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ORIGINAL ARTICLE

Evaluation of groundwater quality for irrigation in a semi-arid region of South India

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Abstract
Groundwater quality was evaluated for irrigation purpose by collecting the groundwater samples from 36 locations during pre- and post-monsoon seasons. These groundwater samples were analyzed for physico-chemical parameters like pH, EC, TDS, major cations, and anions. Furthermore, irrigation quality indices like salinity hazard, chloride hazard, magnesium hazard, carbonate and bicarbonate hazard and sodium hazard were calculated using the analytical results. These parameters were compared with standard limits for irrigation use for the prevailing crops. The hydrochemical results indicate that the groundwater in the study area is neutral to slightly alkaline in nature. Based on the EC and TDS classification, most of the groundwater samples are falling under medium salinity hazard category. The order of abundance of major anions and cations in groundwater was found as $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > CO_3^{2-} > F^-$ and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The Chadha's diagram revealed the dominance of $Na^+ - HCO_3^-$, mixed $Ca^{2+} - Mg^{2+} - Cl^-$, and mixed $Ca^{2+} - Mg^{2+} - HCO_3^-$ and $Na^+ - Cl^-$ types of hydro-geochemical facies. Based on the EC and SAR, classification more than 50% of the samples is falling under slight to moderate reduction in infiltration rate category in both seasons. The study revealed that most of the water samples are exceeding the critical levels of irrigation water quality and it may require careful management to growth suitable crops in the study area. In addition, the study also points out that usage of such a high TDS groundwater for irrigation may cause soil salinity.

Keywords Groundwater quality · Physico-chemical analysis · Irrigation quality indices · Semi-arid region

Introduction

Groundwater plays a crucial role in Indian agriculture, particularly in semi-arid regions due to lack of surface water resources. Agriculture is a leading sector in the economic growth of India and contributes 46% of the entire national product (Jafar Ahmed et al. 2013). Fifty percent of the irrigated area is dependent on groundwater and 60% of irrigated food production is from groundwater wells (Shah et al. 2000; FAO 2003; Vasanthavigar et al. 2012). These activities lead to the over-exploitation of this limited natural resource in several parts of the country resulting in declining groundwater level. Apart from the water table decline, groundwater quality is also a major concern in many parts of the country (Vasanthavigar et al. 2012). Therefore, assessment of groundwater quality for irrigation is essential for sustainable agricultural practices (Sappa et al. 2014). The suitability of irrigation water depends upon many factors, including the quality of water, soil type, climate, and drainage characteristics of the soil and salt tolerance characteristics of the plants (Venkateswaran and Vediappan 2013). Groundwater always contain certain amount of soluble salts dissolved in it. The solubility of these salts depends upon the source of the recharge and the geological strata through which it percolates. If the salt concentration in the groundwater increases, the quality of water will deteriorate (Krishnakumar et al. 2014). The excess quantity of soluble salts may be harmful to many crops. They can limit the plants growth by restricting the water up-take through modified osmotic processes and may damage plant growth through metabolic processes. Sodicity, salinity, and toxicity are important factors to consider the suitability of groundwater quality for irrigation (Khodapanah et al. 2009).

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The quality of groundwater is important for a specified usage, and hence, it has to be critically evaluated. Nationally and internationally, many researchers have focussed on assessment of groundwater quality for irrigation purposes. The quality of irrigation water depends primarily on the total amount of salts present and the proportion of sodium to other cations and also certain other parameters (Kant et al. 2015). Krishnakumar et al. (2014) identified that the factors affecting the groundwater chemistry and evaluated the hidden hydro-geochemical process in and around Vedaraniyam, South India. Nagaraju et al. (2014), assessed the groundwater quality and suitability for irrigation purposes in Guntur district, Andhra Pradesh, South India. Nag and Das (2014) studied on ascertaining the irrigational suitability and potability standards of groundwater in Suri I and II blocks, Birbhum district, West Bengal, India. Jafar Ahmed et al. (2013) assessed the groundwater quality for irrigation use in Alathur block, Perambalur District, Tamilnadu, South India. Dissimilar index methods were used to assess the groundwater quality for irrigation of Bhaskar Rao kuntal watershed, Nalgonda district, India (Srinivasa Reddy 2013). Vasanthavigar et al. (2012) studied the groundwater quality in Thirumanimuttar sub-basin, Tamil Nadu, India and evaluated its chemical composition and suitability for domestic and agricultural uses. Balachandar et al. (2010) evaluated the status of groundwater quality and its suitability to irrigated agriculture in Coimbatore district, Tamil Nadu, India.

Tiwari et al. (2017) assessed the hydro-geochemical processes that control the groundwater composition and its suitability for drinking, domestic, and irrigation purposes in the Aosta valley region, Italy. Sappa et al. (2014) assessed water quality for drinking and irrigation purposes in Southern Latium region, Central Italy by comparing the identified parameters with the standards and guidelines. Mirza et al. (2012) investigated the deep aquifer quality for irrigation in southwestern zone of Bangladesh. Nata et al. (2011) evaluated the groundwater suitability for irrigation in Hantebet watershed and determined the degree of salinity, sodicity, and toxicity of the groundwater and examined the extent of soil salinity and sodicity of the irrigated area. Islam and Shamsad (2009) evaluated the quality of irrigation water and identified the characteristics that are important for plant growth and their acceptable levels of concentrations, Bogra district in Bangladesh.

The above studies indicate that the water quality assessment is essential for selecting the suitability of the crops in any area, particularly where irrigation practices depend on groundwater. In this light, a study has been carried out to evaluate the quality of groundwater for irrigation purposes for avoiding low yield or crop failures in the study area.

Materials and methods

Description of the study area

The Gooty Mandal lies in the part of chronically drought prone areas of Andhra Pradesh, South India. The total geographical area is 295 km^2 falls in the Survey of India (SOI) Toposheet no. 57 E/12 and 16 and lies between 77°31′05″ to 77°46′01″E longitude and 15°01′44″ to 15°13′59″N latitude (Fig. 1). The climate represents semi-arid conditions marked by hot summer (36–43 °C) and mild winter (15–25 °C). Annual average rainfall is only 564 mm (44 years data, from 1971 to 2014) with significant yearly variations. The major crops are peanut (*Arachis hypogaea*), cotton (*Gossypium*), grain sorghum (*Sorghum bicolor*), vegetable crops like the onion (*Allium cepa*), mint (*Mentha*), carrot (*Davcus carota* subsp., sativus), lettuce (*Lactuca sativa*), tomato (*Solanum lycopersicum*), cauliflower (*Brassica oleracea* var. botrytis) and fruit crops like sweet lemon (*Citrus limetta*), mango (*Mangifera indica*), guava (*Psidium guajava*), and floriculture are the common practices in the study area.

The study area is undulating with several denudational ridges and hills. The drainage pattern is dendritic to sub-dendritic at higher elevations and parallel to sub-parallel at lower elevations. There are no perennial streams in the study area and the ephemeral ones flows only during the rainfall events. Most of the area is covered by red soils and certain patches with black soils. Geologically, the area covered by Peninsular Gneissic Complex (PGC) of Achaean age mainly consists of granites with many basic and acidic intrusions. The PGC is represented with banded and streaky gneisses, which contains Hornblende gneisses, Biotite gneisses, and Hornblende–Biotite gneisses (GSI 1995, 2004). Groundwater occurs mainly in fracture zone, under unconfined condition and semi-confined conditions in deeper fracture zones. Weathered zone is dried at most of the places because of over-exploitation. The depth to groundwater levels varies from 5 to 35 m below ground level (bgl) in different seasons.

Measurements of physico-chemical parameters

Groundwater samples were collected from 36 bore wells penetrating the shallow to deep aquifers (~ 3 to < 40 m deep) during pre- and post-monsoon (May and December) seasons in 2014. Sampled well locations are recorded using global positioning system (GPS) and are shown in Fig. 1. Sampling and preservation were done in accordance with the standard procedures given by International standard methods (APHA 2012). Few parameters like

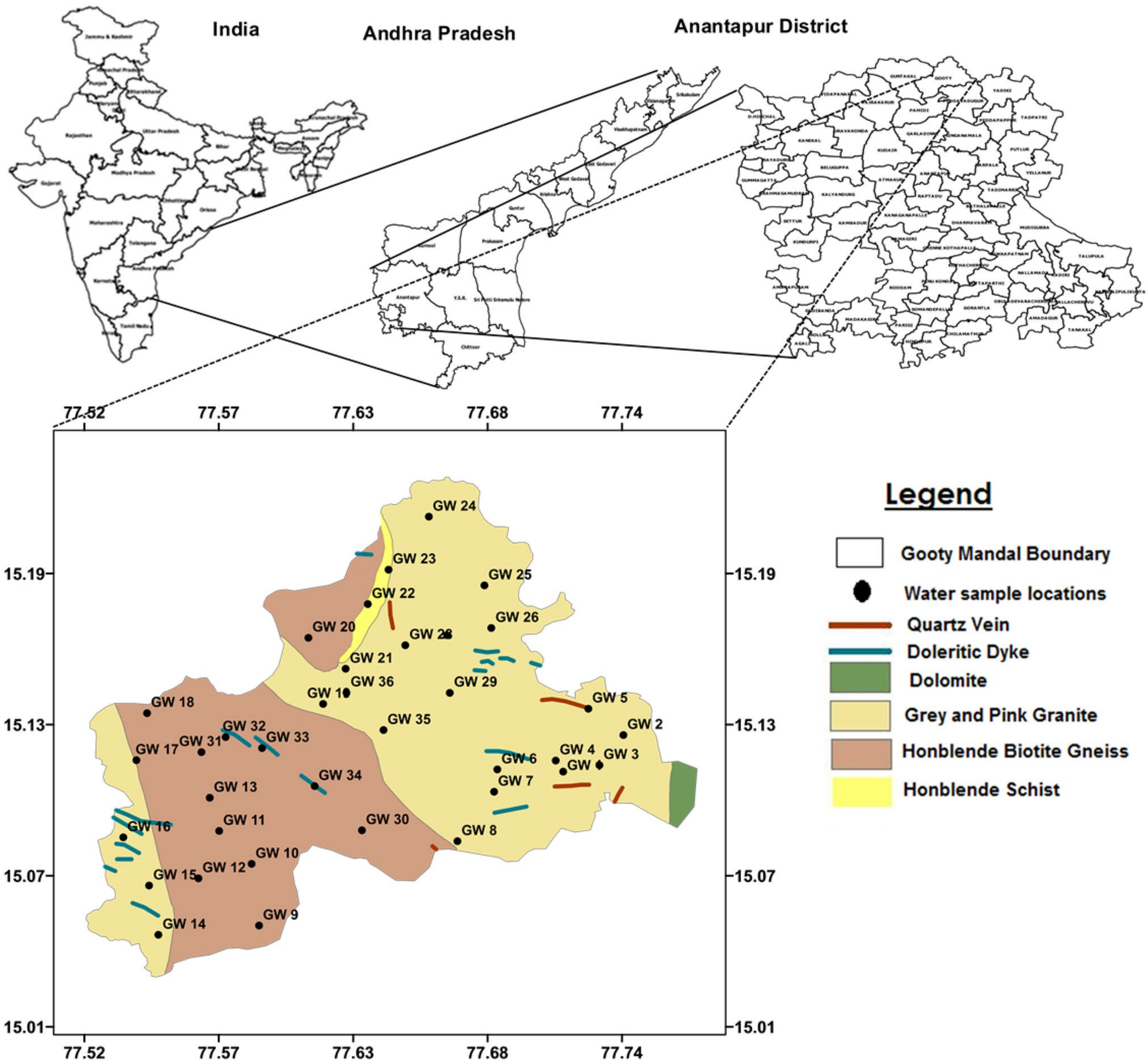

Fig. 1 Location map

electrical conductivity (EC), total dissolved solids (TDS), Redox potential (pE), and pH were measured in-situ using portable field units. Potentiometric method was used to estimate carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-). Major anions like chloride, fluoride, nitrate, and sulfate (Cl^-, F^-, NO_3^- and SO_4^{2-}) and cations like calcium, magnesium, sodium, and potassium (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were analyzed using Ion Chromatograph (IC). AS-14 Ion-pac was used to measure the anions and CS-17 Ion-pac for cations. Appropriate standards were used for both anions and cations by diluting stock solutions (M/S Merck, Germany) and run every day prior to samples. Several routine checks were made on standards. Blanks were run not only every day in the morning hours, but also in between the samples to check the baseline and also contamination from the previous samples. Based on the TDS value (>500 mg/L), samples were diluted appropriately to measure both cations and anions. Major cation and anion concentrations were converted from milligram per litre (mg/L) to milli-equivalent per litre (meq/L) for calculating the irrigation quality indices (Table 1). The analytical accuracy of measured cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (Cl^-, F^-, NO_3^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-) was verified using Ionic Balance Mass Error (IBE) on the basis of ions expressed in meq/L (Domenico and Schwartz 1998). The value of IBE was found tobe within a limit of $\pm 10\%$.

Table 1 Irrigation quality indices parameters

Parameter	Formulae	References
Total hardness (TH) expressed as meq/L as $CaCO_3$	$TH = 2.5(Ca^{2+}) + 4.1(Mg^{2+})$	Twort et al. (1994)
Magnesium absorption ratio (MAR) expressed as meq/L	$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	Paliwal (1972)
Total alkalinity (TA) expressed as meq/L as $CaCO_3$	$TA = [HCO_3^{-} + CO_3^{2-}] \times 50$ (50 is the equivalent weight of calcium carbonate)	AWWA (1971)
Non carbonate hardness (NCH) expressed as meq/L	$NCH = TH - TA$	AWWA (1971)
Residual sodium carbonate (RSC) expressed as meq/L	$RSC = (CO_3^{-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$	Eaton (1950) and Richards (1954)
Percent sodium (%Na) expressed as %	$\%Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$	Wilcox (1948)
Sodium adsorption ratio (SAR) expressed as meq/L	$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$	Richard (1954)

Results and discussion

Based on the results of the physico-chemical analysis for the pre- and post-monsoon seasons minimum, maximum, and the mean values in meq/L and the statistical parameters are determined, as shown in Table 2. The data show that the order of dominance of anions and cations is $HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{2-} > CO_3^{2-} > F^{-}$ and $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$, respectively, in both seasons.

Hydro-geochemical facies

The major cation and anion concentrations (meq/L) are plotted on the Chadha's diagram (1999) to understand the geochemical evolution of groundwater (Sharma et al. 2017) (Fig. 2a, b). This diagram is a modification of Hill (1940) and refined by Piper diagram (1944). The difference is that the two equilateral triangles are omitted, and the shape of the main study field is different (Saikia and Sarma 2011; Singh et al. 2014). In this diagram, the

Table 2 Statistical distribution of hydro-geochemical data of pre- and post-monsoon seasons

Parameter	Pre-monsoon_2014				Post-monsoon_2014			
	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation
pH	6.96	8.24	7.52	0.31	6.90	7.94	7.48	0.25
pE	−117.00	−47.00	−79.25	18.07	−105.00	−48.00	−79.17	13.96
EC (µS/cm)	715.00	5490.00	2259.69	1429.66	730.00	5560.00	1904.47	1191.79
TDS (mg/L)	381.00	2970.00	1213.28	774.14	389.00	3010.00	1020.08	643.10
Cl^{-} (meq/L)	0.50	30.77	9.12	9.29	0.48	37.29	7.80	8.42
Ca^{2+} (meq/L)	1.18	23.11	6.42	6.01	1.13	22.77	5.58	4.87
Mg^{2+} (meq/L)	1.09	18.69	5.82	5.14	1.31	18.71	5.13	4.31
TH as $CaCO_3$	123.83	2011.51	612.14	540.63	121.76	2075.34	535.51	444.50
MAR (meq/L)	29.65	64.84	48.75	8.58	27.13	71.35	48.66	10.10
CO_3^{2-} (meq/L)	0.00	5.33	0.44	1.30	0.00	2.67	0.59	0.81
HCO_3^{-} (meq/L)	3.61	19.01	8.79	4.22	3.77	18.36	8.14	3.42
TA as $CaCO_3$	180.33	1086.34	461.66	228.45	188.52	1051.37	436.55	183.33
NCH as $CaCO_3$	0.00	1506.66	269.13	76.15	0.00	1460.59	204.43	61.34
RSC (meq/L)	−30.11	12.04	−3.00	11.03	−29.19	13.19	−1.97	9.09
Na^{+} (meq/L)	3.06	46.78	14.01	11.64	3.75	48.66	13.26	10.57
%Na (meq/L)	23.03	85.16	54.74	18.63	24.52	83.90	55.39	17.53
K^{+} (meq/L)	0.01	2.38	0.32	0.58	0.00	3.20	0.22	0.55
SAR (meq/L)	1.62	21.40	6.43	4.89	1.91	20.55	6.39	4.64
SO_4^{2-} (meq/L)	0.16	9.84	2.67	2.65	0.15	11.32	2.38	2.70
NO_3^{-} (meq/L)	0.05	17.96	3.85	3.78	0.06	20.03	3.24	3.95
F^{-} (meq/L)	0.04	0.20	0.11	0.04	0.05	0.21	0.12	0.04

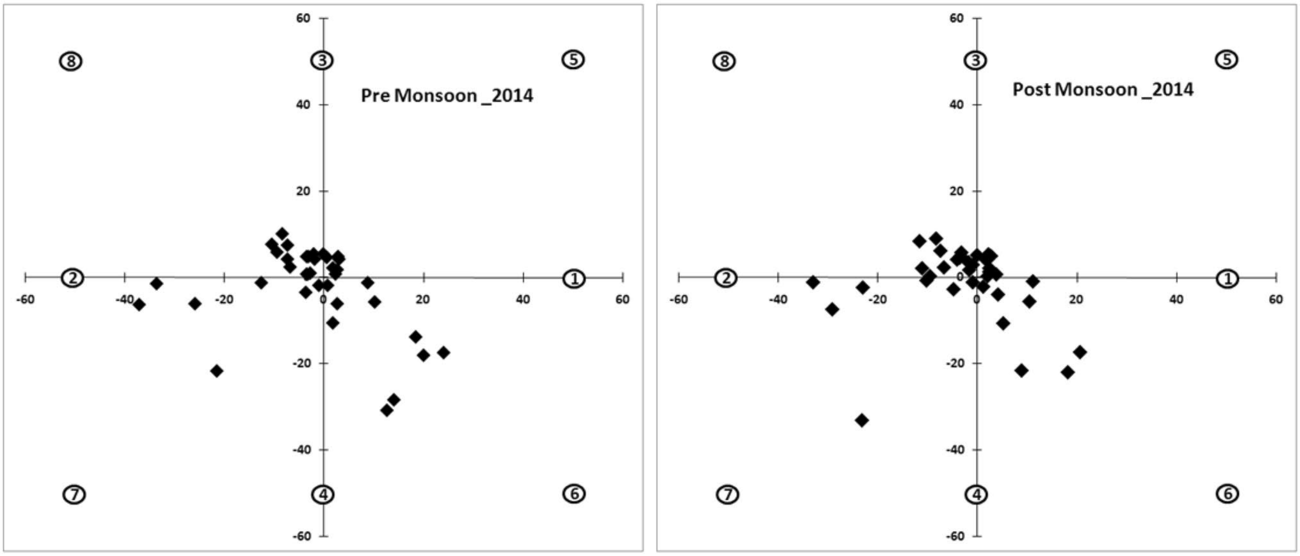

Fig. 2 Chadha's diagram for understanding the geochemical classification **a** pre-monsoon and **b** post-monsoon seasons

difference in milli-equivalent percentage between alkaline earths ($Ca^{2+} + Mg^{2+}$) and alkalis ($Na^{+} + K^{+}$), expressed as percentage reacting values, on the *X*-axis, and the difference in milli-equivalent percentage between weak acidic anions ($CO_3^{2-} + HCO_3^{-}$) and strong acidic anions ($Cl^{-} + SO_4^{2-}$), expressed as percentage reacting values, on the *Y*-axis.

The Chadha's diagram is divided into eight rectangular fields and each field describe the characteristic of the water (Table 3). In the present study, all samples were confined to 5, 6, 7, and 8 fields, respectively (Fig. 2a, b). It represents that the groundwater is (1) $Na^{+} - HCO_3^{-}$ type (31% and 39% of the samples in pre- and post-monsoons), (2) $Ca^{2+} - Mg^{2+} - Cl^{-}$ type (28% and 19% of the samples in pre- and post-monsoons), (3) $Ca^{2+} - Mg^{2+} - HCO_3^{-}$ type (22% and 23% of the samples in pre- and post-monsoons), and (4) $Na^{+} - Cl^{-}$ type (19% of the samples in both seasons).

Assessment of irrigation quality indices as per irrigation standards

In the study area, irrigation is mainly dependent on groundwater throughout the year due to inadequate surface water and erratic rainfall. Large quantity of groundwater draft is occurring from moderate to deep wells. The suitability of groundwater for irrigation is determined by varying values of different ions. Groundwater always contains some soluble salts and the excess quantity of soluble salts may be harmful to many crops and also damages the soil properties in the long run. Irrigation water quality is mostly evaluated by following indices.

During pre-monsoon, groundwater pH varies from 6.96 to 8.24 with a mean of 7.52, while in the post-monsoon samples, it varies from 6.90 to 7.94 with a mean of 7.48, its indicates that the groundwater in the study area is slightly alkaline in nature. The recommended limit of pH for irrigation water is from 6.5 to 8.4 (Bauder et al. 2014), all samples are falling within the permissible limits. pE values ranged from − 117 to − 47 mV with a mean of − 79 mV, while in pre monsoon and − 105 to − 48 mV with a mean of − 79 mV, while in post-monsoon water samples. For the groundwater, these pE values are expected (Vincent et al. 2012).

Salinity hazard (SAH)

The EC ranges from 715 to 5490 µS/cm with a mean of 2260 µS/cm and 730 to 5560 µS/cm with a mean of 1904 µS/cm for pre- and post-monsoon seasons, respectively (Fig. 3), and TDS of the groundwater varies from 381 to 2970 mg/L with a mean of 1213 mg/L during pre monsoon and 389–3010 with a mean of 1020 mg/L during post-monsoon (Fig. 4). Practically, there is a minor difference between pre- and post-monsoon EC and TDS levels, except five samples, where pre-monsoon values are much higher than the post-monsoon. These five samples are (Sample no. 17, 20, 22, 26, and 36) located in the north-western part of the study area. Decrease in the chemical concentrations during the post-monsoon can be expected as dilution due to monsoon recharge to groundwater. According to Bryan et al.'s (2007) classification, most of the samples (> 50%) are falling under medium hazard category followed by high and medium–high hazard category (Table 4). Most of the central part of the study area comes under medium–high-to-high hazard category. These areas are generally intolerable for irrigation, only very salt-tolerant plants with excellent

Table 3 Chadha's diagram classification (after Chadha 1999)

S. no.	Water type	Characteristic of water	Percentage of samples	
			Pre-monsoon	Post-monsoon
1	Alkaline earths ($Ca^{2+}-Mg^{2+}$) exceed alkalis ($Na^{+}+K^{+}$)	–	–	–
2	Alkalis ($Na^{+}+K^{+}$) exceed alkaline earths ($Ca^{2+}-Mg^{2+}$)	–	–	–
3	Weak acidic anions ($CO_3^{2-}+HCO_3^{-}$) exceed strong type acidic anions ($Cl^{-}+SO_4^{2-}$)	–	–	–
4	Strong acidic anions ($Cl^{-}+SO_4^{2-}$) exceed weak acidic anions ($CO_3^{2-}+HCO_3^{-}$)	–	–	–
5	Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively ($Ca^{2+}-Mg^{2+}-HCO_3$ type)	Such water has temporary hardness	22	23
6	Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions ($Ca^{2+}-Mg^{2+}-Cl^{-}$ type)	Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use	28	19
7	Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions ($Na^{+}-Cl^{-}$ type and $Na^{+}-SO_4^{2-}$ type of waters)	Such water generally creates salinity problems both in irrigation and drinking uses	19	19
8	Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions ($Na^{+}-HCO_3$ type)	Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems	31	39

drainage, frequent leaching and intensive management can withstand (Bryan et al. 2007). When enough salts accumulate in the root zone, this may cause the high salinity and this could affect plant growth. High salts in the root zone upset plant roots from pulling back water from surrounding soil. This brings down the amount of water accessible to the plant, despite the amount of water available in the root zone. High levels of salinity can have negative and possibly deadly impacts on plants. As a result, salinity cannot be increased to maintain soil structure without considering potential impacts on plant health (Adam et al. 2017; Jurec 2017). Peanuts (Arachis hypogaea) and cotton (Gossypium) crops are recommended in these zones (Ayers and Wescot 1985).

Chloride hazard (CH)

$Cl^{-}$is essential to plants in very low amounts, but high concentrations may cause toxicity to sensitive crops. The critical level of Cl^{-} in irrigation water is > 2 meq/L. Cl^{-} ranged from 0.5 to 30.77 meq/L with a mean of 9.12 meq/L and 0.48 to 37.29 meq/L with a mean of 7.8 meq/L for pre- and post-monsoon seasons, respectively. The mean of Cl^{-} concentration is low in post-monsoon, and it could be due to dilution during monsoon season recharge. High concentration of Cl^{-} is not absorbed by soil, and therefore, water moves in the transpiration stream of the plant and accumulates in the leaves. It causes the leaf burn or drying of leaf tissue in crops, and it occurs when the absorption of Cl^{-} concentration exceeds the tolerance limits of the crop (Ayers and Wescot 1985). Table 4 summarizes the management considerations for the prevention of Cl^{-} from irrigation water (Ayers and Wescot 1985). Figure 5a, b shows that medium-to-high Cl^{-} concentration is distributed towards central, southwestern, and northeastern parts of the study area. In these areas, management consideration is required for the prevention of Cl^{-} hazard. Crops such as potato (*Solanum tuberosum*), sorghum (*Sorghum bicolor*), corn (*Zea mays*), tomato (*Solanum lycopersicum*), sugar-beet (*Beta vugaris*), barley (*Hordeom vulgare*), asparagus (*Asparagus officinaly*), and cauliflower (*Brassica oleracea* var.botrytis) are susceptible to medium-to-high Cl^{-} hazard zones (Ayers and Wescot 1985).

Magnesium hazard (MH)

Ca^{2+} ranged from 1.18 to 23.11 meq/L with a mean of 6.42 meq/L and 1.13 to 22.77 meq/L with a mean of 5.58 meq/L for pre- and post-monsoon seasons. Mg^{2+}ranged from 1.09 to 18.69 meq/L with a mean of 5.82 meq/L and 1.31 to 18.71 meq/L with a mean of 5.13 meq/L for pre- and post-monsoon seasons, respectively. The excess Ca^{2+} and Mg^{2+}affects the quality of soil adversely resulting in poor

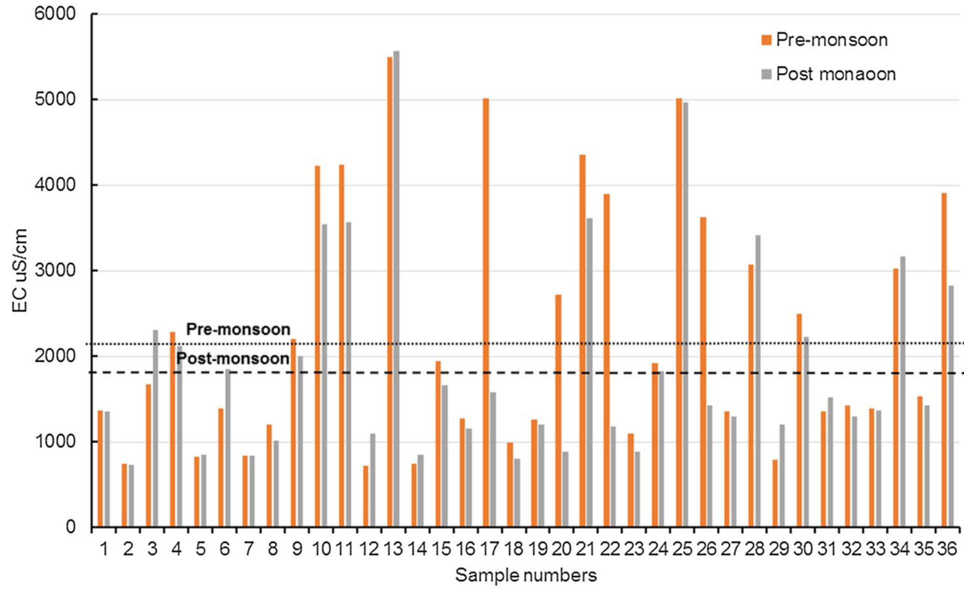

Fig. 3 Variation in EC during the pre- and post-monsoon seasons for collected samples

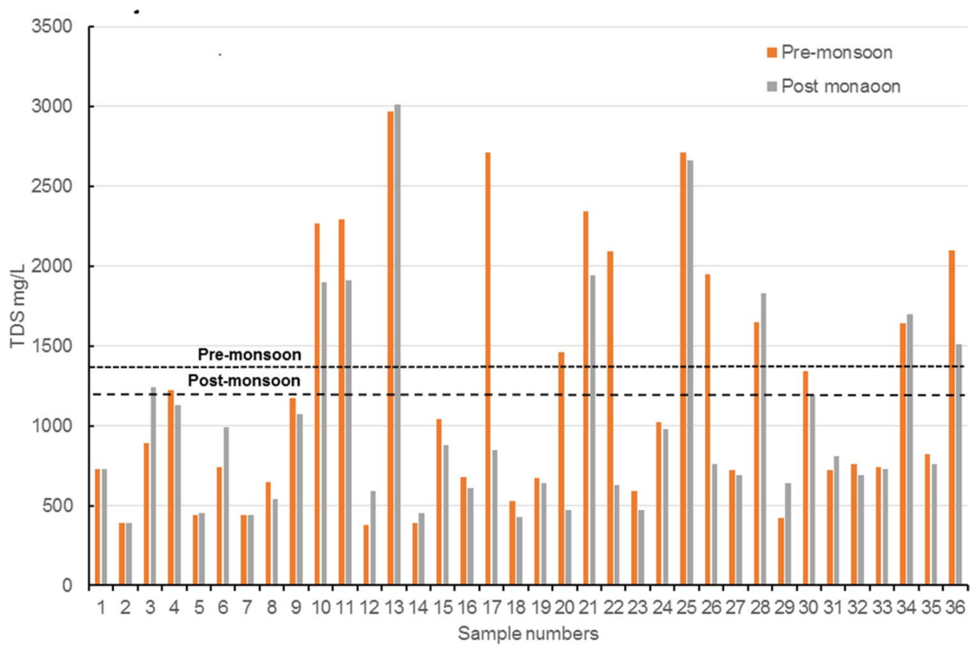

Fig. 4 Variation in TDS during the pre- and post-monsoon seasons for collected samples

agricultural returns (Sreedevi 2002). Mg^{2+}concentration in water plays an important role in determining the quality of water for irrigation purposes and hence, agricultural use. MH more than 50 is considered harmful and unsuitable for irrigation use (Sreedevi 2004; Sappa et al. 2014). Table 4 shows that 50% of groundwater samples come under unsuitable category.

Total hardness (TH)

TH is a very important property of water from its irrigation point of view (Twort et al. 1994). The TH of water samples ranged between 124 and 2012 mg/L as $CaCO_3$ and 122–2075 mg/L as $CaCO_3$ with an average of 612 and 536 mg/L as $CaCO_3$ during pre- and post-monsoon seasons, respectively. Slightly low TH values are found in the post-monsoon season which may be due to dilution of ions by recharge during the monsoon seasons. According to Sawyer and McCarty (1967), classification more than 90% of the water samples in pre- and post-monsoon seasons fall under hard to very hard category (Table 4). Hardness values less than 150 mg/L as $CaCO_3$ are desirable in most irrigation water. Using hard water concentration, more than 150 mg/L as $CaCO_3$ for irrigation can have

Table 4 Irrigation water indices' classification

Parameter	Range	Water classification	Percentage of samples	
			Pre	Post
EC in µS/cm (Bryan et al. 2007)	< 250	Very low hazard	–	–
	250–750	Low hazard	8	3
	750–2000	Medium hazard	50	67
	2000–3000	High hazard	11	11
	> 3000	Very high hazard	31	19
TDS in ppm (Bryan et al. 2007)	< 160	Very low hazard	–	–
	160–480	Low hazard	17	19
	480–1280	Medium hazard	47	58
	1280–1920	High hazard	11	15
	> 1920	Very high hazard	25	8
Chloride (meq/L) (Ayers and Wescot 1985)	< 2	Safe for most plants (low hazard)	36	19
	2–4	Sensitive plants show injury (medium hazard)	14	28
	4–10	Moderately sensitive plants show injury (high hazard)	14	28
	> 10	Can cause severe problems (very high hazard)	36	25
TH as $CaCO_3$ (meq/L) (Sawyer and McCarty 1967)	< 75	Soft	0	0
	75–150	Moderately hard	8	8
	150–300	Hard	31	22
	> 300	Very hard	61	70
MR (Hem 1985)	< 50	Suitable	53	50
	> 50	Unsuitable	47	50
RSC (meq/L) (Richards 1954)	< 1.25	Good	56	58
	1.25–2.5	Doubtful	8	8
	> 2.5	Unsuitable	36	34
Na % (meq/L) (Wilcox 1955)	< 20%	Excellent to good	0	0
	20–40%	Good to permissible	31	22
	40–60%	Permissible to doubtful	31	36
	60–80%	Doubtful to unsuitable	31	28
	> 80%	Unsuitable	7	14
SSP (meq/L) (Wilcox 1955)	< 20	Excellent	–	–
	20–40	Good	31	22
	40–80	Fair	61	64
	> 80	Poor	8	14
SAR (meq/L) (Richards 1954)	< 10	Excellent	83	83
	10–18	Good	11	14
	18–26	Fair	6	3
	> 26	Poor	–	–

a liming effect and white deposition on the soil and plant foliage and also clog irrigation equipments like to sprinklers or dripps (Gurpal and Mary 2014). More than 90% of groundwater samples in the study area were exceeding the limit of > 150 mg/L as $CaCO_3$ hardness. Hard water can influence soil and does not influence plants directly, but hardness caused by HCO_3^- can influence soils, thus indirectly affecting plant growth (Nagaraju et al. 2014).

Magnesium absorption ratio (MAR)

MAR is the excess amount of Mg^{2+} over Ca^{2+} and Mg^{2+} concentrations (Paliwal 1972). In normal conditions the Ca^{2+} and Mg^{2+} concentrations will be in a equilibrium state in natural water (Hem 1985). The MAR values range from 29.65 to 64.84 meq/L and 27.13 to 71.35 meq/L with a mean of 48.75 meq/L and 48.66 meq/L for pre- and post-monsoon

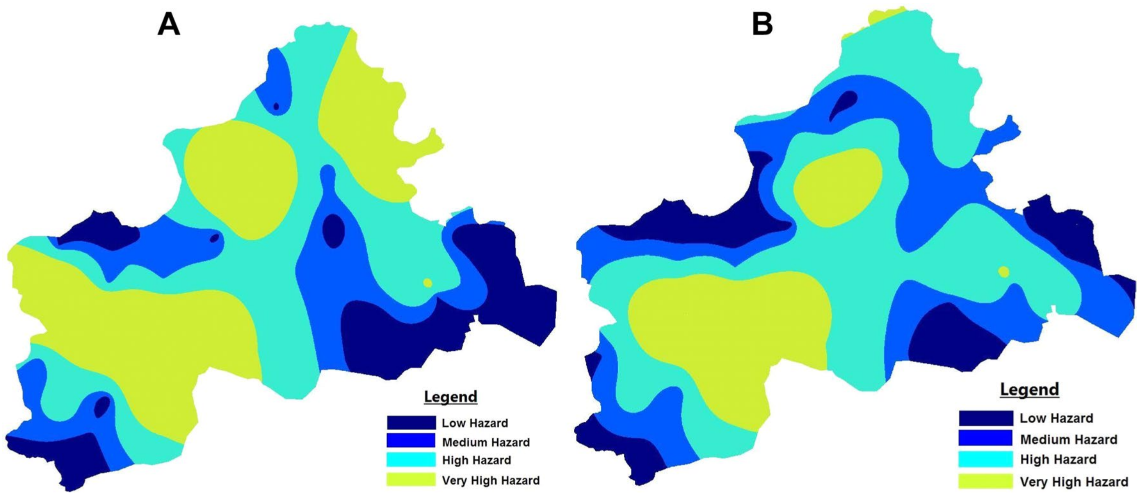

Fig. 5 **a, b** Cl hazard distribution in the pre- and post-monsoon seasons

seasons, respectively. Table 4 shows that 47% and 50% of samples during pre- and post-monsoon seasons falls above the permissible limit (50 meq/L). It is indicating that the samples with high MAR would adversely affect the crop yield by making the soil more alkaline soils (Paliwal 1972; Vasanthavigar et al. 2012; Nagaraju et al. 2014). Figure 6a, b shows that most of the unsuitable zones are located in central, southwest and southeast portions of the study area.

Carbonate and bicarbonate hazard (CBH)

CO_3^{2-} and HCO_3^- are common constituents of irrigation water and can influence soil properties (Nagaraju et al. 2014). In the study area, the concentration of CO_3^{2-} varies from 0 to 5.3 meq/L and 0 to 2.67 meq/L with an average value of 0.44 meq/L and 0.59 meq/L in pre- and post-monsoon seasons, respectively. The concentration of HCO_3^-ranges from 3.61 to 19.01 meq/L and 3.77 to 18.36 meq/L with an average value of 8.79 meq/L and 8.14 meq/L in pre- and post-monsoon seasons, respectively. Figure 7a, b shows that high concentration zones located isolated patches in the central part of the study area.

Total alkalinity (TA)

The most significant compounds in water that determine alkalinity include the CO_3^{2-} and HCO_3^- ions (AWWA 1971). TA is a measure of the acid-neutralizing capacity of water. High TA can cause an increase in the pH of the soil and it will reduce the micro-nutrient availability in soil.

In the present study, alkalinity ranges between 180 and 1086 mg/L and 189 to 1051 mg/L during pre- and

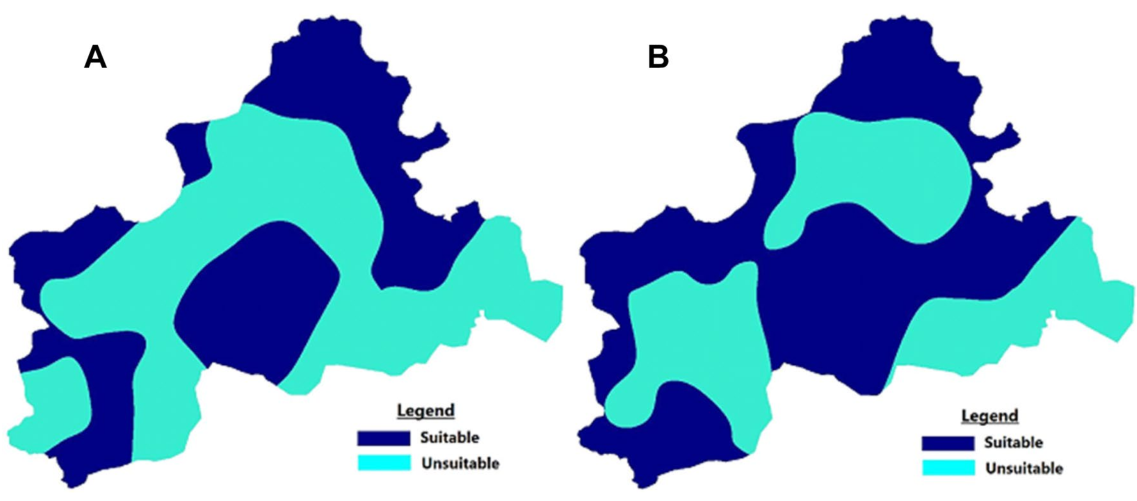

Fig. 6 **a, b** MAR distribution in the pre- and post-monsoon seasons

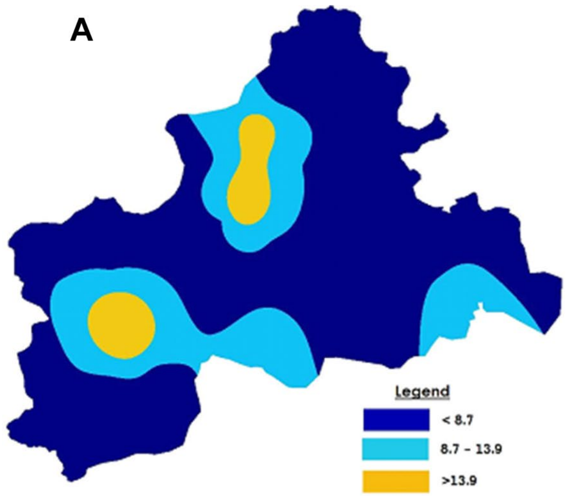

Fig. 7 **a, b** HCO_3 distribution in the pre- and post-monsoon seasons

post-monsoons, respectively, with average concentrations of 462 and 437 mg/L. The desired range of alkalinity as $CaCO_3$ is < 150 mg/L (Gurpal and Mary 2014). It is observed that all samples in both the seasons have exceeded the desired limits. Continued use of alkaline waters for irrigation in a closed system may cause adverse effects on soil physical properties and deteriorate the soil and water characters in the region and also affect the sustainability of crop production in the long run (Halliwell et al. 2001; Tillman and Surapaneni 2002; Nagaraju et al. 2014).

Non carbonate hardness (NCH)

NCH is different from carbonate hardness (AWWA 1971). The difference between the alkalinity as $CaCO_3$ and total hardness as $CaCO_3$is called as NCH. The NCH is caused by the combination of Ca^{2+} and Mg^{2+} with Cl^-, NO_3^- and SO_4^{2-}. Scale caused by carbonate hardness is generally is porous and easily removed, but that caused by NCH is hard and difficult to remove. The NCH also called as permanent hardness (Nagaraju et al. 2014). In the study area NCH ranges between 0 and 1507 mg/L and 0 to 1461 mg/L with a mean of 269 and 204 mg/L in pre- and post-monsoon seasons, respectively. In the study area 53% and 47% of groundwater samples are having NCH during pre- and post-monsoon seasons. Figure 8a, b shows that suitable zones are located in the eastern part, isolated patches in western and eastern parts of the study area.

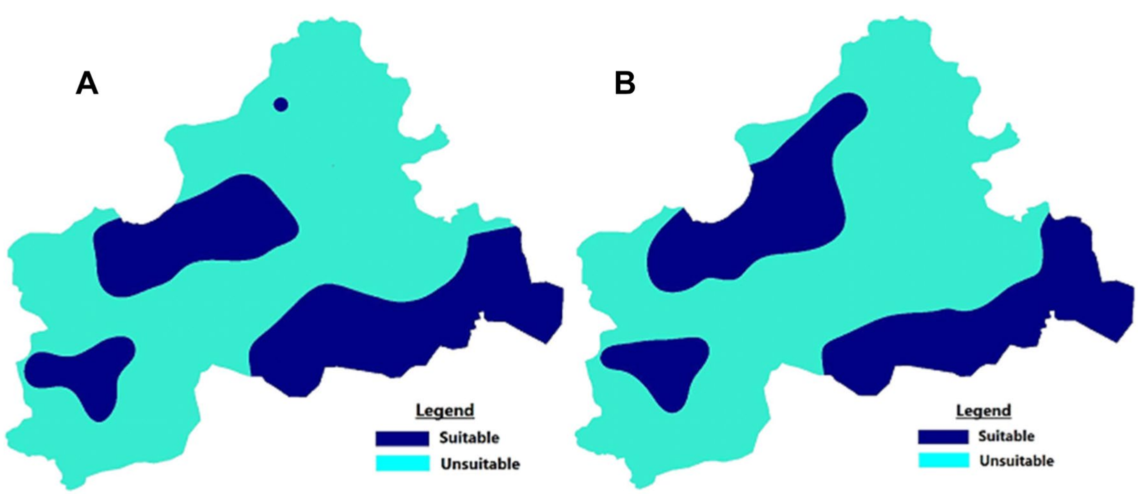

Fig. 8 **a, b** NCH distribution in the pre- and post-monsoon seasons

Residual sodium carbonate (RSC)

RSC is defined as the excess of carbonate and bicarbonate amount over the alkaline earths mainly Ca^{2+} and Mg^{2+}concentration in excess of permissible limits affects irrigation adversely (Eaton 1950; Richards 1954).

The RSC in the water of the study area varies from − 30 to 12 meq/L and − 29.19 to 13.19 meq/L with a mean of − 3 to − 1.97 in pre- and post-monsoons. According to Richards (1954) classification, 56% and 58% of the water samples fall under good category and 36% and 33% of the water samples fall under unsuitable category in pre- and post-monsoon seasons, respectively, and 8% of the water samples fall under doubtful category in both seasons (Table 4). Continuous usage of high RSC water affect the yields of crops (Sreedevi 2004).

High carbonate water can have good infiltration properties even if Ca^{2+} and Mg^{2+} levels are also high, while poor water infiltration is due to high carbonates and low Ca^{2+} and Mg^{2+}. RSC is another predictor of sodium hazard in irrigation water. If RSC increases above zero, it causes sodium hazard to soil structure. However, the water adds more carbonates than divalent cations to the soil (Steven 1994). When RSC is positive Ca^{2+} is lost from the soil solution via the following chemical reaction (Bryan et al. 2007):

$$CO_3^- \text{ (water)} + Ca^{2+}\text{(soil)} \rightarrow CaCO_3\text{(lime deposit in soil)}. \quad (1)$$

As RSC in water increases, so does the need for monitoring soil pH and the rate of water infiltration into soil. Water with an RSC above 1.0 usually require amendment to decrease RSC. Very high RSC zones are located in eastern, western and north-western part of the study area (Fig. 9a, b). If water high in RSC is repeatedly used the soil becomes alkaline and is likely to become sodic over the time even if the water also contains appreciable quantities of Na^+ (Ramesh and Elango 2012).

Sodium hazard (SH)

Na^+ exists in nearly all irrigation water and is not necessarily a cause for concern unless high concentration is present. The Na^+ ion ranges between 3.1 and 46.8 meq/L and 3.8–48.7 meq/L with average concentrations of 14 and 13.3 meq/L during pre- and post-monsoon seasons. The maximum permissible limit of Na^+ is > 40 meq/L. High Na^+ in irrigation water can be taken up by the roots, foliage and foliar burning can take place if sufficient amount accumulate in leaf tissue (McFarland et al. 2002). Figure 10a, b shows that high concentration of Na^+ is located in isolated patches in central and western part of the study area. High concentration of Na^+ ion in water affects the soil permeability, causes infiltration problems and it can be harmful to crops and soils (Ayers and Westcot 1985; Ramesh and Elango 2012).

Percent sodium (%Na)

High concentration of Na^+ in irrigation waters may cause sodium hazard (Wilcox 1955). Excess Na^+ in waters produces the undesirable effects on reducing soil permeability, changing soil properties and may stunt the plant growth (Nishanthiny et al. 2010; Obiefuna and Sheriff 2011). Hence, the assessment of %Na is essential in considering the suitability of irrigation water (Wilcox 1948).

The %Na in the study area varies from 23.03 to 85.16 meq/L and 24.52 to 83.90 meq/L with an average value of 54.74–55.39 meq/L in pre- and post-monsoon seasons, respectively. Irrigation waters are classified based on

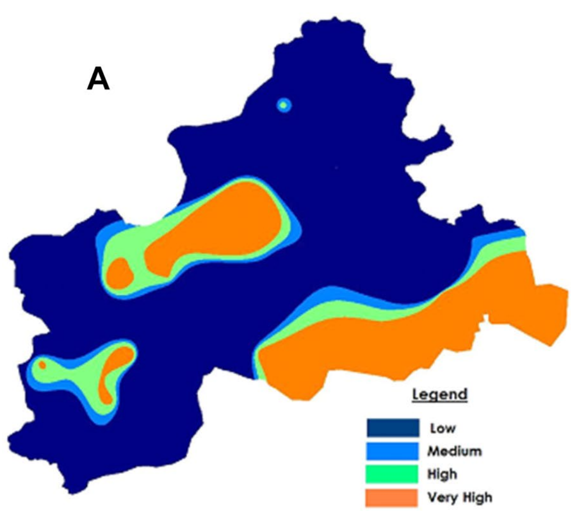

Fig. 9 **a, b** RSC distribution in the pre- and post-monsoon seasons

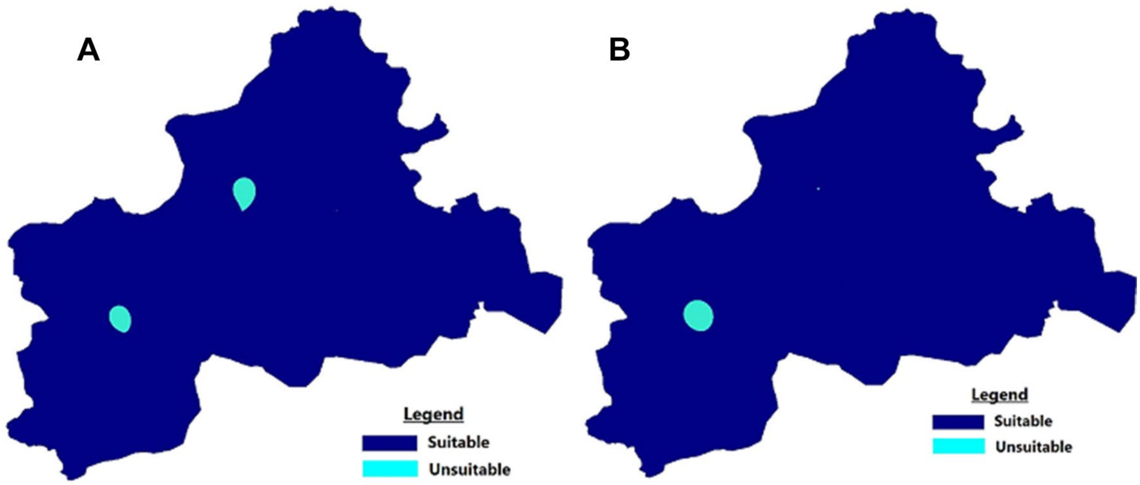

Fig. 10 **a, b** SH distribution in the pre- and post-monsoon seasons

%Na alone (Wilcox 1948), as shown in Table 4. As per the Indian Standards (BIS 2003), a maximum Na^+ content of 60% is recommended for irrigation water. %Na greater than 60 may result in Na^+ accumulations that will cause a breakdown of the soil physical properties (Fipps 1998; Ramesh and Elango 2012).

Sodium adsorption ratio (SAR)

According to Kelley (1951), excess Na^+accumulations in waters used for irrigation produce undesirable effects on reducing soil permeability by changing soil properties due to clogging of particles. Therefore, it was suggested that concentrations of Na^+ be considered in assessing the suitability of irrigation waters (Towfiqul Islam et al. 2017).

Irrigation waters are classified by the U.S. salinity laboratory (1954) based on SAR alone (Richards 1954), as shown in Table 4. Based on the classification it is noticed that eighty-three percent of the water samples fall under the excellent category, while others are of good to fair category in both the seasons (Sreedevi 2004).

Estimation of infiltration rate capacity of groundwater

The infiltration properties of irrigation water are assessed by determining the SAR and EC of the water. The effects of high SAR on irrigation water are dependent on EC of the water. Both EC and SAR index are in higher in irrigation watercausing infiltration problems. On the other hand the lower the EC and greater the SAR is the risk of infiltration. According to Rhoades (1977) and Oster and Schroer (1979) classification more than 50% of the samples are falling under slight to moderate reduction in the infiltration rate category in both seasons. The percentage of samples under slight to moderate reduction in the rate of infiltration category is slightly increased in the post-monsoon season. Rainfall can reduce the soil salinity and, therefore, increase the SAR index and reduce water penetration into soil resulting occurence of excessive runoff (Kar et al. 2015) (Table 5).

Table 5 Classification of water infiltration capacity (after Rhoades 1977 and; Oster and Schroer 1979)

SAR	Classification of water infiltration problem			Percentage samples fall under different infiltration problems					
	EC of water µS/cm			Low		Moderate		High	
	Low	Moderate	High	Pre	Post	Pre	Post	Pre	Post
0–3	Above 700	700–200	Below 200	30	30	–	–	–	–
3–6	Above 1200	1200–300	Below 300	28	19	–	–	7	17
6–12	Above 1900	1900–500	Below 500	6	8	–	–	17	14
12–20	Above 2900	2900–1300	Below 1300	6	6	–	–	–	3
20–40	Above 5000	5000–2900	Below 2900	–	–	–	–	6	3

Conclusion and recommendations

The groundwater pH in the study area is near neutral to alkaline. HCO_3^- and Cl^- dominate the groundwater among anions and Na^+ and Ca^{2+} among cations. In most of the groundwater samples, alkalies ($Na^+ + K^+$) exceeded alkaline earths ($Ca^{2+} + Mg^{2+}$) and weak acids ($CO_3^{2-} + HCO_3^-$) exceeded strong acids ($SO_4^{2-} + Cl^-$). The type of groundwater that predominate in the study area are (1) $Na^+ - HCO_3^-$, (2) $Ca^{2+} - Mg^{2+} - Cl^-$, (3) $Ca^{2+} - Mg^{2+} - HCO_3^-$ and (4) $Na^+ - Cl^-$. The results of irrigation indices show that few water samples in this area were good to suitable for irrigation purposes. However, remaining groundwater samples were found within permissible to doubtful and doubtful to unsuitable categories for irrigation in isolated places, may be due to long water–rock interaction (based on MH). High Cl^- concentration is distributed in isolated patches in central, southwestern and northeastern parts of the study area. Concerning %Na parameter, 31% and 22% of groundwater samples in pre- and post-monsoon comes under good to permissible category, remaining samples fall under permissible to doubtful (31% and 36%); doubtful to unsuitable (31% and 28%) and unsuitable (7% and 14%) categories. According to Rhoades (1977) and Oster and Schroer (1979) classification more than 50% of the samples are falling under slight to moderate reduction in the infiltration rate category in both seasons.

Thus, the study reveals that most of the groundwater samples have exceeded their permissible limits in the irrigation water. High salinity and chloride hazards may reduce the crop production and growth; which may require careful management and special type of irrigation practices to avoid crop failures. The overall results of the study indicate alarming situation with reference to groundwater quality and it may need suitable remedial measures. To reduce the higher chemical concentrations in the groundwater artificial recharge techniques maybe worked out or alternatively suitable crops may be adopted to sustain the present groundwater quality.

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