1778	1.4	330	440	380	360	0.28	0.216	2.05	0.021	49
28.	8.35	3310	2118	1.7	319	480	370	573	0.24	0.086	2.13	0.011	BDL
29.	7.61	844	540	0.4	45	180	220	63	0.141	0.075	7.54	1.23	NA
30.	7.63	1077	689	0.6	75	170	230	90	0.24	0.103	12.11	1.25	NA
31.	7.57	1279	818	0.7	113	190	260	115	0.65	0.515	10.12	1.49	NA
32.	8.17	373	238	0.2	22	110	100	31	0.058	0.040	1.33	0.39	33
33.	8.15	384	245	0.2	27	110	100	29	0.067	0.041	1.23	0.33	30
34.	7.92	2198	1406	1.1	215	380	370	200	0.102	0.025	0.38	0.32	BDL
35.	7.83	1156	739	0.6	92	230	250	104	0.109	0.087	0.37	0.13	42
36.	7.68	3130	2003	1.6	340	400	350	512	0.096	0.068	2.26	0.23	BDL

Table 2 (continued)

S:ID	PH	EC (µs/cm)	TDS (mg/L)	Sal (ppt)	Cl (mg/L)	TH (mg/L)	Alk (mg/L)	SO_4 (mg/L)	T-PO_4 (mg/L)	O-PO_4 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	COD (mg/L)
37.	7.98	1504	962	0.8	141	220	260	88	0.091	0.083	0.42	0.12	3.2
38.	7.82	3770	2412	2.0	645	520	320	412	0.095	0.054	0.53	0.41	BDL

within limits of WHO (10 µg/L). The chief exposure way of the inorganic Pb is through adsorption by stomach tract and breathing inhalation. The copper (Cu) is important for the creation of enzyme in the human beings. Extremely high dosages of Cu intake effect to mucosal corrosion, irritation, renal damage and harm central nervous system (Ahmed and Krishnamurthy 1990). The concentration of Cu of study area was found from 3.7 to 81.4 µg/L. The Cu results of all samples were within limits of WHO. The cadmium (Cd) has been used in the industries for a long time. The food smoking of cigarettes and water are the main source of Cd. Daily nutritional consumption of Cd is from 40 to 50 µg/day. The concentration of cadmium of study area was found from BDL to 25.9 µg/L; the Cd results of 28 samples were within limits of WHO (3.0 µg/L). The Cd gathers within the liver and kidney over long time. Long period contact with Cd leads to cancer and cardiovascular diseases. It disturbs renal tubular system of the amino acids, sugar and reabsorbing proteins (McLaughlin et al. 1999). The values of chromium (Cr) of study area were found between BDL and 100 µg/L. The results Cr of 22 samples were within limits of WHO (70 µg/L). The daily intake of Cr ranges from 100 to 300 µg/day. The dangerous effects of chromium to human beings are commonly related with hexavalent (Cr^{+6}) form. The chromium poisonousness comprises membrane ulcers and liver necrosis (O'Brien et al. 2003). The nickel is present in small concentration in the groundwater. Daily consumption of Ni through vegetables and food is about 300 µg. The values of nickel of study area were between 6.9 and 140 µg/L; the results Ni of 23 samples were within limits of WHO (70 µg/L). The higher level of nickel causes eosinophilic pneumonitis, conjunctivitis. Ni is comprising prostheses like joint replacements, cardiac valve replacements, pins, dental inlays and cardiac pacemaker wires (Athar and Vohora 1995). The cobalt results of study area were between 0.1 and 60.7 µg/L; the Co results of all samples were within limits of WHO. Low concentration of cobalt is present naturally in surface, sea and groundwater. Nevertheless, high levels of Co in the water and soil may be due to the anthropogenic activities including Co-bearing minerals and mining (Smith and Carson 1981). Manganese (Mn) is necessary nutrient and daily requirement of Mn is approximately 2.5 to 5.0 mg for adults (Athar and Vohora 1995). The results of manganese of study area were between BDL and 95.3 µg/L. The Mn results of all samples were within limits of WHO. Manganese is fairly less harmful to human but may causes serious harming result at higher values. The nervous illness is caused due to the exposure of manganese dust fume to occupation workers (Järup 2003; NRC-NAS 1980). Iron (Fe) is an essential constituent in our body metabolism. It is existing in higher quantity than other trace elements. Iron is a constituent of proteins, haemoglobin and enzymes. The Fe results of study area were between 15.4 and 279 µg/L; the

Table 3 Results of essential, heavy and toxic elements

S:ID	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cr (ppb)	Cd (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Pb (ppb)	F (ppm)	As (ppm)
1.	877	56	690	480	92	BDL	BDL	7.22	21.7	53.4	34	7.2	19.30	0.00
2.	55	5	81	36	BDL	BDL	BDL	15.4	16.9	27.0	24	BDL	0.65	0.005
3.	699	109	720	506	86	BDL	36.5	28.1	40.1	37.6	18	9.3	22.45	0.005
4.	910	56	750	645	99.8	BDL	15.0	10.2	42.9	19.9	27	10.2	25.70	0.005
5.	370	14	260	115	67.7	BDL	8.9	95.8	23.1	28.8	23	8.8	6.24	0.00
6.	290	29	220	110	ND	BDL	4.1	125	18.2	13.9	19.5	BDL	3.9	0.005
7.	590	150	510	490	100	BDL	3.0	129	29.2	16.9	4.0	24	18.3	0.00
8.	365	63	237	220	41	BDL	3.3	61.7	13.0	23.8	3.7	34	5.82	0.010
9.	1442	62	947	801	81	25.9	ND	49.3	60.7	105	14.1	7.1	18.60	0.005
10.	290	18	140	100	59	15.8	68.4	131	24.7	140	8.2	ND	4.10	0.00
11.	224	13	80	61	90	10.9	95.3	88.1	24.8	99	12	BDL	2.20	0.005
12.	40	12	43	33	10	10.7	48.1	102	19.2	75	20	BDL	0.63	0.005
13.	925	140	651	646	40	17.4	74	82.7	38.5	137	10.9	37.4	1.24	0.005
14.	70	8	52	35	58	BDL	77	198	ND	30	14.2	BDL	0.48	0.005
15.	1005	15	601	354	98	2.9	12.3	51.6	ND	11	16.0	16.6	1.75	0.005
16.	170	25	110	80	6.8	1.5	8.7	120	33.1	12	81.4	8.0	13.80	0.005
17.	135	12	60	53	61	20.4	25.3	86.1	1.8	68.7	19.4	2.0	1.35	0.005
18.	103	11	69	41	10	BDL	6.6	62.7	32.4	14	9.4	BDL	4.75	0.005
19.	110	17	51	40	12	2.0	14.8	111	7.2	45	14.1	BDL	1.12	0.005
20.	142	11	60	38	21	17.6	7.3	93.4	ND	36.3	11.0	BDL	1.15	0.005
21.	165	10	44	30	74	21.2	0.6	62.1	ND	34.4	16	BDL	1.15	0.010
22.	280	15	280	247	10	BDL	60.8	92.0	17.5	10.5	62.0	12.7	5.87	0.005
23.	43	11	35	29	80	2.7	18.2	50.0	1.0	27.7	21.5	BLD	0.25	0.25
24.	261	42	340	296	21	BDL	75.7	70.5	19.4	52.0	74.0	2.8	9.80	0.005
25.	933	19	625	350	10	3.0	63	54.3	26.2	9.7	62.5	21.1	9.65	0.010
26.	300	29	184	120	30	BDL	24.5	73.4	7.3	ND	22.3	2.9	4.65	0.005
27.	120	17	170	145	83	1.5	19.4	115	ND	6.9	7.3	BDL	3.85	0.005
28.	190	15	200	140	8.9	21.2	68.5	268	ND	50.0	21.4	BDL	3.30	0.005
29.	25	8	60	28	15	5.2	BDL	18.2	32.3	102	13.4	BDL	0.63	0.005
30.	42	10	90	32	11	1.9	BDL	25.8	18.5	11.3	18.2	6.9	0.85	0.005
31.	65	6	110	30	24.5	BDL	BDL	56.1	25.8	9.4	19.0	3.9	1.84	0.005
32.	19	7	17	15	40	2.0	21.0	38.3	32.9	ND	3.1	BDL	0.46	0.005
33.	20	6	20	19	50	1.0	3.9	279	25.9	8.0	1.1	BDL	0.41	0.005
34.	130	17	110	91	12	1.6	39.7	90.1	38.7	ND	8.2	2.4	1.97	0.005
35.	65	11	80	42	19	1.5	25.8	68.5	5.4	ND	9.0	2.7	1.45	0.005
36.	222	17	184	120	42	2.6	49.7	53.9	19.9	47.0	3.0	20.6	4.12	0.005

Table 3 (continued)

S:ID	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cr (ppb)	Cd (ppb)	Mn (ppb)	Fe (ppb)	Co (ppb)	Ni (ppb)	Cu (ppb)	Pb (ppb)	F (ppm)	As (ppm)
37.	100	15	60	40	73	3.0	23.4	87.9	6.6	ND	3.0	8.2	0.70	0.005
38.	313	14	220	140	20	BDL	10.1	103	18.7	ND	35	3.5	4.25	0.005

Fe results of all samples were within limits of WHO (Dietary Reference Intake 2001). The average values of heavy metals for all the samples were present in the following decreasing order Fe > Ni > Cr > Mn > Cu > Co > Pb > Cd (Table 3).

The results of arsenic for study area were between BDL and 25 µg/L, the results of As of 37 samples were within limits of WHO and only one sample was above the limit. The exposure to arsenic is mainly due to the intake of drinking water and food. The long-term exposure to As in water is mostly associated with increased threats of hyperkeratosis, skin cancer and pigmentation variations (Järup 2003; Franzblau and Lilis 1989). The fluoride is abundant in earth's crust as a form of minerals. The large number of human population depends on the geographical site of the inhabitants. The chief causes of fluoride (F^-) in groundwater are F^- containing rocks which inter in water through weathering and leaching of fluoride. Fluoride (F) is present as calcium fluoride (CaF_2), cryolite (Na_3AlF_6), fluorspar or apatite phosphate $[Ca_3F\ (PO_4)]_3$. The concentration of fluoride is five times greater in granite than basalt rock. Similarly, shale has a greater concentration than limestone and sandstone (Maheshwari 2006). The fluoride result of study area was found between 0.25 and 25.7 mg/L (Table 3), the results F^- of 15 (39.47%) samples were within limits of WHO (1.5 mg/L), four (10.53%) samples were found in maximum permissible limits of WHO (3.0 mg/L), and 19 (50%) samples were above the maximum limits (> 3.0). The higher concentrations of fluoride in water may have significant health effects. The fluoride results indicated that collected groundwater samples of study area were seriously contaminated by presence of fluoride (F^-) ion, whereas distribution pattern indicated high concentration of F^- in taluka Shahdadkot and low concentration was found in Sijawal Junejo taluka. The concentration of fluoride (F^-) is governed by the solubility of fluoride. High level of fluoride causes fluorosis.

Correlation coefficient

The coefficient of determination was examined of parameters of study area to each other. The pH was less correlated with Cu and As (< 0.5) but was negative correlated with other parameters. Total hardness was good correlated with TDS and Cl (> 0.7), sodium was good correlated with TDS, TH, Cl and sulphate but moderately correlated with alkalinity (0.5–0.7). Calcium and magnesium were good correlated with TDS, Cl, TH and SO_4 but moderately correlated with alkalinity. Fluoride was good correlated with alkalinity, moderately correlated with K but less correlated with TDS, Cl, TH, SO_4, Cr, Mn, Ni and Pb (< 0.5). The correlation showed that the major parameters were good correlated with each other which indicated that these samples were in the similar locations (Table 4).

Table 4 Correlation determination of the parameters

	PH	TDS	Cl	TH	Alk	SO_4	Na	K	Ca	Mg	Cr	Mn	Fe	Co	Ni	Cu	Pb	F	As
pH	1.000																		
TDS	−0.150	1.000																	
Cl	−0.174	0.996	1.000																
TH	−0.151	0.997	0.989	1.000															
Alk	−0.262	0.711	0.667	0.733	1.000														
SO_4	−0.080	0.994	0.987	0.992	0.668	1.000													
Na	−0.212	0.988	0.994	0.979	0.675	0.973	1.000												
K	−0.267	0.392	0.357	0.386	0.771	0.332	0.379	1.000											
Ca	−0.142	0.994	0.987	0.995	0.720	0.992	0.970	0.388	1.000										
Mg	−0.123	0.981	0.969	0.986	0.772	0.976	0.948	0.447	0.991	1.000									
Cr	−0.236	−0.083	−0.040	−0.099	0.066	−0.170	0.010	0.127	−0.127	−0.114	−0.102								
Mn	−0.580	−0.049	−0.054	−0.025	0.288	−0.110	0.012	0.293	−0.094	−0.070	0.202	1.000							
Fe	−0.053	−0.246	−0.229	−0.253	−0.290	−0.233	−0.241	−0.209	−0.237	−0.213	−0.120	−0.112	1.000						
Co	−0.387	−0.312	−0.282	−0.310	−0.456	−0.302	−0.261	−0.376	−0.340	−0.351	−0.145	0.480	0.326	1.000					
Ni	−0.513	−0.047	−0.021	−0.050	0.186	−0.131	0.045	0.389	−0.100	−0.070	−0.002	0.780	0.067	0.324	1.000				
Cu	0.103	0.369	0.348	0.378	0.255	0.387	0.330	0.330	0.383	0.369	0.133	−0.150	−0.361	−0.383	−0.065	1.000			
Pb	−0.061	0.958	0.955	0.950	0.547	0.968	0.943	0.206	0.950	0.909	0.449	−0.211	−0.260	−0.317	−0.236	0.368	1.000		
F	−0.491	0.300	0.290	0.321	0.705	0.244	0.293	0.694	0.331	0.419	0.339	0.445	0.041	−0.036	0.467	−0.035	0.037	1.000	
As	0.251	−0.146	−0.146	−0.129	−0.169	−0.136	−0.158	−0.147	−0.145	−0.152	0.256	−0.138	−0.253	−0.267	−0.096	0.648	−0.098	−0.315	1.000

Cluster analysis (CA)

The cluster analysis method was used for the 38 water samples of area to know the similarity among sampling locations (Fig. 1). The samples were observed to be grouped into clusters in dendrogram. Group A is based on 16 samples with samples numbers 30, 35, 31, 16, 26, 28, 29, 5, 6, 37, 32, 33, 3, 7, 4, 9 and showed similarity of samples; B group contains 13 samples with numbers 8, 22, 20, 36, 14, 24, 12, 38, 19, 2, 34, 13, 25, 10. The cluster C comprises two groups C_1 and C_2, the C_1 contains three samples 11, 21, 17, and C_2 contains four samples 1, 15, 18, 27. It is observed that group C samples have higher values for most of parameters than groups A and B. The group B has higher values in terms of average concentration then group A.

Hydrochemical composition

It was applied to describe the hydrochemical composition structure in two similar triangles with diamond to top in this diagram (Chadha 1999). The cations are grouped as Ca, Mg, Na, K in left trilinear and anions Cl, HCO_3, SO_4 in right trilinear which indicated the nature of groundwater.

The 38 groundwater samples were applied for the diagram. The piper diagram showed the hydrochemical composition of the study area. The triangle right showed predominance of Cl^- towards HCO_3^- and SO_4^{2-}, and (triangle left) showed slightly predominance of Na^+ and K^+ towards Ca^{2+} and Mg^{2+}. The right side of triangle indicated groundwater samples were rich in chloride, also indicated chloride-type water. The left side of triangle indicated slightly sodium-type

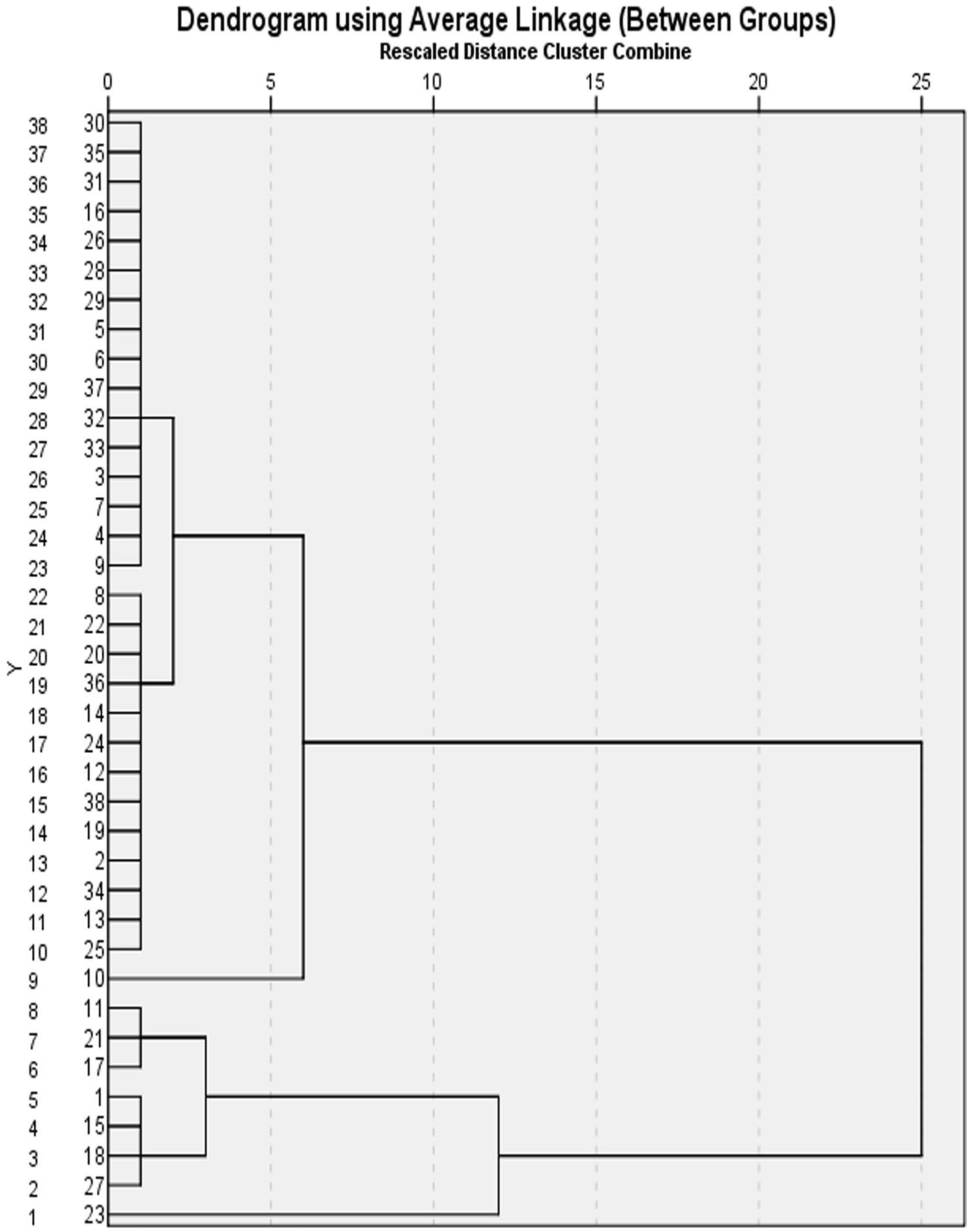

Fig. 1 Cluster analysis dendrogram of the samples

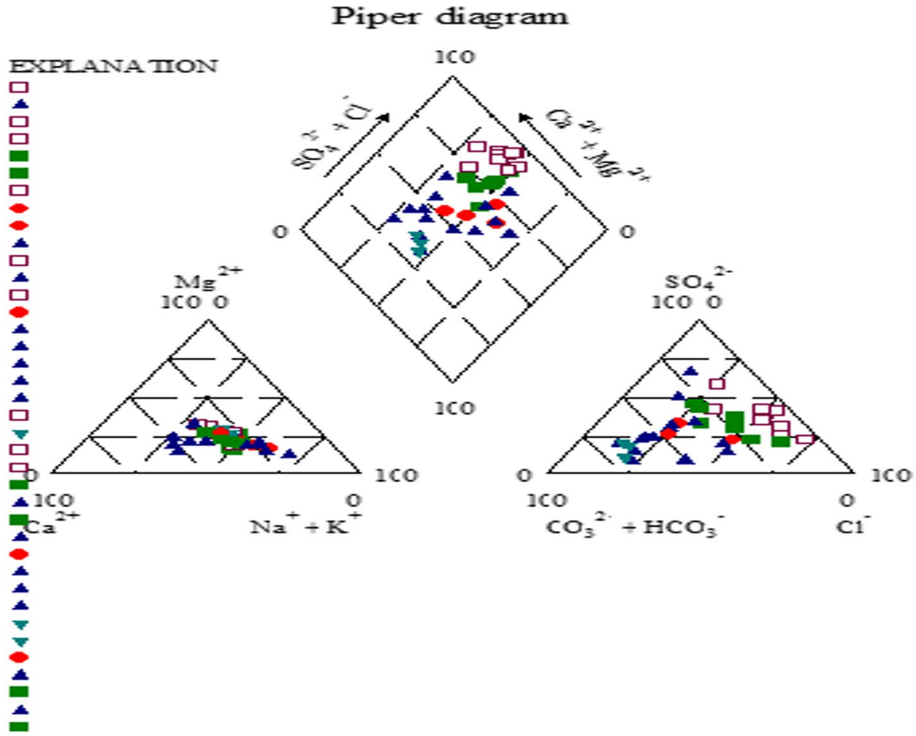

Fig. 2 Piper diagram of the samples

water. The Ca^{2+}, Mg^{2+} and Cl^-, SO_4^{2-} were found at both sides simultaneously, and arrows raised upwards within diamond shape of diagram (Fig. 2). The most of samples gathered upwards Ca^{2+} and Cl^- and also indicated that the water samples were calcium and chloride type.

Scatter diagram analysis

The scatter diagram is used to identify the relationship between two variables on *Y* and *X* axis. If the variables are correlated with each other, the curve will be linear, and the diagram showed *Y* axis indicated the fluoride values and *X* axis indicated the TDS concentration. The first cluster of dots gathered between TDS 500 and 1000 mg/L; second cluster of dots gathered between TDS 2000 and 3000 mg/L. It is observed that the concentration of fluoride increased with increase in the value of TDS except samples number 13 and 15, where the concentration decreased (Fig. 3).

Principal component analysis (PCA)

Principal component analysis (PCA) is powerful tool that attempts to describe the variance of the large data set of inter-correlated variables with the smaller data set of independent variables. It extracts an eigenvalues from covariance matrix of original variables and weighted linear combination of original variables. The rotated components matrix for 25 physicochemical parameters of the water samples of study areas are shown in Table 6. It includes loading components for rotated matrix, eigenvalues for six components, and cumulative percent of variance described by each component. It shows that six rotated principal components account together for 89.038% of the total variance of the data set, in which the first component account for 39.971%, second 11.451%, third 11.389%, fourth 9.259%, fifth 9.166% and sixth 7.802% of total variance. The eigenvalues of first component were greater than others and can be used to evaluate the leading of hydrogeochemical process. The component 1 which is based on load 39.971% indicated for parameters conductivity, TDS, salinity, chloride, sulphate, total hardness, sodium, calcium, magnesium, and lead with high positive loading (0.956–0.990), potassium and alkalinity was with medium positive loading (0.503–0.633), and F, Cr, Cu and O-PO_4 low positive loading (0.02–0.295). Similarly the component 2 which has 11.451% indicated high loading only for COD and NO_3 (0.735–0.757), moderate positive loading for pH (0.507) and low positive loading for calcium, total hardness, sulphate, fluoride, Pb, Fe, Mg, Cr, As, NO_3, T-PO_4, O-PO_4 and alkalinity (0.152–0.473). The component 3 which has loading of 11.389% has good positive loading for F and K (0.833–0.858), moderate positive loading for alkalinity (0.656) and low positive loading for conductivity, TDS, salinity, Ca, Mg, Na, SO_4, total hardness, Cd, Fe, Cr, Ni, COD, Mn, NO_3, T-PO_4, and O-PO_4, (0.006–0.375). The component 4 which has loading of 9.259% has good positive loading for Cu and As (0.826–0.869) and low positive loading for conductivity, TDS, salinity, Ca, Mg, Na, SO_4, total hardness, Cl, alkalinity, sulphate, Cr, Ni

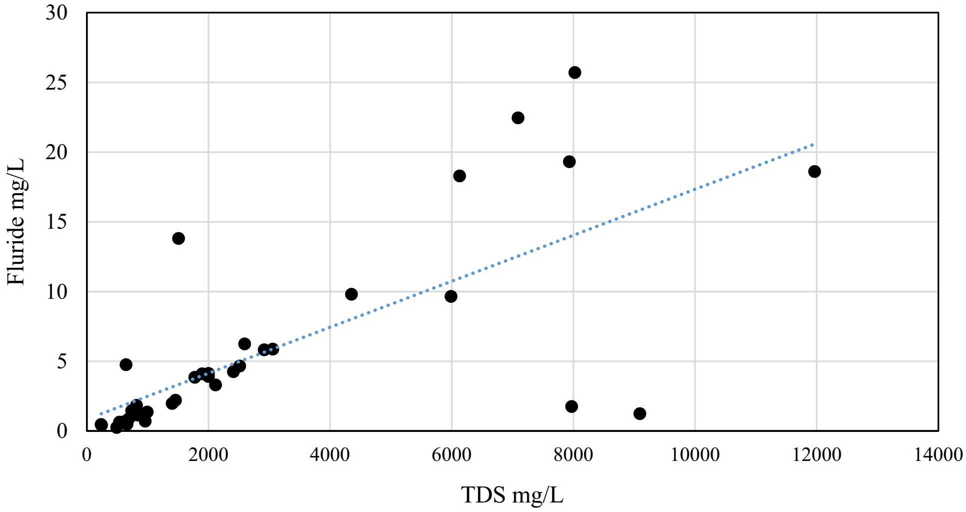

Fig. 3 Scatter diagram of fluoride versus TDS

and Pb (0.019–0.201). The component 5 which has loading of 9.166% has good positive loading for O-PO_4 and Mn (0.805–0.826), moderate positive loading only for Co (0.522) and low positive loading for conductivity, TDS, alkalinity, Mg, Na, F, Cd, Cr, Ni, COD, NO_3, NO_2 and T-PO_4 (0.005–0.465) (Table 5). The component 6 which has loading of 7.802% has good positive loading for T-PO_4 (0.896), moderate positive loading only for pH (0.569) and low positive loading for conductivity, TDS, salinity, alkalinity, T hardness, K, Mg, Cd, Cr, Ni, Mn, COD, NO_3 and O-PO_4 (0.005–0.465). It reflects the composition of the components within the water bodies at study area.

Ions balance

The ions balance method was used for the seven major parameters of groundwater, cations Na, K, Ca, Mg and anions Cl, SO_4 and HCO_3. The pie chart showed predominance of chloride than other parameters 23.86 meq/L, and potassium was found to have the lowest value than other parameters 0.74 meq/L. The ions balance results were in meq/L Na 13.85, K 0.74, Ca 12.05, Mg 14.91, Cl 23.86, SO_4 11.27 and HCO_3 6.11 meq/L. The sum of cation 41.55 and sum of anions 41.24 meq/L and error percentage 0.75% meq/L were observed in the ions balance equation (Fig. 4).

Suitability of water for irrigation

Salinity hazard

Low-salinity groundwater (EC < 500 µS/cm) can be used for agriculture of most cultivation, and salinity of soil will not be developed. Only two (5.26%) samples were found in low-salinity category (Fig. 5). Medium salinity (EC 500–1000 µS/cm) may be used for the soils washed with enough volume of water. Most of the crops with moderate quantity of salt may grow without using special procedures for the regulation of the salinity. Four (10.52%) samples were found in medium-salinity category. Water with high salinity (EC 1000–3000 µS/cm) cannot be used on the soils without controlled drainage. Special managing of salinity and selection of crops will require best salt tolerance even for the soils with suitable drainage. Fifteen (39.47%) samples were found in high-salinity category. Very high salinity (EC > 3000 µS/cm) is not fit for crops under normal conditions; nevertheless, it may be used under very special conditions. The soils may be necessary permeable, drainage must be tolerable, and water must be used in extreme quantities in order to certify higher level of soil leaching to be able to cultivate crops that are very high salt tolerant. Seventeen (44.73%) samples were found in very high-salinity category (Fig. 5).

Sodium percentage

The Na% results of water are divided in the three categories (20–40 Na%) good, (40–60 Na%) permissible and (60–80 Na%) doubtful. The Na% of study area was found between (21.6 and 61.3 Na%), 26 samples were within (20–40 Na%) as good, 11 samples were between (40 and 60 Na%) permissible, and only one sample was in (60–80 Na%) doubtful category.

Sodium adsorption ratio (SAR)

The results of SAR in study areas varied from 0.66 to 8.30 meq/L, the SAR values of 33 samples were suitable (SAR < 6), and five samples were above the limits for irrigation (SAR > 6).

Table 5 Rotated principal component of the parameters

Parameters	Components					
	1	2	3	4	5	6
Sal	0.992	−0.019	0.099	0.061	−0.003	0.004
SO4	0.990	0.059	0.075	0.060	−0.008	0.001
TDS	0.989	−0.022	0.133	0.051	0.005	0.010
Cond	0.989	−0.022	0.133	0.051	0.005	0.010
Cl	0.987	−0.060	0.104	0.028	−0.014	−0.012
TH	0.984	0.008	0.143	0.065	0.050	0.021
Ca	0.981	0.049	0.166	0.044	−0.016	−0.004
Pb	0.980	0.001	−0.091	0.100	−0.115	−0.029
Na	0.978	−0.132	0.106	0.031	0.018	−0.003
Mg	0.956	0.098	0.254	0.019	0.020	0.024
Cr	0.503	0.228	0.181	0.201	0.465	−0.017
COD	−0.008	0.757	0.006	0.022	0.122	0.143
Ni	−0.125	−0.750	0.375	−0.103	0.372	0.048
NO3	−0.133	0.735	0.104	−0.450	0.069	0.058
Cd	−0.112	−0.692	0.167	−0.313	0.005	0.445
K	0.271	−0.195	0.858	0.120	0.032	0.058
F	0.202	0.019	0.833	−0.274	0.353	−0.058
Alk	0.633	0.024	0.656	0.066	0.262	0.205
NO2	−0.223	0.389	−0.652	−0.329	0.027	−0.488
As	−0.185	0.101	−0.080	0.869	−0.041	−0.029
Cu	0.295	0.029	0.209	0.828	−0.179	−0.162
Fe	−0.234	0.125	0.035	−0.535	−0.089	−0.315
Mn	−0.094	−0.502	0.214	−0.024	0.826	0.027
O-PO4	0.020	0.285	0.186	−0.128	0.805	0.307
Co	−0.259	−0.200	−0.375	−0.360	0.522	−0.495
T-PO4	−0.069	0.015	0.164	−0.108	0.346	0.896
pH	−0.125	0.507	−0.290	0.174	−0.353	0.569
Eigenvalues	10.792	3.092	3.075	2.500	2.475	2.106
% Of variance	39.971	11.451	11.389	9.259	9.166	7.802
Cumulative%	39.971	51.422	62.811	72.070	81.023	89.038

Rotated component matrix

Permeability index (PI)

The permeability index PI in the study area was found between 34.2 and 96.6 meq/L. According to the present study, the 17 samples (44.74%) were in high permissibility PI, (75%) Class I which were good for irrigation and 12 samples (31.58%) were between 50 and 75% (Class II), and were suitable for irrigation and nine samples (23.68%) were in less than 50% permissibility (Class III) which were unsuitable for irrigation purposes (Table 6).

Kelly's index (KI)

The KI (<1) showed suitability for irrigation and KI value (>1) showed high level of Na and not fit for irrigation. Kelly's index KI in the investigated area was from 0.20 to 1.52 meq/L. According to the present study, 35 water samples were suitable and three were unsuitable for irrigation.

Residual sodium carbonate

RSC is divided in three categories (<1.25 'safe'), (1.25–2.5 'marginal') and (>2.5 'unsuitable'). The RSC value of all samples was founded in 'safe' category (<1.25 meq/L).

Chloroalkaline indices

If CAI-1 value is negative (−), it means the base exchange occurs among Na^+ and K^+ in groundwater with Ca^{2+} and Mg^{2+} in the soils, and if CAI-1 value is positive (+), it indicates there cannot be base exchange. A total of 14 samples CAI-1 values were founded in negative, and 24 samples were founded positive.

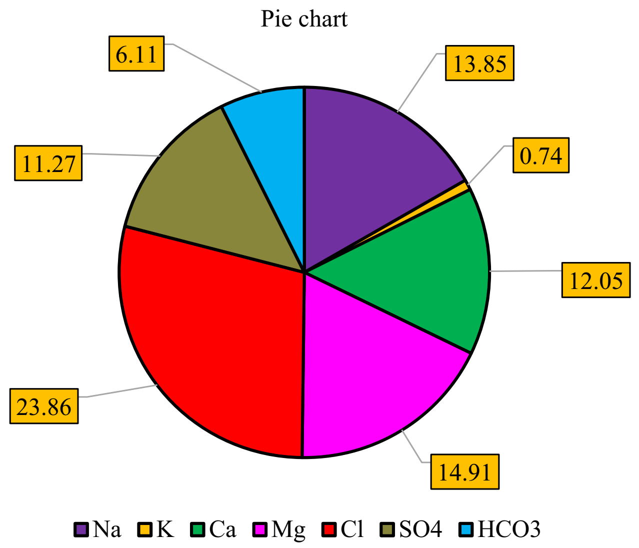

Fig. 4 Pie chart of anions and cations

Chloride–sulphate ratio (Cl^-/SO_4^{2-})

The chloride–sulphate ratio of the study area was between 0.62 and 6.60 meq/L. If (Cl^-/SO_4^{2-}) is less than one, the sample is suitable for irrigation, and if (Cl^-/SO_4^{2-}) value is higher than 1, it means the sample is salty and not suitable for irrigation. The 33 samples of the present study indicated chloride–sulphate ratio greater than one, and five samples were less than one (Table 6).

Chloride bicarbonate ratio

The chloride bicarbonate in the study area was found between 0.29 and 21.42 meq/L. If chloride bicarbonate ratio is less than one, the sample is suitable, and if ratio is above than 1, the sample is not suitable for irrigation. The 24 samples indicated chloride bicarbonate ratio greater than one and 14 samples were less than one (Table 6).

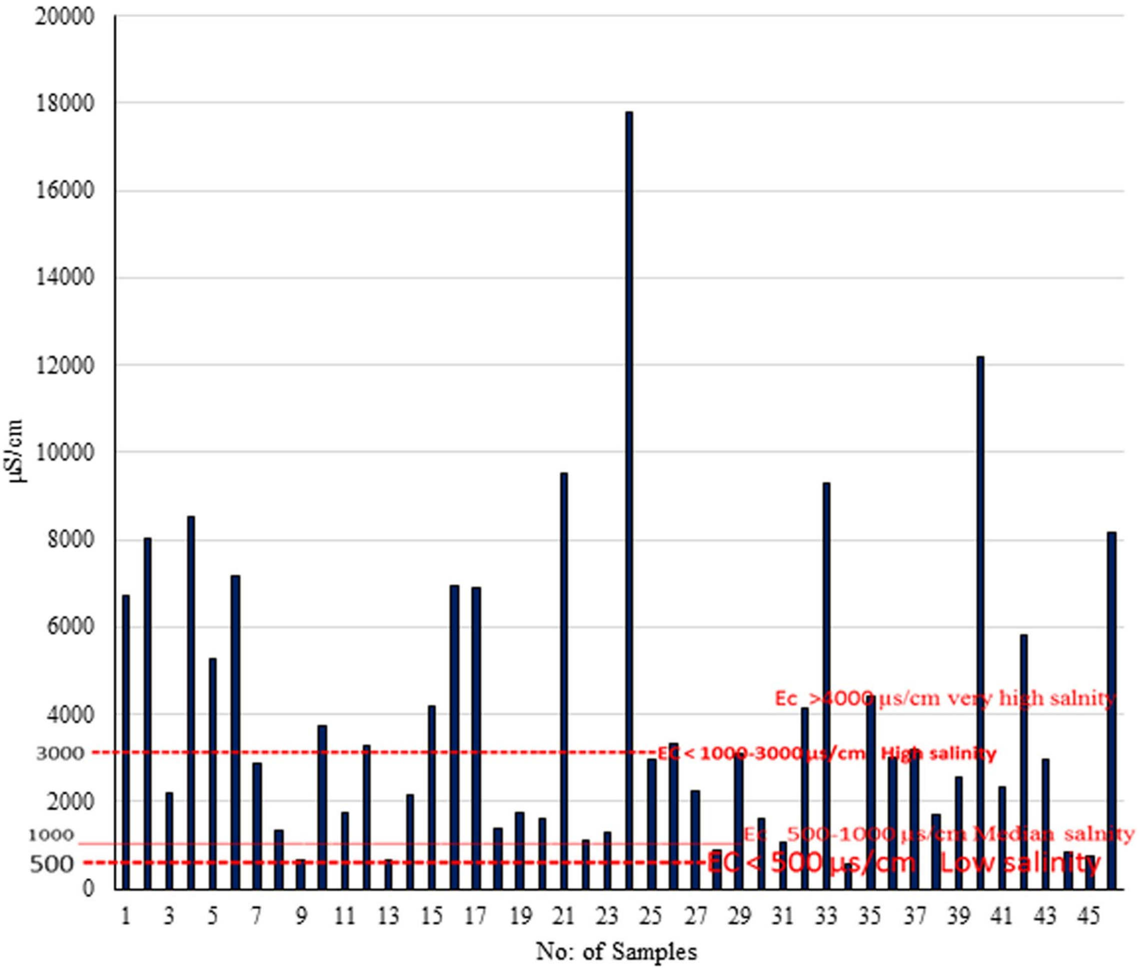

Fig. 5 Salinity hazards

Table 6 Suitability of water for irrigation

S:ID	SAR (meq/L)	Na% (meq/L)	PI (meq/L)	KI (meq/L)	RSC (meq/L)	CA1 (meq/L)	Cl/SO4 ratio (meq/L)	Cl/ HCO$_3$ ratio (meq/L)
1.	6.25	34.7	41.0	0.51	−66.5	0.54	2.78	10.67
2.	1.28	26.3	63.4	0.34	−3.45	0.09	1.17	0.77
3.	4.86	29.7	36.0	0.39	−69.6	0.50	1.82	7.68
4.	5.86	31.1	38.3	0.43	−80.6	0.54	3.54	8.47
5.	4.78	42.1	53.0	0.71	−18.2	0.46	4.51	6.93
6.	3.98	39.8	54.3	0.62	−15.0	0.16	1.61	3.10
7.	4.43	30.7	38.7	0.37	−56.3	0.52	2.05	6.15
8.	4.08	36.7	52.7	0.53	−21.8	0.43	3.43	3.66
9.	8.30	36.1	39.2	0.43	−107	0.55	4.50	21.42
10.	4.57	46.0	66.6	0.82	−9.33	0.14	3.10	2.52
11.	4.57	52.6	84.6	1.07	−2.88	−0.16	1.82	1.40
12.	1.12	29.5	83.4	0.35	−1.1	−0.15	1.92	0.46
13.	6.12	33.7	36.5	0.46	−80.4	0.48	1.80	13.91
14.	1.84	37.1	96.3	0.55	−0.31	−0.25	3.86	0.50
15.	8.01	42.7	50.2	0.73	−51.4	0.30	1.60	7.60
16.	3.00	39.7	75.6	0.61	−4.77	−0.15	1.15	0.94
17.	3.06	45.4	85.0	0.79	−2.01	−0.14	3.23	1.0
18.	2.42	41.0	80.1	0.65	−2.26	0.09	6.60	1.13
19.	2.81	47.0	86.0	0.81	−1.43	−0.46	1.10	0.81
20.	3.52	51.1	77.5	1.01	−2.76	0.10	4.98	2.11
21.	4.68	61.3	90.7	1.52	−1.10	−0.03	3.30	2.01
22.	2.92	26.6	45.7	0.35	−25.4	0.31	1.10	1.97
23.	0.90	34.0	93.8	0.45	−0.36	−0.36	2.51	0.41
24.	2.48	23.0	34.2	0.27	−34.8	0.25	0.62	2.44
25.	7.38	40.4	50.0	0.67	−50.6	0.28	2.06	5.87
26.	4.22	41.7	67.7	0.68	−10.4	0.10	1.44	1.42
27.	1.63	21.6	49.6	0.25	−13.0	0.39	1.24	1.22
28.	2.51	28.5	52.3	0.38	−14.3	0.04	0.75	1.21
29.	0.66	19.6	85.5	0.20	−0.93	0.02	0.96	0.29
30.	1.00	22.6	71.5	0.26	−2.56	0.01	1.13	0.46
31.	1.41	27.1	74.1	0.35	−2.8	0.06	1.33	0.61
32.	0.83	32.5	96.6	0.39	−0.1	−0.61	0.95	0.31
33.	0.77	28.3	83.2	0.34	−0.5	−0.34	1.26	0.38
34.	0.21	31.7	69.6	0.43	−5.7	−0.4	1.45	0.82
35.	1.41	29.3	75.7	0.38	−2.5	−0.20	1.20	0.52
36.	3.12	34.4	57.7	0.50	−12.2	−0.06	0.90	1.37
37.	2.46	42.7	89.4	0.69	−1.13	−0.19	2.17	0.76
38.	4.05	38.1	55.2	0.60	−16.3	0.23	2.12	2.84

Conclusion

The present study analysed the groundwater of three talukas of District Qambar Shahdadkot. The samples analysed were compared with standard values of WHO for drinking water. The pH value of all samples was within limits. The results of electrical conductivity and total dissolved solids of 57.89% were higher than WHO limits. The concentration of anions and cations of about half of samples was above the limits. The concentration of fluoride in 50% was above than maximum permissible limits of WHO. The heavy metals like Fe, Mn, Co and Cu of all samples were within permissible limits of WHO, but concentration of Cr 49.42%, Ni 21.05%, Cd 28.94% Pb 18.42% and NO$_3^-$-N 7.89% samples was higher than permissible limits of WHO. The heavy metals were present in following decreasing order Fe > Ni > Cr > Mn > Cu > Co > Pb > Cd. The high concentration of Ni, Cr, Pb and Cd may due to the drainage waste water and geological nature of area. The concentration of, NO_2^--N, T-PO_4^{3-}-P and O-PO_4^{3-}-P and COD of 10 samples were above than limits; arsenic of only one sample was above the permissible limits of WHO. The concentration of Cl and K 60.52%, hardness 36.84% and SO_4^{2-} 52.63%, Na, Ca, Mg and alkalinity 47.36% were higher than permissible limits of WHO. The water quality of study area at (57.89%) places is not suitable for human consumption. The taluka Shahdadkot was more contaminated than other two talukas and taluka Sijawal Junejo was less contaminated by TDS and the majority of samples were suitable for human consumption as well as irrigation. However, it could be used for irrigation with controlled drainage, keeping in view the quality of groundwater and the nature of soil.

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