Sustainable Water Resources Management (2019) 5:1593–1614
https://doi.org/10.1007/s40899-019-00319-0

ORIGINAL ARTICLE

A study on groundwater hydrochemistry in Khatra Block, Bankura district, West Bengal

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Received: 16 July 2018 / Accepted: 17 April 2019 / Published online: 22 May 2019

Abstract

A study was conducted to detect the hydrochemistry of groundwater in Khatra Block,Bankura district, West Bengal. For this, nineteen water samples from borewells during postmonsoon and premonsoon sessions each were collected. Analyses of these water samples were done to evaluate their hydrochemistry and usability for domestic and agricultural uses. Measurement of some parameters which include pH, TDS, and EC has been done in situ sample location points itself. For determining other parameters like cations (Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+}) and anions (Cl^{-}, HCO_3^{-}, SO_4^{2-}, F^{-}), samples were brought to the laboratory. For determining irrigation suitability of collected groundwater samples, parameters such as sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), magnesium adsorption ratio (MAR), Kelly's ratio (KR), permeability index (PI) and corrosivity ratio (CR)were calculated. The waters are found to belong to low salinity and sodium types when marked in the US Salinity Laboratory (1954) diagram and suggest good for agricultural uses. The hydrochemistry of the investigated area is normally good but varies from very hard to hard. In few localities of the investigated area, total hardness is identified as high, which suggest not to use the water for drinking purpose. In such places, the groundwater may be contaminated by interaction between rock and water along with agricultural drain out. The Piper plot shows marked domination of Ca^{2+}–Na^{+}–SO_4^{2-}, mixed Ca^{2+}–Mg^{2+}–Na^{+}–HCO_3^{-} types. To determine the suitability of these groundwater samples for domestic purposes, Water Quality Index (WQI), Gibb's ratio for both cations and anions, and Chloro-Alkaline Indices (CAI) have been calculated along with plotting in Chadha's and Schoeller diagrams. It also indicates the preponderance of alkaline earth over alkalis and weak acids over strong acids. For utilizing the groundwater in domestic purposes, index of water quality was also determined. Water Quality Index values varied from 74.74 to 209.4 in postmonsoon, and 70 to 205 in premonsoon period which suggest the water good enough to use for domestic purposes.

Keywords Hydrochemistry · Irrigation suitability · Piper's diagram · WQI · Gibb's diagram · Chadha's diagram · Khatra block · Bankura district

Introduction

Groundwater forms a principal source of water supply in the world (Todd 1980). It forms our most abundant fresh water resource. The contribution of groundwater is only 0.6% of the whole resources of water on earth. In the developing countries, like India, groundwater constitutes ~ 80% of the domestic water supply in rural areas and only 50% in urban areas. Groundwater constitutes a major safe source of water for drinking in Indian subcontinent (Acworth 1987; Ahn and Chon 1999), but currently its quality is deteriorating due to combined effects of over extraction, chemical pollution, etc. Hard rocks consisting of gneisses of granitic composition of Archean/Precambrian ages constitute the major aquifers of the world. These aquifers occur mostly within the fissured/fractured or weathered formations of the hard rocks (Al-Futaisi et al. 2007). The study on quality assessment of groundwater exposes usefulness of this water to be used for domestic or agricultural purposes. Only 77% of populations in urban areas and only 31% of populations in rural areas obtained access to usable water supply in Indian

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40899-019-00319-0) contains supplementary material, which is available to authorized users.

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subcontinent (Kaul et al. 1999). In dry climatic regions, ground waters are utilized for agriculture and, hence, quality of water used in agriculture is significant for successful crop production. Crop yields are affected by the use of poor quality water in agricultural purposes along with physical conditions of the soil (Talukder et al. 1998). With the movement of ground water from the recharge site to the discharge site, the chemistry gets changed due to several geochemical processes. The evaluation of various hydrogeochemical processes responsible for such changes in groundwater helps the administrators for taking necessary steps in maintaining quality control to improve in any area's development (Hem 1991).

Water being a very good solvent can dissolve the minerals of the rocks where it is stored. Hence, the hydrochemical attributes of such water depend largely on geology of that area. The thickness and structures of the rock types greatly influence the transportation and storage of groundwater. Hydrogeologically, the weathered overload is presumed with high porosity and has a good amount of water, but its permeability is low due to relatively high clay content. The rocks occurring as basement are relatively fresh, highly fractured and thus possess good permeability (Dewandel et al. 2006). A clear knowledge of probable differences in quality is better understood by studies of hydrochemistry of groundwater, and this allows deciphering the usability of groundwater for domestic and agricultural purposes which have been done by various workers in Indian subcontinent and around the globe as well (Kundu Anindita and Nag 2018; Nag and Das 2017; Nag 2014; Nag and Ghosh 2013; Rao et al.2012; Nag and Lahiri 2012; Brindha and Elango 2012; Tiwari 2011; Prasanna et al.2011; Kaka et al.2011; Bhardwaj and Sen Singh 2011; Rao and Rao 2010; Naik et al. 2009; Pritchard et al. 2008; Gupta et al. 2008; Irfan and Said 2008; Al-Futaisi et al. 2007; Jalali 2006; Tripathy and Panigrahy1999; Rivers et al. 1996; Reddi et al.1993).

Decipherment of hydrochemistry provides a clear vision on the geologic environments underneath the surface where water actually occurs (Raju et al.2011). A good number of studies in various portions of the globe have already been done to assess the hydrochemistry (Belkhiri and Mouni 2012; Siddiqui et al. 2005).Variations in hydrochemistry in an area are influenced greatly by geological units and anthropogenic activities (Singh et al. 2013; Schiavo et al. 2006; Subramani et al. 2005). Proper assessment of the usability of groundwater for domestic and agricultural purposes depends on some key parameters, such as pH, TDS, EC, Mg^{2+},Ca^{2+}, K^+, Na^+, HCO_3^-, Cl^-, SO_4^{2+} and F^-. Index of Water Quality (WQI) is capable of converting huge quantity of data on water quality into a unique number that represents the scenario on quality of water. Various research scientists have previously utilized the tool of WQI to determine the quality of groundwater (Tiwari and Mishra 1985; Debels et al. 2005; Vasanthavigar et al. 2010). Mapping of different parameters on water quality has successfully been done by many authors (Dar et al.2011; Nas and Berktay 2010; Ahn and Chon 1999).

Groundwater samples from nineteen (19) different spots from Khatra block, Bankura district, West Bengal were compiled to have knowledge on its groundwater scenario and its quality. In study region (Khatra Block), weathered/fractured granites and their gneissic equivalents constitute the main aquifer. In Khatra Block, a detailed study on geochemical variation has been done in postmonsoon and premonsoon sessions, to discern the wellness of groundwater for domestic and agricultural uses. Hence, an evaluation on groundwater quality gained importance.

Dug wells, borewells and surface water form the major sources of water supply in Khatra block. Human activities are responsible for polluting the water resource, particularly in the dug cum open wells as well as surface water. Indiscriminate dumping of house hold solid waste and the adoption of pit latrines by most residents owe their main contributions in polluting water in Khatra block area. These are responsible for preponderance of water-borne diseases here—a very common unfortunate situation. Keeping this information in background, the hydrogeochemical assessment of groundwater of Khatra block in Bankura District was duly executed. The outputs of such study will act as useful guidelines in controlling further deterioration of the arising circumstances.

Study area

The district of Bankura is placed on the eastern sector of the Chotonagpur Plateau and is situated at western section of West Bengal. The study area, Khatra Block, is situated in the western sector of Bankura district and falls between 22°50′30″N to 23°12′30″ N latitude and 86°45′0″E to 86°56′, and covers approx. 447 km^2 (Fig. 1). SoI Toposheet nos. 73 I/12, 73 I/16 and 73 J/13 were utilized to map the area. The terrain is vastly consisting of granite gneisses and their metamorphic equivalent rocks with schistose rocks at places. The undulating topography along with the presence of low hillocks and wide valleys is characteristic of the area. Elevation varies from 180 meters (north western part) to 40 meters (south and south eastern part). Whole area is enclosed by undulating hilly tract intersected by valleys, and the region is drained by two main rivers Kangshabati, Silabati along with their tributaries. Kangshabati covers southern periphery and Silabati covers north eastern fringe of the area. In general, the drainage characteristics of the area are parallel to sub-parallel and are controlled by structural elements. The study region lies in semi-arid climatic zone. The mean rainfall in the area is 132 cm/annum, and maximum

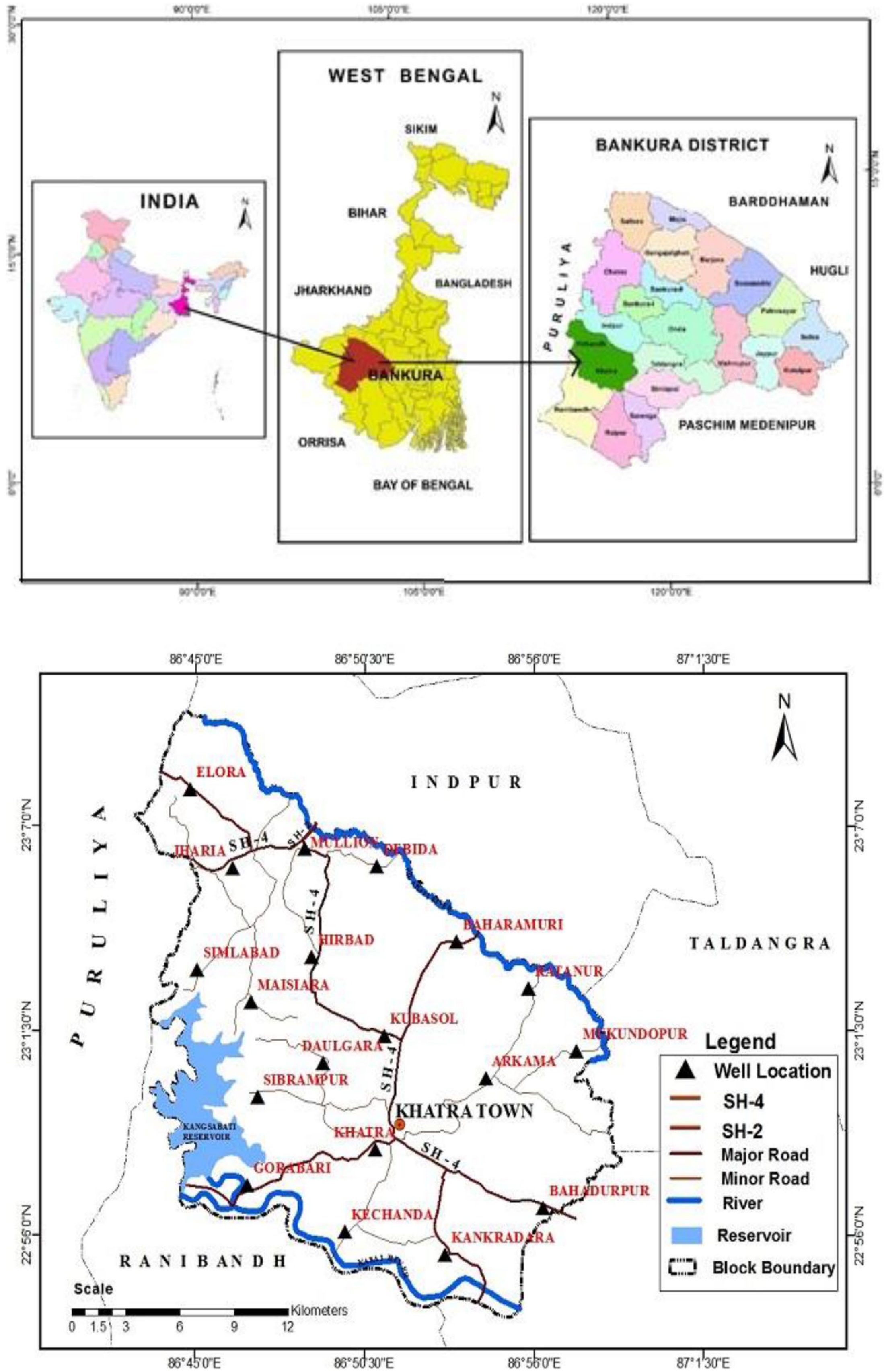

Fig. 1 Map showing locations of sampling points in the study region

precipitation occurs during June–September with the arrival of southwest monsoon. The temperature varies from 22 °C to 44 °C. May is the warmest month when temperature exceeds 40 °C, and the coldest month is January when temperature goes down often to below 12 °C.

Hydrogeology

Granite gneisses, hornblende schists and alluvium occur in Khatra region. The rock types are of Archean age. For the current study, map showing geology of the area has been prepared from the pre-existing map done by Geological Survey of India (GSI 2001; Fig. 2). Granite gneiss occurs in the northern part, eastern and south-western part of the region. Hornblende schist also occurs in the lower part of the region and covers 6 km^2 areas. Usually, basement rocks occur as massive and unfractured units and have practically no influence on availability of groundwater. But sometimes, with the development of secondary porosity due to weathering of overburden rocks and fracturing of bed rocks, very good groundwater potential zones are developed. The rock types are composed mainly of gray and pink feldspar (alkali and plagioclase feldspar) with quartz grains, pyroxene, biotite and hornblende. The rock types are composed mainly of pink and gray feldspar with quartz grains, pyroxene, biotite and hornblende. The occurrence of groundwater is limited to maximum 10–13 m below the ground level during post-monsoon and premonsoon sessions. In areas covered by the valley-fills, water table occurs at very shallow depth. Groundwaters in alluvial part occur in water table conditions. These formations are generally highly permeable and porous, and the thickness is very shallow. Normally, the thickness of weathered residuum, in crystalline rocks, is very irregular—both in areal extent and depth. As a result, the frequency of weathering has an influence on the renewal of groundwater. Unconsolidated weathered residuum originated through bedrock decomposition produces high porosity and low permeability (Acworth 1987). Groundwater occurrence in crystalline rocks is dependent on rock types and intensity of the fractures as well. In crystalline rock aquifers, storage of groundwater is very complex because of their impervious nature and the fracture system present in them mainly controls the presence and movements of groundwater. These are the places of accumulation of groundwater. Consequently, increased well yields are expected from these places (SubbaRao et al. 2001; Das et al. 1997).

Methodology

Altogether 19 groundwater samples each in both post- and premonsoon sessions, from various locations spreading over the Khatra Block area, have been collected from borewells to evaluate the physico-chemical parameters. The study region falls under SoI Topo sheets 73I/12, 73I/16 and 73 J/13. We have used ArcGIS and Surfer Golden 13 software in this study. Map comprising location points was prepared based

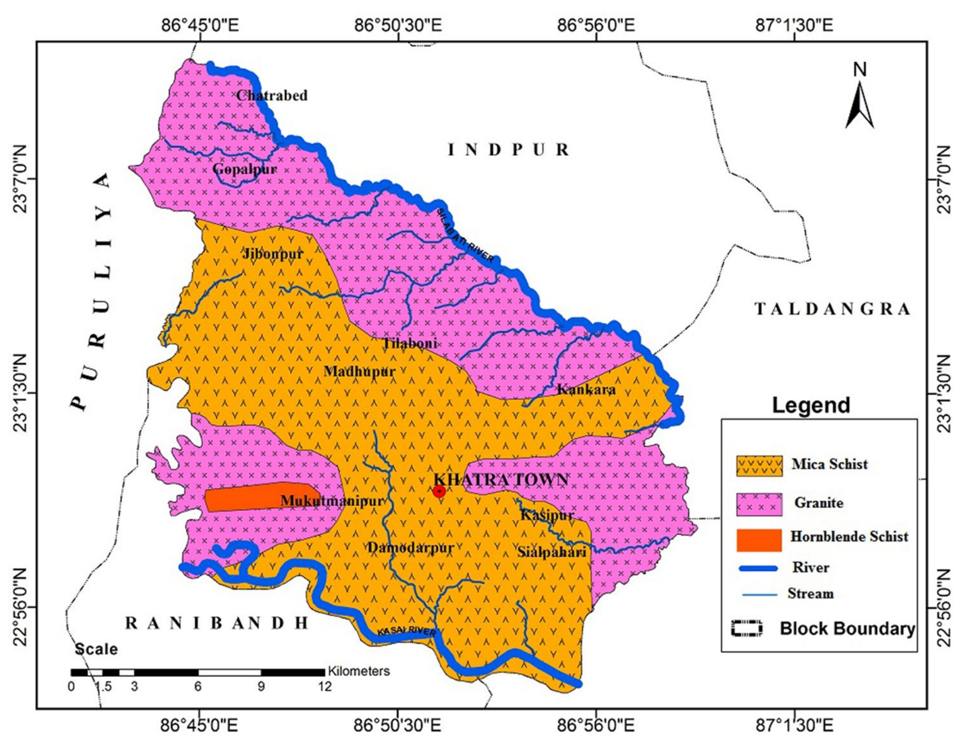

Fig. 2 Map showing geology of the study region

on GPS readings corresponding to each location (Fig. 1). pH Testr2, EC Testr + and DIST3 of Hanna Instruments were used for on-spot measurement of pH, TDS and EC. The samples were collected in the polyethylene bottles of 1000 mL after cleaning them thoroughly by acid. The bottles were entirely filled before sealing tightly. All required protections have been taken (Brown et al.1974) for analysis of collected samples, using solutions prepared from high-quality pure chemicals and double-deionized water. Analyses for collected samples of groundwater have been done for ions like Mg^{2+}, Ca^{2+}, K^+, Na^+, Total alkalinity, HCO_3^-, SO_4^{2-}, Cl^- and F^-. Standard steps of analyses were pursued (APHA 1995).Calculation of ionic balances was done to verify the accuracy of analyzed data by 100 × (cations − anions)/(cations + anions), and the outputs were generally within ± 5% (Srinivasamoorthy et al.2012).

Further calculations have been made for the SAR (Sodium Adsorption Ratio), SSP (Soluble Sodium Percentage), MAR (Magnesium Adsorption Ratio, RSC (Residual Sodium Carbonate), KR (Kelley's Ratio), PI (Permeability Index),CR (Corrosivity Ratio). Piper trilinear and index for water quality specially calculated for determining drinking water suitability. Graphical presentations in diagrams of U.S. Salinity, Wilcox, Doneen and Water Quality Index (WQI), Gibb's Chadha's, Schoeller followed by calculations of Chloro-Alkaline Indices (CAI) have been made to decipher the suitability of groundwater for agricultural and drinking purposes.

Results and discussions

Fluctuation in level of groundwater

Levels of groundwater measurement were done as a routine job of the investigation, in 19 locations during post- and premonsoon sessions (Table 1) with Heron automatic recorder of level of water. In all cases recorded water levels were converted to heads which indicate the fluctuations in levels of groundwater (head) from 100.61 m to 177.96 m a.m.s.l during postmonsoon and 98.22 m to 175.81 m a.m.s.l in premonsoon. In both sessions, the lowest value of head was observed in Kankradara bore well. The value noticed to be maximum at Kubasol in both post- and premonsoon sessions. Generally, levels of water in postmonsoon become higher in comparison to premonsoon. The hydrograph (Supplementary Fig. 1) was made showing variation from 1.48 m to 5.31 m between postmonsoon and premonsoon. The variation is maximum in Sibrampur area (5.31 m) but minimum in Moisiara area (1.48 m).

Quality of groundwater

Different parameters (both physical and chemical) (pH, TDS, EC, Ca^{+2}, Mg^{+2}, Na^+, K^+, HCO_3^-,SO_4^{2-}, Cl^-, TH, TA and F^-) have been determined/measured for nineteen groundwater samples each in both sessions collected from Khatra block area which are presented in Table 2.

Table 1 Depth of water tables (Head) for bore wells

Location name	Location	Water tables head (m)		Fluctuation (m)
		Postmonsoon (m)	Premonsoon (m)	
Baharamuri	L1	109.65	105.21	4.44
Kubasol	L2	177.96	175.81	2.15
Daulgara/Maisile	L3	149.69	147.12	2.57
Moisiara	L4	143.93	142.45	1.48
Simlabad	L5	148.06	143.44	4.62
Sibrampur	L6	145.35	140.04	5.31
Gorabari	L7	110.45	107.32	3.13
Kechenda	L8	118.88	115.11	3.77
Kankradara	L9	100.61	98.22	2.39
Bahadurpur	L10	118.51	116.11	2.4
Arkama	L11	134.95	132.11	2.74
Mukundopur	L12	112.69	110.34	2.35
Ratanpur	L13	105.85	102.78	3.07
Debida	L14	127.95	123.56	4.39
Mullion	L15	140.36	137.45	2.91
Elora	L16	167.13	163.44	1.69
Jharia kuchi	L17	155.76	151.82	3.94
Hirbad	L18	170.45	168.67	1.78
Khatra	L19	138.48	136.11	2.37

Three parameters pH, TDS and EC were determined in spot and their values vary from 6.46 to 7.3, 280 to 1390 µS/cm and 140–690 mg/l in postmonsoon period, respectively, and 6.5–7.5, 290–1140 µS/cm and 110–530 mg/l in premonsoon period, respectively (Table 2). The results reveal that pH, TDS and EC values are well within WHO (1984) permissible limit. In the current study, none of the samples have values more than allowable limits. The pH below seven indicates neutral to feebly acidic nature of water samples. Weathering of silicate minerals (Pelig-Ba1989; Wright et al.1985) present in granitoids and schists may cause the neutral to faintly acidic type of waters. Continuous and exhaustive irrigational uses along with influence from local rock types may influence for high intensifications of the dissolved minerals giving rise to high conductivity in some samples. Digestive disorder in human beings can occur due to high values of EC in water. Geochemical processes like, reverse ion exchange, interaction between rock and water, weathering of silicates, oxidation and reduction process of sulfate may increase the EC amount in underground water (Ramesh and Elango 2012). Depending on the values of EC (Handa 1969), the collected waters of Khatra region have been grouped into four classes. Based on the concentration of TDS, groundwaters are classified as (1) low ($EC < 250$ µS/cm), (2) medium (250–750 µS/cm), (3) high (750–2250 µS/cm), and (4) very high ($EC > 2250$ µS/cm) and marked as C1, C2, C3 and C4 salinity zones, respectively (Singh et al. 2011; Richards 1954). Nearly, 26% samples ($EC > 750$ µs/cm) of the Khatra block belong to high salinity zone. Bharamuri, Arkama, Sibrampur villages have shown much higher EC values during post- and premonsoon sessions.

TDS values for both post- and premonsoon sessions have shown higher concentration in Baharamuri whereas lower concentration occurred in Hirband (premonsoon), and Kechenda (postmonsoon). Classification of water based on TDS (after Caroll 1962) is shown in Supplementary Table 2.

Mg^{2+} and Ca^{2+} are most important constituent of granitic gneiss terrain. Both the ions contribute to hardness of water. Water with high hardness causes scums formation and leads to corrosion of pipes. It also checks off the cleaning action of detergents (WHO 2009). Calcium generally occurs in groundwater, as minerals like feldspar, pyroxene, and amphibole which are the prime contributors in major rock types. The concentration values of calcium vary from 43.7 to 146 mg/l and 30.12 to 120 mg/l in post- and premonsoon respectively. The highest value is found at Debida in both sessions. Weathering of magnesium-bearing minerals (pyroxene, amphibole, mica) is responsible for occurrence of magnesium (Mg^{+2}) in higher concentration than calcium in the study region. Concentration of magnesium varies between 33 and 176 mg/l and 40 and 190 mg/l in both post- and premonsoon sessions. It was noticed that the 26% of samples exceed the prescribed limit of magnesium in postmonsoon and 32% during premonsoon. In both the sessions, Mg concentration is maximum at Elora.

In the earth's crust, sodium (Na^{+}) is found in many minerals like sodalite, feldspars, and rock salt. Na concentration is normally less than that of Mg and Ca in the Khatra region. Minimum values are recorded both in postmonsoon (24 mg/l) and premonsoon (40 mg/l) at Elora and the maximum values are found in Khatra (82 mg/l) in postmonsoon and at Gorabari (110 mg/l) in premonsoon. Since the Khatra block is covered mostly by granite-gneiss and schists, the effect of geology on cation concentration is noticeable.

Concentration of K^{+} is relatively less than Na^{+} in granite-gneiss terrain. In groundwater, the main supply of potassium comes from decomposition of potash-bearing silicate minerals/potash fertilizers (Karanth 1987). Potassium content varies from 1 to 10 mg/l in postmonsoon and 4 to 20 mg/l in premonsoon sessions. Debida village shows high K concentration in both sessions.

Iron (Fe) is commonly found in soils, minerals and rocks. Groundwater remains with such solid materials, dissolves them and causes release of their components, including Fe. The extents of iron concentration in water utilized for domestic purposes range between 0.3 mg/l (acceptable limit) to 1.0 mg/l (allowable limit). Concentration of iron is high in groundwater where the pyrite-bearing rock gets exposure with oxygenated water or when ferric oxide/hydroxide minerals are in relation with reducing materials (Hem 1985). The iron content values range from 0 to 5.96 mg/l in postmonsoon and 0.13–6.8 mg/l in premonsoon sessions. The maximum value of iron during postmonsoon is found at Baharamuri, whereas during premonsoon the highest value is found in Kubasol. Nearly, 80% samples in Khatra region show high occurrence of iron. Noticeably high occurrence of Fe was observed in eastern portion of investigated area. If Fe concentration is greater than 0.3 mg/l, then water may become extremely harmful, due to its metallic taste and smudging of plumbing fixtures. To avoid the contamination from iron, the borewells are required to be cleaned from time to time along with checking and proper cementation of annular space between the borehole and the casing (Reddy 2003).

In Khatra region, HCO_3^- forms the most dominant anion. The water may be used safely for irrigational purposes if concentration of HCO_3^- is less than 91.5 mg/l. If the concentration comes within 91.5–457.5 mg/l, the waters are not useful for irrigational purposes and if the value is beyond 457.5 mg/l, irrigation will be severely affected. High concentration of HCO_3^- in surrounding country rocks indicates the presence of mineral weathering (Stumm and Morgan1996). The value of HCO_3^- ranges from 158.6 to 536.8 mg/l in postmonsoon and 130.2–480.3 mg/l in premonsoon. In both seasons, high values are observed in Debida. It is found that HCO_3^- values in Khatra region are lower than standard limit (600 mg/l) (BIS2012) during both sessions.

Table 2 Measured values of different parameters of groundwater samples for postmonsoon (PoM) and premonsoon (PrM)

Location no.	Location name	pH		TDS		EC		TA		TH		Na^+		Ca^{2+}		Mg^{2+}		Fe		K^+		HCO_3^-		Cl^-		SO_4^{2-}		F^-	
		PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM
P1	Bahara- muri	6.75	6.9	690	530	1390	1140	320	140	719	726	59	77	101	88.2	112.04	121	5.96	6.2	5	9	390.4	440.5	304.91	340.1	76.68	87.21	0.38	0.41
P2	Kubasol	7.08	7.1	320	311	640	520	280	90	573	535	32	48	123	97	63.77	70.1	5.9	6.8	4	6	341.6	280.6	114.96	128	6.78	12.11	0.673	0.69
P3	Maisile	7.3	6.9	270	190	470	480	130	60	376	344	51	80	67.2	70.1	49.97	40.5	0.92	1.7	4	7	158.6	130.2	49.98	60.1	13.72	22.23	0.512	0.54
P4	Moisi- ara	7.07	7.5	140	180	290	300	190	120	260	285	32	51	43.7	40.5	36.19	44.15	2.94	3.3	2	4	231.8	210	59.98	36.3	8.49	16.36	0.242	0.38
P5	Sim- labad	6.82	6.5	270	155	540	310	240	180	400	406	58	90	77.3	60.6	49.46	61.2	2.41	4.4	1	5	292.8	310.5	84.97	92.1	14.32	20.5	0.52	0.61
P6	Sibram- pur	6.46	6.7	480	350	960	704	160	55	745	748	70	105	118	101.7	107.95	119	0.14	0.9	7	16	195.2	245.8	214.93	200	69.05	80.12	0.4	0.44
P7	Gora- bari	6.66	6.8	360	365	730	660	330	170	485	480	81	110	85.7	69.4	64.98	73.5	0	0.1	6	10	402.6	360.7	104.97	125	29.68	35.2	0.4	0.41
P8	Kech- enda	6.91	7	140	155	280	290	210	80	254	273	30	65	45.4	30.12	33.8	47.3	0.77	0.9	3	8	256.2	220.1	24.99	34.7	3.77	7.71	0.52	0.52
P9	Kankra- dara	6.9	7	220	171	450	330	200	137	375	456	44	71	80.6	85.9	41.81	57.8	0	0.2	1	4	244	180.2	79.98	85.3	16.21	21.8	1.22	1.34
P10	Baha- dur- pur	7.2	6.8	240	222	480	400	340	157	356	321	64	80	53.8	44.8	53.25	50.1	4.23	5.6	5	12	414.4	381.4	34.99	54.1	18.27	26.6	0.95	1.02
P11	Arkama	6.7	6.9	510	512	1020	911	300	210	834	827	58	50	146	120	112.69	127	0.74	0.8	4	11	336	270.3	229.93	216.3	53.78	60.4	0.54	0.58
P12	Mukun- dopur	7.12	7.3	370	340	740	842	300	230	575	556	57	66	111	80	71.52	85.4	0	0.13	5	6	336	290	139.96	158.2	42.97	48.9	0.52	0.49
P13	Ratan- pur	7.15	7	250	142	510	310	150	70	416	414	42	77	85.7	78.9	48.39	52.1	0.18	0.2	4	5	183	231.6	119.96	158.21	28.73	36.4	0.238	0.33
P14	Debida	7.17	6.9	290	233	570	390	440	280	936	894	63	62	99.1	72.1	165.16	171	1.75	2.3	10	20	536.8	480.3	29.99	44.33	4.97	8.81	0.501	0.55
P15	Mullion	6.96	7	430	355	860	704	220	130	475	458	75	92	101	82.9	53.48	60.22	1.71	2.7	3	8	268.4	333.5	214.9	240.45	69.05	76.11	0.273	0.29
P16	Elora	7.06	7.2	260	221	520	432	230	70	925	960	24	40	75.6	66.8	176.75	190.4	4.12	5.2	2	4	280.6	202.2	99.97	104	24.44	30.3	0.334	0.39
P17	Jharia kuchi	7.01	7	250	264	510	350	340	210	507	609	46	56	70.6	73.1	79.41	102	0.96	0.5	5	12	414.8	371.5	34.99	45	12.18	31.45	0.464	0.54
P18	Hirbad	6.8	6.7	190	110	370	390	180	110	325	371	32	66	60.5	55.4	41.85	55.9	1.47	1.7	3	6	219.6	261.7	59.98	71.22	8.66	14.2	0.454	0.49
P19	Khatra	6.65	6.8	340	212	680	411	320	160	538	571	82	97	94.1	90.7	72.69	82.7	2.03	3.5	5	10	390.4	427	104.97	133	24.44	37.1	0.732	0.81
Min.		6.46	6.5	140	110	280	290	130	55	254	273	24	40	43.7	30.12	33.8	40.5	0	0.13	1	4	158.6	130.2	24.99	34.67	3.77	7.71	0.238	0.29
Max.		7.3	7.5	690	530	1390	1140	440	280	936	960	82	110	146	120	176.75	190.4	5.96	6.8	10	20	536.8	480.3	304.91	340.1	76.68	87.21	1.22	1.34
Mean		6.94	6.95	316.84	264.1	632.11	519.68	257	140	530	539	52.6	72.8	86.28	74.12	75.54	84.806	1.907	2.482	4.16	8.58	309.07	296.22	111.02	122.48	27.694	35.451	0.52	0.57
Median		6.96	6.9	270	222	540	411	240	137	485	480	57	71	85.7	73.1	63.77	70.1	1.47	1.72	4	8	292.8	280.6	99.97	98.05	18.27	30.3	0.50	0.52
Std. Dev.		0.22	0.23	135.89	119.47	274.36	241.78	81.7	63.1	211	207	17.7	19.8	27.11	21.97	41.46	43.148	1.912	2.223	2.14	4.29	99.61	94.996	78.37	65.953	23.39	24.361	0.24	0.254

TDS total dissolved solids (mg/L), *EC* electrical conductivity (μs/cm), *TA* total alkalinity (mg/L),*TH* total hardness (mg/L), *Ca* calcium (mg/L), *Mg* magnesium (mg/L), *Na* sodium (mg/L), *K* potassium (mg/L), *Fe* iron (mg/L), HCO_3^- bicarbonate (mg/L), Cl^- chloride (mg/L), SO_4^{2-} sulfate (mg/L), F^- fluoride (mg/L), *PoM* postmonsoon, *PrM* premonsoon

Cl^- bears a close relationship with Na^+ and is widely distributed through all varieties of rocks. In case of high temperature and reduced rainfall conditions, the chloride occurrences are also high. Cl^- ion in combination with Na^+, generated through decomposition of granitic terrain, forms NaCl. When Cl^- occurs in excessive amount in water, it becomes saline and unsuitable for drinking and irrigational uses. People also experience laxative effects for consuming such water. In water, Cl^- concentration also comes from weathering of minerals (mica, apatite, etc.) and also from liquid inclusions present in crystalline rocks (Das and Malik 1988). The occurrence of excessive chloride along with magnesium is responsible for corrosion of domestic utensils (Gaikwad et al. 2010). The value of Cl^- ranges from 24.99 to 304.91 mg/l in postmonsoon and 34.67–340.10 mg/l in premonsoon sessions. Baharamuri, Mullion, Arkama, Sibrampur villages showed little high Cl^- concentration in the both sessions.

Another major anion occurring in natural waters is Sulfate. Sulfates (SO_4^{2-}) are derived from rocks having iron sulfides, gypsum and other sulfur-bearing minerals. Under conditions of low dissolve oxygen concentrations in presence of anaerobic bacteria, sulfide is produced from the reduction of sulfate. Bacteria responsible for sulfate reduction obtain its energy from oxidation process of organic compounds and oxygen from sulfate ions (Lehr et al. 1980). If the sulfate along with magnesium concentration is high, the water under low alkalinity corrodes metals used in water supply system (Raju et al. 2011). SO_4^{2-} values in Khatra region range between 3.77 and 76.68 mg/l in postmonsoon and 7.71–87.21 mg/l in premonsoon sessions. The highest value is noted at Baharamuri in both periods but the lowest value is found at Kechenda in postmonsoon and at Balarampur in premonsoon. The results suggest that the quantity of sulfate in all samples of groundwater is within permissible limits when compared with the standards of BIS (2012) for drinking purposes.

Fluoride generally occurs in nature as fluorspar (CaF_2), triphite, rock phosphate, phosphorite crystals, etc. Fluoride occurrence is high in groundwater where bedrock contains fluoride minerals (Handa 1975; Wenzel and Blum 1992; Bardsen et al. 1996). Anthropogenic activities also contribute to considerable amount of fluoride in groundwater (Ravikumar et al. 2013). Normally, fluoride concentration in water used for domestic purposes is 1.0 mg/l though it can extend up to 1.5 mg/l (BIS 2012). If the water with excess fluoride (> 1.5 mg/l) is used for drinking purposes, it causes skeletal and dental fluorosis. The fluoride content varies from 0.238 to 1.22 mg/l in postmonsoon and 0.29–1.34 mg/l in premonsoon periods. Most samples show fluoride content below 1 mg/l in the study region except, in Kankradara, where the concentration of fluoride observed is > 1 mg/l (1.22 mg/l) during postmonsoon.

The presence of salts (carbonates, sulfates of magnesium and calcium) in solution commonly creates hardness of water. Hard water causes the formation of scales in cooking utensils, pump wells, boilers and supply pipes, and also needs more soaps for washing of clothes (Hem 1991; Todd 1980). TH (total hardness) should be below 300 mg/l and allowable limit is up to 600 mg/l (WHO 2004).The TH values in this region vary from 254 to 936 mg/l in postmonsoon and 273 to 960 mg/l in premonsoon sessions. The lowest value of TH is found at Kechenda, while the highest value is at Debida in postmonsoon session, whereas in premonsoon period, the minimum value is obtained at Kechandra and the maximum value is at Elora (Table 2, Supplementary Table 3). Baharamuri, Sibrampur, Arkama, Debida, and Elora areas have very high hardness levels in both periods.

The capability of neutralizing a strong acid is the total alkalinity (TA) of water. The prime causes for alkalinity are HCO_3^- and CO_3^{2-} which also govern the water hardness. The maximum allowable limit of TA is 600 mg/l (WHO 2004). High value of alkalinity causes a sour taste and use of such water for irrigation purposes is not desirable as it damages the soil and reduces the crop yields. In the investigated region, the total alkalinity values vary from 130 to 440 mg/l in postmonsoon and 55 mg/l to 280 mg/l in premonsoon sessions. The water samples of Khatra region lie in permissible limit.

Suitability for agriculture

The groundwater suitability for irrigational uses of any region is dependent on the occurrence of elements in water. Irrigation water should contain salts in assessable amounts. Occurrence of high salt in water will increase the osmotic pressure of solution in soil (Singh et al. 2015; Throne and Peterson 1954). This creates difficulties for the plant root to extract osmosis water. To get an idea on the water suitability for irrigation purposes, the following eight criteria were taken into consideration: (1) soluble sodium percent (SSP), (2) sodium adsorption ratio (SAR), (3) residual sodium carbonate (RSC), (4) permeability index (PI), (5) Kelly's ratio (KR), (6) magnesium adsorption ratio (MAR), (7) EC, and (8) corrosivity ratio (CR). All these criteria are calculated and presented in Table 3.

Sodium adsorption ratio (SAR)

The sodium adsorption ratio (SAR) values have been derived from the chemical analyses data for all the collected water samples of the Khatra block following Richards (1954). The equation is given below:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\mathrm{Ca} + \mathrm{Mg}/2}} \quad (1)$$

in which all ionic concentrations are expressed in meq/l. For deciphering whether the groundwater is useful for agricultural purposes, determination of sodium, magnesium and calcium ions concentrations are of great importance. For identification of irrigation suitability of waters, this process is intensively used nowadays. In this method, the EC and SAR values of the collected water samples are first evaluated and thereafter their positions are marked on the standard U.S. Salinity Laboratory (USSL 1954) Diagram. This diagram gives us knowledge on salinity and alkalinity hazards. In all water samples obtained from Khatra region, SAR values vary from 0.74 to 0.11 in postmonsoon and 2.18 to 0.56 in premonsoon (Table 3; Supplementary Fig. 1). In both sessions, the lowest value is noted at Elora and highest value at Gorabari area of Khatra block. It is noticed that all water samples are marked in medium to high salinity and low alkalinity zone, suggesting that the water can safely be utilized for agriculture. Since SAR values for all samples are < 10, the water of Khatra region is categorized as excellent type (Table 4).

Soluble sodium percentage (SSP)

The content of sodium in groundwater plays a very significant factor in defining the water quality used for irrigation, as sodium by reacting with soil diminishes its permeability (Domenico and Schwartz 1990; Todd 1980). The parameter, percent sodium, is derived for determination of its suitability toward irrigation (Wilcox 1955). High content of sodium in the water used for irrigation replaces the Mg^{2+} and Ca^{2+} ions by absorbing clay particles. This process is responsible for reducing the permeability of the soil and ultimately diminishes the soil drainage. This creates restricted circulation of air and water in wet conditions rendering such soils to be hard when dried up (Subramani et al. 2005; Saleh et al. 1999; Collins and Jenkins 1996). SSP values are derived from the expression given below:

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

All ionic concentrations are expressed in meq/l. The SSP values vary from 6 to 29 in postmonsoon and 9 to37 in premonsoon sessions. The minimum value of SSP is found at Elora, while the maximum value is found at Bahadurpur during the both sessions (Table 3). Water utilized for irrigational purposes is classified based on Na percentage and EC value (µS/cm) following Wilcox (1955) (Figs. 3, 4). It is noticed that during postmonsoon period, 52% samples are excellent, and 47.82% of samples lie in good to permissible zone, while in premonsoon period, 32% are excellent and 68% fall in good to permissible category (Table 4).

Magnesium adsorption ratio (MAR)

Normally, magnesium sustains balance state in majority of groundwater (Hem 1985). The presence of magnesium in waters in high quantity will harmfully affect crop production. Since in Khatra region, the aquifer rock types are granite, schists and gneisses of Archean age, groundwater bears high amount of magnesium. MAR has been derived from the following expression (Raghunath 1987):

$$\mathrm{MAR} = \frac{\mathrm{Mg} \times 100}{(\mathrm{Ca} + \mathrm{Mg})} \tag{3}$$

where all ionic concentrations are expressed in meq/l. In the present case, values of MAR range from 46.33 to 80 in postmonsoon and 49.05–82.61in premonsoon sessions (Table 3). The value observed was minimum at Kankradara and Kubasol during postmonsoon and values noted at Elora in both sessions are maximum. Groundwater is categorized normally into two classes (1) water with MAR < 50 is suitable and (2) water with MAR > 50 is unsuitable for agricultural uses (Kumar et al. 2007). The maximum samples of investigated area lie in magnesium hazard zone in both post- and premonsoon sessions (Table 4) (Supplementary Fig. 2).

Residual Sodium Carbonate (RSC)

If concentrations of HCO_3^- and CO_3^{2-} are more in comparison to Mg^{2+} and Ca^{2+}, the chances of precipitation of Mg^{2+} and Ca^{2+} as carbonates increase. RSC values have been derived from the expressions given below (Raghunath 1987):

$$\mathrm{RSC} = \left(\mathrm{HCO}_3^- + \mathrm{CO}_3^{2-}\right) - (Ca^{+2} + \mathrm{Mg}^{+2}) \tag{4}$$

where all ionic concentrations are expressed in meq/l. Depending on the values of RSC, waters are classified into three broad groups: (1) RSC value greater than 2.5 meq/l, generally unsuitable (2) RSC value within 1.25–2.5 meq/l, marginally suitable and (3) RSC value less than 1.25 meq/l, suitable for irrigation purposes(USDA 1954). In Khatra region, the RSC values are presented in Table 3 during post- and premonsoon sessions. However, following the already stated classification, all samples are grouped under safe category (Table 4).

Permeability index (PI)

Soil permeability gets affected by prolonged utilization in irrigation purposes owing to the occurrence of Ca^{2+}, Na^+, Mg^{2+}, and HCO_3^- in the soil. The Permeability Index values have been derived following the equation Doneen (1964):

Table 3 Different parameters for irrigation quality in postmonsoon (PoM) and premonsoon (PrM)

Location no.	Location name	SAR		SSP		P.I		RSC		MAR		KR		CR	
		PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM	PoM	PrM
P1	Baharamuri	0.37	1.2	16	18	30	33	− 8	− 7.3	64.8	69.62	0.17	0.23	1.3	1.29
P2	Kubasol	0.27	0.9	11	17	29	33.1	− 5.86	− 6.09	46.33	54.6	0.12	0.2	0.49	0.69
P3	Maisile/Daulgara	0.56	1.87	24	34	40	47.7	− 4.86	− 4.75	55	49.05	0.29	0.51	0.53	0.83
P4	Moisiara	0.46	1.31	22	28	47	51.4	− 1.39	− 2.26	58	64.5	0.26	0.39	0.4	0.32
P5	Simlabad	0.63	1.94	24	33	45	51.2	− 3.12	− 3.04	52.02	62.73	0.31	0.48	0.46	0.49
P6	Sibrampur	0.43	1.67	18	24	27	33.6	− 11.69	− 10.9	61.61	66.03	0.204	0.3	1.91	1.48
P7	Gorabari	0.74	2.18	27	34	46	50.2	− 3	− 3.68	56.25	63.84	0.36	0.5	0.44	0.59
P8	Kechenda	0.44	1.71	21	36	52	57.1	− 0.88	− 1.84	55.31	72.36	0.25	0.52	0.15	0.26
P9	Kankradara	0.51	1.45	22	25	42	39.4	− 3.51	− 6.16	46.33	52.86	0.25	0.34	0.53	0.79
P10	Bahadurpur	0.72	1.94	29	37	54	60.4	0.68	− 0.16	62.21	65.08	0.36	0.54	0.16	0.27
P11	Arkama	0.34	0.76	14	12	26	22.9	− 10.69	− 12.1	56.26	63.73	0.15	0.13	1.04	1.36
P12	Mukundopur	0.46	1.22	13	21	35	36.1	− 5.51	− 6.36	51.78	64.02	0.21	0.26	0.66	0.94
P13	Ratanpur	0.44	1.64	18	30	35	45.5	− 5.31	− 4.49	55.71	52.39	0.21	0.4	1.09	1.12
P14	Debida	0.3	0.9	14	15	26	26.7	− 9.91	− 10	73.54	79.83	0.145	0.15	0.08	0.14
P15	Mullion	0.72	1.87	26	31	42	48.2	− 5.1	− 3.7	47	54.77	0.34	0.44	1.4	1.25
P16	Elora	0.11	0.56	6	9	16	17	− 13.9	− 15.9	80	82.61	0.05	0.09	0.59	0.8
P17	Jharia kuchi	0.38	0.99	17	18	38	33.5	− 3.34	− 6.1	65.18	70.01	0.19	0.2	0.15	0.26
P18	Hirbad	0.4	1.49	18	29	42	48	− 2.9	− 3.13	53.53	62.69	0.21	0.39	0.43	0.44
P19	Khatra	0.68	1.76	25	28	42	43.9	− 4.35	− 4.43	56.27	60.31	0.33	0.37	0.44	0.53
Min.		0.11	0.56	6	9	16	17	− 13.9	− 15.9	46.33	49.05	0.05	0.09	0.08	0.14
Max.		0.74	2.18	29	37	54	60.4	0.68	− 0.16	80	82.61	0.36	0.54	1.91	1.48
Mean		0.472	1.443	19.211	25.6	37.58	41.04	− 5.402	− 5.92	57.74	63.73	0.23	0.34	0.64	0.73
Median		0.44	1.49	18	28.13	40	43.87	− 4.86	− 4.74	56.25	63.83	0.21	0.37	0.49	0.69
Std. Dvn.		0.17	0.462	6.03	8.41	9.91	11.7	3.85	3.92	8.72	8.85	0.08	0.14	0.48	0.41

$$\mathrm{PI} = \frac{\left(\mathrm{Na} + \sqrt{\mathrm{HCO_3}}\right) \times 100}{(\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na})} \tag{5}$$

where all ionic concentrations are given in meq/l. The PI values vary from 16 to 54 in postmonsoon and 17 to 60.4 in premonsoon sessions. The value is found to be minimum at Elora and the highest value is at Bahadurpur in both sessions. For deciphering the suitability of water for irrigational uses on the basis of permeability index, WHO (1996) made three classes: (1) PI value less than 80 and it should be rendered as good, (2) PI value between 80 and 100 as moderate and (3) PI value between 100 and 120 as poor (Table 7). In the present case, 100% water samples lie in the good water zone for irrigational uses (Table 5; Fig. 5).

Kelly's ratio (KR)

Another parameter in which Na^+ is considered against $Mg^{2+}$and Ca^{2+} was considered by Kelly (1957). This parameter (Kelly's ratio) suggests water quality as good if the ratio is < 1 where as if the ratio is > 1, the water becomes unsuitable (Arumugam and Elangovan 2009; Karanth 1987). Kelly's ratio was derived from the equation as follows:

$$\mathrm{KR} = \frac{\mathrm{Na}}{(\mathrm{Ca} + \mathrm{Mg})} \tag{6}$$

where all ionic concentrations are given in meq/l. The KR values vary from 0.05 to 0.36 in postmonsoon and 0.08 to 0.86 in premonsoon sessions. The value is found to be minimum at Elora and the highest value is at Bahadurpur in both sessions. In the present case, 100% water samples lie in the invulnerable zone for irrigational uses.

Corrosivity ratio (CR)

Corrosivity ratio (CR) is signified by the vulnerability of corrosiveness of groundwater. It is expressed by the ratio between alkaline earth metals and saline salts occurring in water (Ryznes 1944; Raman 1985). Corrosion is a process of electrolytic attack on metal surface. So the problems are related with salinity and scaling on metal surface. Water

Table 4 Classification according to calculated parameters standards

Parameters	Range	Class	No. of samples		Percentage of samples	
			Postmonsoon	Premonsoon	Postmonsoon	Premonsoon
EC	< 250	Excellent	0	0	0	0
	250–750	Good	15	16	79	84
	750–2250	Permissible	4	3	21	16
	> 2250	Unsuitable	0	0	0	0
SAR	0–10	Excellent	19	19	100	100
	10–18	Good	0	0	0	0
	18–26	Permissible	0	0	0	0
	> 26	Doubtful	0	0	0	0
SSP	< 20	Excellent	10	6	53	32
	20–40	Good	9	13	47	68
	40–60	Permissible	0	0	0	0
	60–80	Doubtful	0	0	0	0
	> 80	Unsuitable	0	0	0	0
MAR	≤ 50	Suitable	3	1	15	5
	> 50	Unsuitable	16	18	85	95
RSC	< 1.25	Low	19	19	100	100
	1.25–2.50	Medium	0	0	0	0
	> 2.50	High	0	0	0	0
PI	< 80	Good	19	19	100	100
	80–100	Moderate	0	0	0	0
	100–120	Poor	0	0	0	0
KR	≤ 1	Suitable	19	19	100	100
	> 1	Unsuitable	0	0	0	0
CR	< 1	Suitable	14	14	75	75
	> 1	Unsuitable	5	5	25	25
WQI	< 50	Excellent	0	0	0	0
	50–100	Good	6	7	32	37
	100–200	Poor	12	11	63	58
	200–300	Very Poor	1	1	5	5
	> 300	Unfit for Drinking	0	0	0	0

samples having corrosivity ratio < 1 are regarded as non-corrosive, but if the value is greater than 1, it becomes corrosive. Corrosivity ratio is derived from the equation given below:

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

where all ionic concentrations are given in meq/l. The CR values vary from 0.08 to 1.91 in postmonsoon and 0.14 to 1.48 in premonsoon sessions. The value is found to be minimum at Debida and the highest value is at Sibrampur in both sessions. It suggests that 75% samples in both post- and premonsoon sessions are non-corrosive in nature, whereas 25% samples are found to be corrosive in both sessions and, thus, affect the pipelines for carrying and groundwater lifting (Table 4).

Domestic suitability

Increasing population growth puts extensive pressure in supply of pollution-free domestic water. Amongst various water sources, groundwater is regarded as the safest for domestic purposes. For this, it has become necessary to the study on spatial changes of the groundwater quality and its relationship with local geologic, anthropogenic factors. For assessing the domestic water quality, it is essential to decipher the hydrochemistry of groundwater along with the remedial steps for restoring the water quality as well. This is required, particularly where worsening demands the identification of possible sources of groundwater contamination. The prime target of this investigation is to determine the domestic water

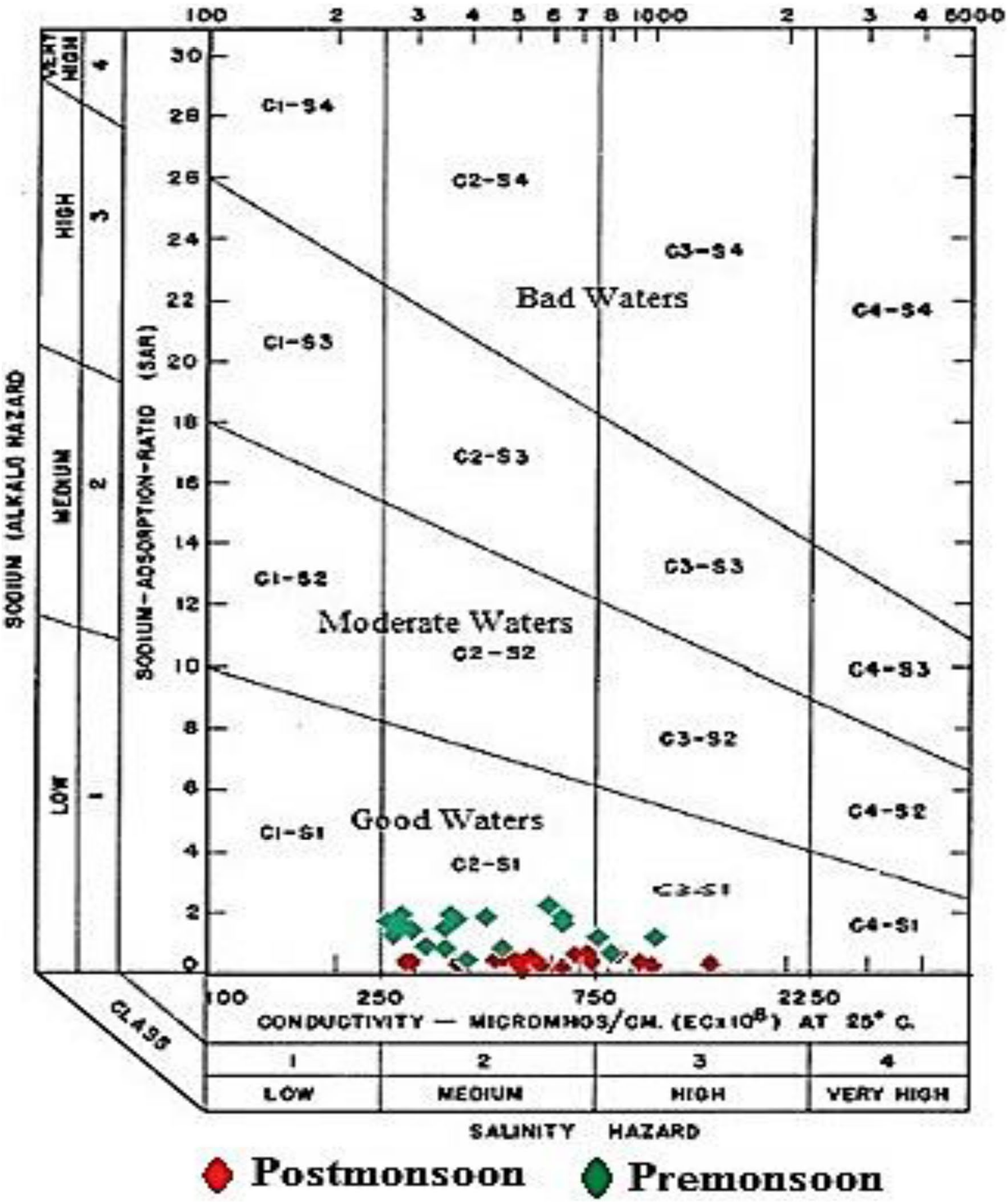

Fig. 3 Diagram showing positions of samples in U.S. Salinity diagram

quality and correlate the hydrochemistry with the water quality standards.

In conveying out the groundwater chemistry, Piper's (Piper 1944) Trilinear diagrams are of great significance. In this, hydrochemical data are projected onto the central diamond-shaped portion in which all the four sides are denoted by the proportions of measured cations and anions in the water. The samples of the present investigating region fall under fresh and sulfate-rich sectors of the central diamond shaped portion (Fig. 6). It is also observed that some samples of groundwater have high sulfate concentration. Postmonsoon data when plotted over this figure (Piper 1944) reveal that water samples lie in the groups Ca–Mg–HCO_3 and Na–HCO_3, both of which signify 'bicarbonate' type water which comes under 'fresh water' category; thus, during postmonsoon 79% of groundwater samples are recognized as

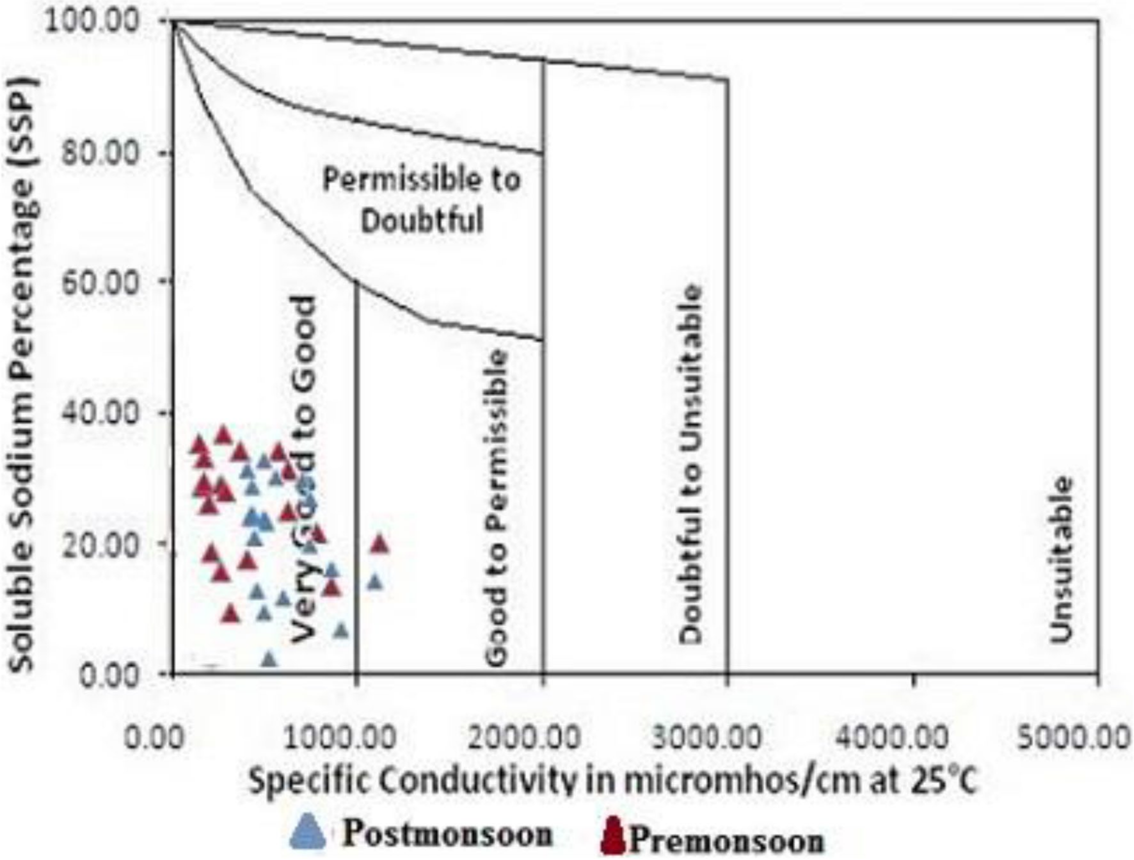

Fig. 4 Diagram showing positions of samples in Wilcox diagram

'fresh water' class. During premonsoon, 48% of samples fall in groups Ca–Mg–HCO_3 and Na–HCO_3, and 52% of samples lie in Ca–Mg–SO_4 and Ca–Mg–Cl–SO_4 groups which indicate that water is of 'sulfate' variety. Most of the water samples in the investigating region exhibit higher amount of Ca^{+2} and Mg^{+2} ions amongst cations and bicarbonate among anions. The underlying lithology may be in contact with sulfur-rich minerals like pyrite within granitic rocks which may cause sulfur enrichment. During premonsoon, season sulfate-rich water has noticeably increased (Supplementary Fig. 3). During postmonsoon, areas like Mullion, Baharamuri, Arkama, Sibrampur and during premonsoon Elora, Jhariakuchi, Baharamuri, Kubasol, Daulgara, Sibrampur, Gorabari areas are having sulphate dominating water. Such type of water is favorable for irrigation. All other remaining villages lie as fresh water zone that can be used for drinking.

Water quality index (WQI)

Water quality index (WQI) indicates environmental changes and is intensely associated with socio-economic development. Water quality index may be defined as a measurement which depicts the combined effects of various parameters related to water quality. Depending on WQI, five water quality classes have been designed: (1) if WQI < 50, excellent, (2) if WQI = 50–100, good, (3) if WQI = 100–200, poor, (4)

Table 5 The weight and relative weight of each of the parameters used for WQI determination

Parameters	Weight (w_i)	Relative weight (W_i)
pH	5	0.11363
Electrical conductivity	2	0.04545
Total dissolved solids	4	0.09090
Calcium	2	0.04545
Magnesium	2	0.04545
Chloride	3	0.06818
Sulfate	5	0.11363
Bicarbonate	3	0.06818
Fluoride	5	0.11363
Sodium	3	0.06818
Iron	5	0.11363
Total alkalinity	2	0.04545
Total hardness	3	0.06818
	$\sum$ wi = 44	$\sum Wi = 1$

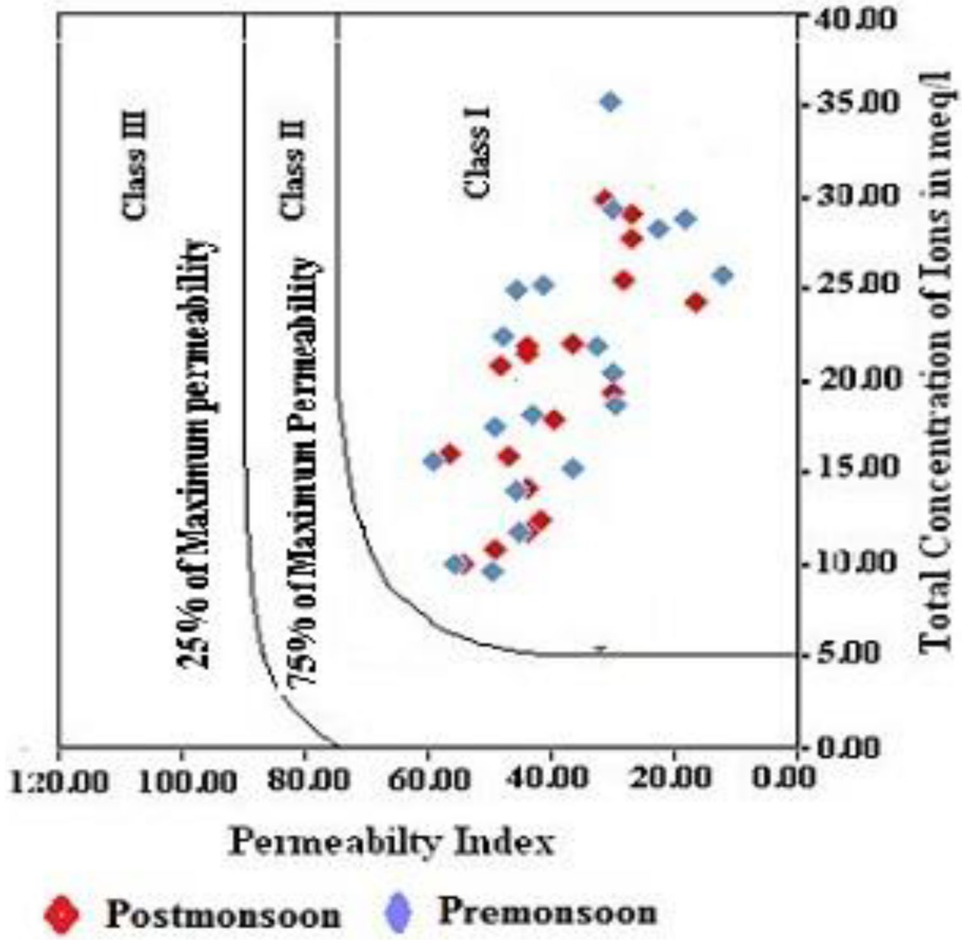

Fig. 5 Diagram showing positions of samples in Permeability index diagram

if WQI = 200–300, very poor and (5) finally if WQI > 300, unsuitable (Ramakrishnaiah et al. 2009; Bhuven et al. 2011; Kushtagi and Srinivas 2012). Depending on the importance of parameters, individual weightages are assigned. Using the expression given below, the relative weight (W_i) is determined:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{8}$$

in which Wi denotes the relative weight, wi is the weight corresponding to each parameter and n stands for the number of parameters. For each parameter, the rating scale is *qi* which is expressed by ratio of its content in every sample and its corresponding standard following the guidelines multiplied by 100

$$q_i = \frac{C_i}{S_i} \times 100 \tag{9}$$

in which q_i is the quality rating, ci is the content of individual cation/anion present in water in mg/l, Si is the standards of Indian drinking water for individual cation/anion in mg/l.

Before deriving the WQI values, the SI value is determined first for each cation/anion and then used to find out the WQI values as follows (Table 5):

$$\mathrm{SI}_i = W_i \times q_i \tag{10}$$

$$\mathrm{WQI} = \sum \mathrm{SI}_i \tag{11}$$

The computed WQI values in Khatra Block were 71.74 to 209.4 in postmonsoon and 70.05 to 205.8 in premonsoon (Table 6).The variation of WQI values in both sessions are shown in Supplementary Fig. 4. Postmonsoon samples fall 32% under good, 63% under poor, 5% in very poor, whereas premonsoon samples fall 37% under good, 58% under poor, 5% in very poor (Supplementary Table 4; Supplementary Fig. 5). The Western and south-western part of Khatra region showed water of good quality during both seasons, whereas Eastern part showed poor water quality in both seasons. Baharamuri area showed very poor water quality in both seasons, which is unsuitable for drinking purposes (Supplementary Fig. 6). It may be owing to active leaching of ions from the underground rock formation, overexploitation of groundwater or agricultural runoff from surroundings.

Gibb's diagram

Gibbs (1970) has clearly demonstrated the interdependence between water-chemistry and the aquifer materials. It gives us information on the genesis of groundwater. It has three distinct fields: (1) precipitation dominance, (2) evaporation dominance, and (3) interaction between rock–water dominance areas. Gibbs ratio is derived from the following formulae:

$$\text{Ratio I (Cation)} = \frac{(\text{Na} + \text{K})}{(\text{Na} + \text{K} + \text{Ca})} \quad (12)$$

$$\text{Ratio II (Anion)} = \frac{\text{Cl}}{\left(\text{Cl} + \text{HCO}_3\right)} \quad (13)$$

The hydrochemical data of Khatra region are plotted in Gibbs's diagram (Fig. 7). The use of scattered plots of TDS vs Gibbs ratio I for cation and TDS vs. Gibbs ratio II for anions is utilized to distinguish rock–water interaction processes. It is observed that most of the samples of both post- and premonsoon sessions occur in rock-dominance category, which indicates that chemical weathering was influenced by rainfall and the dissolution of rock-forming minerals contributed to the alteration of groundwater chemistry.

Chadha's diagram

Groundwater chemistry is affected by the number of mechanisms such as rock–water interaction during ground water transportation system, storage within the aquifer, suspension of different minerals, oxidation–reduction process, and human activities, etc. (Todd 1980; Hem 1991; Naik et al. 2009; Kozlowski and Komisarek 2013).

For understanding the chemistry of groundwater, Chadha's diagram (1999) has been used here. Data were plotted for both post- and premonsoon sessions (Fig. 8). In Chadha's diagram, there are eight sub-fields. From the Chadha's plot, it was noted that 78% of samples of postmonsoon occur in fifth sub-division and thereby suggests the alkaline earths and anions of weak acid occur more over alkali metals and anions of strong acid, respectively. Hence, the positions of the samples in the diagram suggest HCO_3-dominant Mg^{2+}–Ca^{2+} type of water. The rest 22% of samples occur in sixth sub-division and suggest that alkali earths surmount alkali metals and anions of strong acid surmount anions of weak acid. Such water types possess hardness of permanent nature and indicate that deposition of residual sodium carbonate did not take place. This represents Ca^{2+}–Mg^{2+}–Cl^- type or Ca^{2+}–Mg^{2+} dominant Cl^-–SO_4^{-2} type water in postmonsoon season. In premonsoon season, 70% of samples occur in fifth sub-division that is HCO_3 dominant Ca^{2+}–Mg^{2+} type waters. But the rest 30% of samples occur in sixth sub-division that is Cl^-–SO_4^- dominant Ca^{2+}–Mg^{2+} type waters. This diagram indicates enrichment of Cl^-–SO_4^{2-} in premonsoon groundwater which suggests the possibility of occurrence of some sulfur-rich mineral in subsurface formation.

The hydrochemical mechanism that controls the hydrochemistry of groundwater has also shown HCO_3^-as the most prominent anion and Ca^{+2} and Mg^{+2} are most dominant cations in groundwater for both sessions (Fig. 9) which primarily is an indicator of decomposition of rock-forming minerals from surrounding lithological environment (Fisher and Mullican 1997; Kim 2003).

Chloro-alkaline indices (CAI)

Values of chloro-alkali indices (1 and 2) were derived from chemical analyses results to determine the extent of ion exchange in the aquifer. Negative CAI values suggest exchange of Ca^{2+} and Mg^{+2} in water having Na^+ and K^+ in associated rocks called chloro-alkaline disequilibrium, while positive CAI values point to exchange of Na^+ and K^+ in water having Ca^{2+} and Mg^{+2} in associated rocks, called chloro-alkaline equilibrium (Nagaraju et al. 2006). The chloro-alkali indices (1 and 2) are derived using equations given below:

$$\text{CAI 1} = \frac{[\text{Cl}-(\text{Na} + \text{K})]}{\text{Cl}} \quad (14)$$

$$\text{CAI 2} = \frac{[\text{Cl}-(\text{Na} + \text{K})]}{\left(\text{SO}_4 + \text{HCO}_3 + \text{CO}_3 + \text{NO}_3\right)} \quad (15)$$

where all ionic concentrations are given in meq/l (Table 7). During premonsoon period, 57% samples show negative values and 43% show positive values (Fig. 10). Observation indicates normal process of ion exchange to be dominant during premonsoon. Ion exchange of reverse process is much active throughout postmonsoon.

Schoeller diagram

Schoeller (1977) diagram is a kind of representation in graphs showing the classification for drinking water quality. In this diagram, the major water-soluble salts which include all important ions along with total hardness and TDS are plotted for classifying the drinking water quality (Sayad et al. 2011).This diagram helps us to represent on a single graph, most of the ions of number of samples, where samples showing similar patterns can be easily identified. Close observation on this diagram exhibits similar slope of

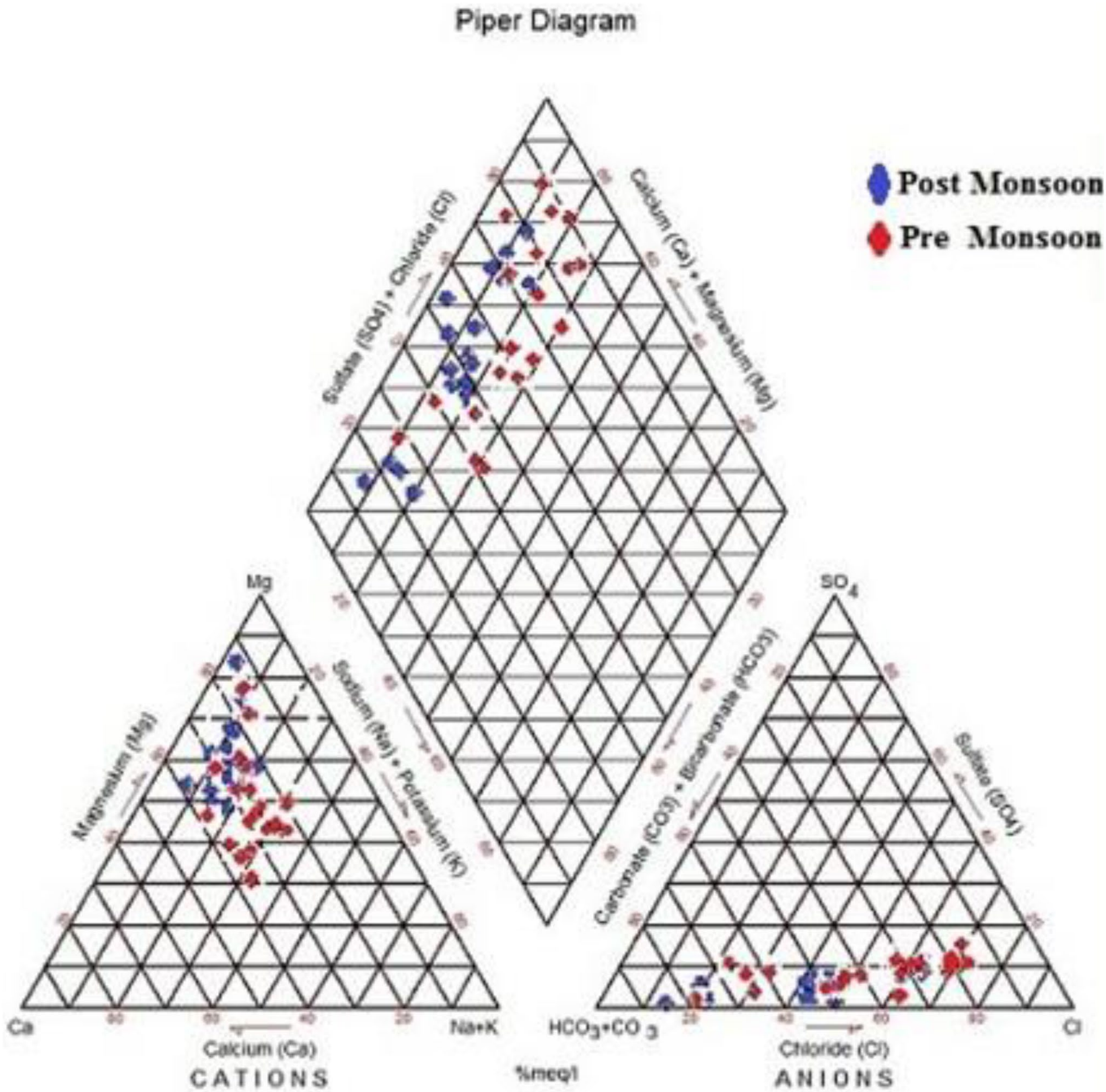

Fig. 6 Diagram showing positions of samples in Piper's trilinear diagram

lines connecting solute concentrations. This also suggests that groundwater has the similar type of source in both sessions. This diagram (Supplementary Fig. 7) also suggests that Mg^{+2} values of both post- and premonsoon sessions are very high, which indicate that the aquifer may be in contact with carbonate minerals or the leaching of Mg^{+2} rich minerals like pyroxene, amphibole, and mica which may be derived from weathering and leaching of Mg^{2+} into the groundwater. Similarly, low K^{+} concentration indicates the less presence of potassium-rich minerals like alkali feldspar (e.g., Orthoclase, Microcline).

Classification of Groundwater samples

Based on the content of Cl^{-}, SO_4^{2-} and HCO_3^{-}, groundwater is normally divided into three different classes: (1) normal chloride (< 15 meq/l), (2) normal sulfate (< 5 meq/l), and (3) normal bicarbonate (2–7 meq/l) (APHA 1992; IIED 2002).

Table 6 Water quality index values during post- and premonsoon seasons

Location Name	Location	Water quality index values	
		Postmonsoon (November 2016)	Premonsoon (April 2017)
Baharamuri	L1	209.4	205.8
Kubasol	L2	167.9	164.8
Maisile/Deulgara	L3	78.2	80.9
Moisiara	L4	94.06	99.04
Simlabad	L5	111.17	129.9
Sibrampur	L6	111.68	116.20
Gorabari	L7	105.31	99.47
Kechenda	L8	71.74	70.05
Kankradara	L9	80.12	80.45
Bahadurpur	L10	143.65	147.6
Arkama	L11	141.64	130.6
Mukundopur	L12	109.37	105.15
Ratanpur	L13	74.74	73.8
Debida	L14	158.13	149.3
Mullion	L15	118.94	129.0
Elora	L16	159.03	161.9
Jharia kuchi	L17	110.50	103.75
Hirbad	L18	82.80	89.27
Khatra	L19	131.07	142.37

Normally to express the exchange of ions between the groundwater and its surrounding rocks, (1) base exchange (r_1) and (2) meteoric genesis (r_2) are in general used. Base exchange index (r_1) is evaluated using the equation given below (Matthess 1982):

$$r1 = \frac{(\mathrm{Na-Cl})}{\mathrm{SO_4}} \tag{16}$$

where all ionic concentrations are shown in meq/l.

The groundwater is classified into two main divisions: (1) $Na^+–HCO_3$ type if r_1 is > 1 and (2) $Na^+–SO_4^{2-}$ type if r_1 is < 1 (Matthess 1982). The 64% samples are of $Na^+–SO_4^{2-}$ type in postmonsoon session and the rest 36% are of $Na^+–HCO_3^-$ variety in postmonsoon whereas in premonsoon 42% samples are of $Na^+–HCO_3^-$ type and 58% belong to $Na^+–SO_4^{2-}$ type (Supplememtary Table 5). The disintegration of gases and minerals, specifically CO_3-related composites lying in atmosphere and in unsaturated zone during precipitation and infiltration, would impart the observed HCO_3 water type (Singh et al. 2006).

The average chemical compositions and their range for four major hydrochemical facies have been demonstrated in Supplememtary Table 5. The Na-HCO_3 and Na-SO_4 facies represent, respectively, for all premonsoon samples analyzed, while Na–HCO_3 and Na-SO_4 represent 36% and 64%, respectively, for all postmonsoon water samples analyzed.

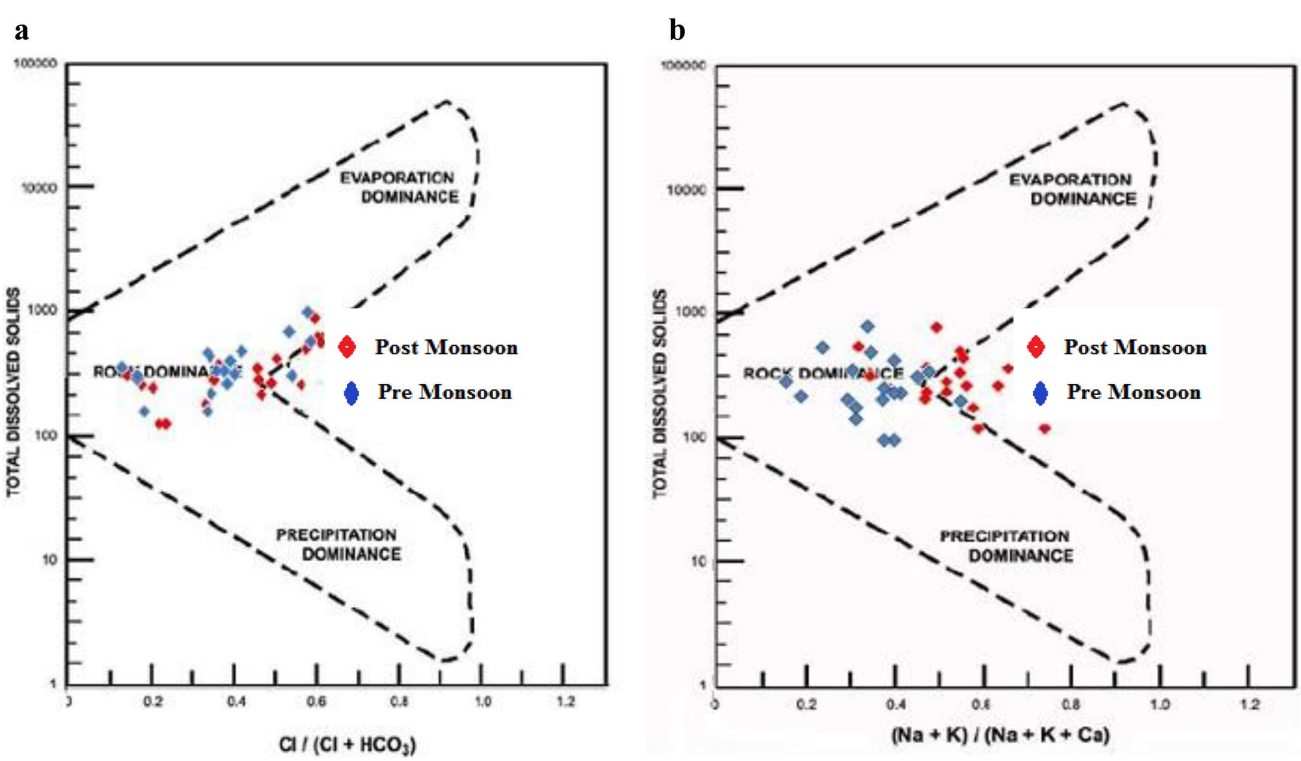

Fig. 7 Diagram showing positions of samples in Gibb's plots for postmonsoon. Diagram showing positions of samples in Gibb's Plots for premonsoon

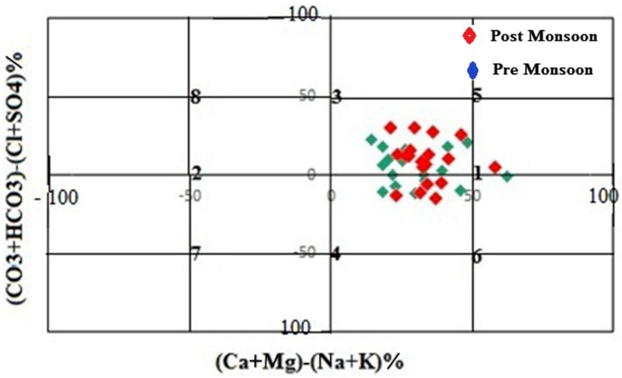

Fig. 8 Figure showing positions of samples in Chadha's Diagram for postmonsoon and premonsoon

Sulfate facies in postmonsoon period increases because sulfate dissolution is greater in rainy period due to infiltration of rainwater. In the premonsoon period, SO_4^{2-} and Cl^- bearing salts come to the ground surface by evaporation and evapotranspiration.

The groundwater sources can also be subdivided on Meteoric genesis index and calculation is done through the equation given below (Soltan 1998):

$$r2 = \frac{[(K + Na) - Cl]}{SO_4} \quad (17)$$

where all ionic concentrations are given in meq/l.

The ground water source may be of percolation type (deep meteoric), if r2 < 1, where as if r2 > 1, it is regarded as of percolation type (shallow meteoric). Results indicate that during postmonsoon 58% water samples are of percolation type (deep meteoric) and 42% are of percolation (shallow meteoric) type. During premonsoon session, the results are vice versa, i.e., 42% are of percolation type (deep meteoric) and 58% are of percolation type (shallow meteoric) (Fig. 11).

Conclusions

An investigation was undertaken to have an idea on the water level fluctuations and variation in hydrochemistry in post- and premonsoon periods. Altogether nineteen (19) borewells in each session have been monitored. The hydrographs show that highest fluctuation occurs in Sibrampur area (5.31 m) and lowest fluctuation occurs in Moisiara area (1.48 m). Other components like Mg^{2+}, Ca^{2+}, Na^+, Cl^-, HCO_3^-, SO_4^{2-}, and F^- in majority areas (80-90%) are within allowable limits, but in few locations samples have higher contents of Mg^{2+} which is beyond the allowable limits. The major objectives of the present investigation are to decipher the groundwater relevance for agriculture and domestic uses, since the Khatra block, selected for present investigation,

Fig. 9 Pie charts of mean concentration of major ions showing high Mg^{+2}, Ca^{+2}, Na^+ and HCO_3^- in groundwater during both seasons

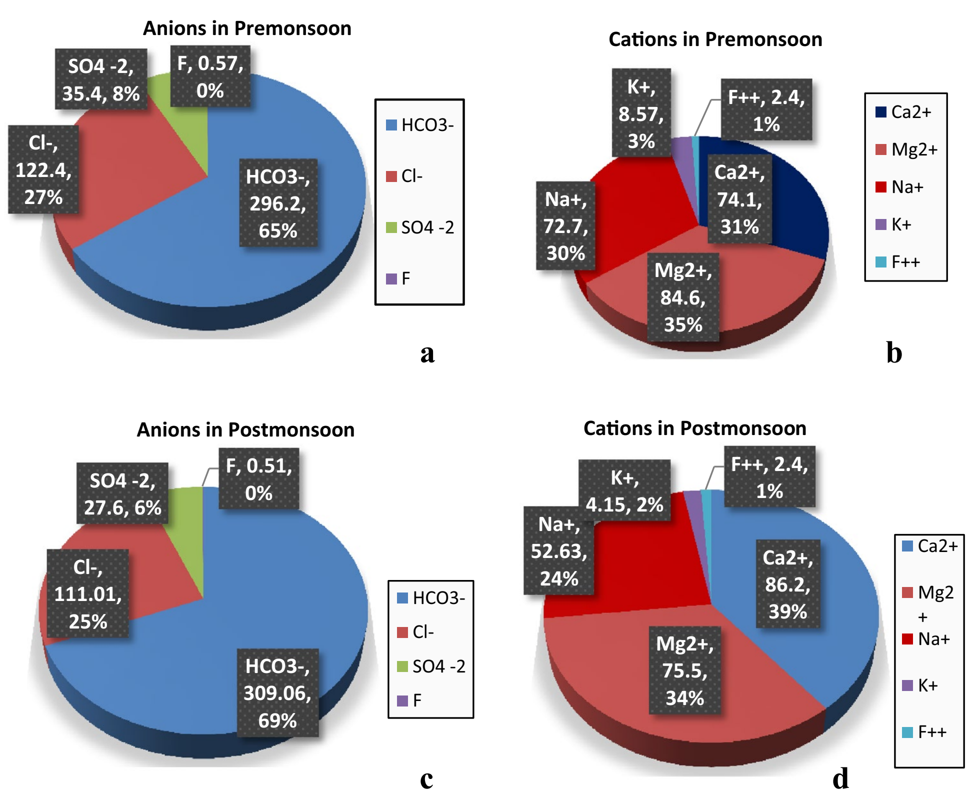

Table 7 Showing chloro-alkaline indices in the study region

Location name	Location no.	Postmonsoon		Premonsoon	
		CAI 1	CAI 2	CAI 1	CAI 2
Baharamuri	L1	0.690827	0.752522	0.631724	0.679179
Kubasol	L2	0.545186	0.311901	0.388713	0.293657
Maisile/Deulgara	L3	0.62462	− 0.30908	− 1.12943	− 0.74687
Moisiara	L4	0.158211	0.068176	− 1.23626	− 0.33898
Simlabad	L5	− 0.04929	− 0.02347	− 0.53576	− 0.25553
Sibrampur	L6	0.47516	0.629054	0.130683	0.131251
Gorabari	L7	− 0.22555	− 0.09371	− 0.40957	− 0.22029
Kechenda	L8	− 0.93455	− 0.15596	− 2.06007	− 0.54145
Kankradara	L9	0.151613	0.079871	− 0.30825	− 0.2205
Bahadurpur	L10	− 1.91165	− 0.26615	− 1.44932	− 0.32912
Arkama	L11	0.600528	0.554058	0.602595	0.654476
Mukundopur	L12	0.348197	0.201936	0.331104	0.259227
Ratanpur	L13	0.437289	0.416496	0.231015	0.229252
Debida	L14	− 2.49596	− 0.24021	− 1.5332	− 0.24101
Mullion	L15	0.456461	0.480097	0.3879	0.377844
Elora	L16	0.616719	0.344777	0.380199	0.286298
Jharia kuchi	L17	− 1.12881	− 0.15998	− 1.13304	− 0.21596
Hirbad	L18	0.143248	0.064936	− 0.48581	− 0.21556
Khatra	L19	− 0.23149	− 0.10049	− 0.17732	− 0.08669

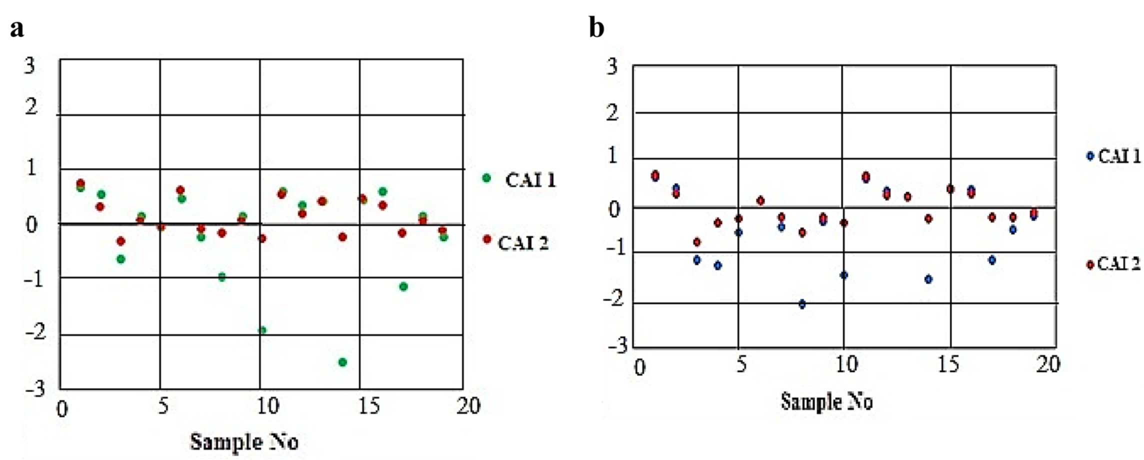

Fig. 10 Diagram showing positions of samples in Chloro-alkaline index (CAI 1 2) **a** premonsoon, **b** postmonsoon

has a rural setup in which agriculture is the main occupation of the residents and supply of potable water through piped supply water distribution systems is still not introduced. The study suggests that the major portions of the Khatra block have fresh water, while some areas have sulfate-rich water throughout the year. Determination of the groundwater suitability for agricultural uses, and water quality indices like SAR, SSP, MAR, RSC, KR, and PI has been calculated. The results show an excellent SAR value for all samples in both the sessions. Water samples are found in the category 'very good to good' based on SSP values [according to Wilcox (1955) diagram], except for one sample which lies in good to permissible zone. From WQI calculation, it may be stated that during postmonsoon period, 32% samples lie in 'good' water zones, 63% samples in 'poor' water zones and 5% water samples lie in 'very poor' water zones. The number changes to 37% and 58%, respectively, for 'good' and 'poor' water zones, while 5% lies in 'very poor' category. It is noticeable that there were no 'unfit' water samples for domestic purposes either in post- or premonsoon sessions. According to Gibb's Diagram, all samples are of rock dominance category.

The results further suggest a good control on the chemistry of groundwater through the interactions between the

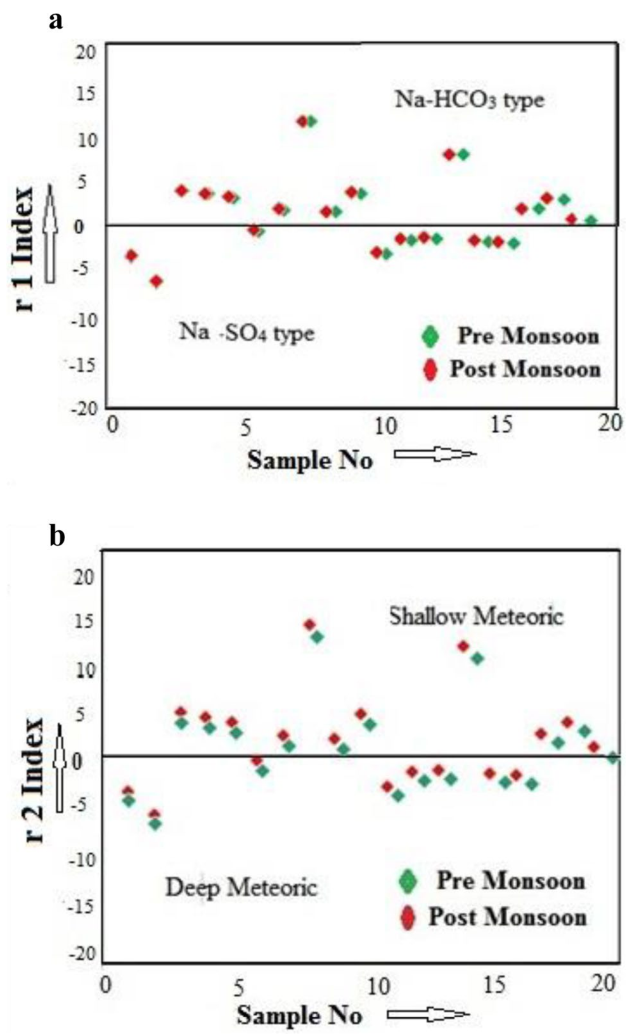

Fig. 11 Diagram showing positions of samples in base exchange indices **a** (r_1) and **b** meteoric genesis index (r2) for postmonsoon and premonsoon

aquifer formations and percolating water. Hence, this can safely be stated from the above results that the quality of groundwater and its usability for both domestic and agricultural purposes of this area are 'good to moderate' with minor exceptions encountered on a local scale.

Acknowledgments The financial support for this research work received from UGC Major Research Project [F. No. 41-1045/2012 (SR) Dated 23 Jul, 2012].The authors gratefully acknowledge it.

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