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Assessment of groundwater quality for irrigation use: a peninsular case study

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Abstract

The grade of irrigation water available to irrigators has a significant impact on crops as well as yields. Therefore, it is a need to better understand irrigation water quality. The present study mainly focuses on the assessment of the suitability of water of forty-four fixed bore wells of Kanchipuram district, Tamil Nadu, India. The groundwater sample datasets of post-monsoon (2005–2013) and pre-monsoon (2006–2013) season were collected for 9 years. Water quality indices, namely sodium adsorption ratio, exchangeable sodium percent (SSP or %Na), residual sodium carbonate (RSC or RA), Kelly's ratio, permeability index, chloroalkaline indices (CAI1 and CAI2), potential salinity (PS), magnesium hazard, total dissolved solids and total hardness, have been calculated for separate bore wells. The r_1 and r_2 indices show that groundwater of the study area is Na^+–SO_4^{2-} and deep meteoric percolation type. Majority of the wells are fall under moderate to unsuitable category of water for irrigation purposes. Further, wells water has also been classified on the base of meteoric genesis index.

Keywords Irrigation water quality · Meteoric genesis index · Sodium adsorption ratio · Magnesium adsorption ratio · Geochemistry

Introduction

Groundwater has become the major source of water use in the agricultural sector in many countries where river and drainage systems are not sufficient. Therefore, poor groundwater quality for irrigation purpose is a matter of worry in recent years. Under or over chemical fertilization is resulting in groundwater pollution (Ayers and Westcot 1985; Rowe and Abdel-Magid 1995; Singh et al. 2013; Gautam et al. 2015, 2016; Nemčić-Jurec et al. 2017). Groundwater quality depends on the nature of recharging water, precipitation, subsurface and surface water and hydro-geochemical processes in aquifers (Keesari et al. 2016a; Das et al. 2017), land-use/land-cover change (Amin et al. 2014; Srivastava et al. 2013; Gajbhiye et al. 2015; Nemčić-Jurec et al. 2017; Rawat et al. 2017; Rawat and Singh 2018) and mining activities (Gautam et al. 2016; Keesari et al. 2016b; Gautam et al. 2018). Temporal changes in the constitution and origin of the water recharged, and human factor, frequently cause periodic changes in groundwater quality (Vasanthavigar et al. 2010; Milovanovic 2007).

Groundwater quality degrades in twofold, first, due to geochemical reactions in the aquifers and soils and, second, time when it is supplied through improper canals/drainages for irrigation. Therefore, it is necessary to perform a regular assessment of irrigation and drinking water quality (Gupta et al. 2009; Jacintha et al. 2016; Rawat et al. 2018; Gautam et al. 2018). Irrigation demands sufficient water supply of usable quality. The index based on composition and concentration of dissolved elements in water can be useful in determining its applicability for agricultural utilization (Gautam et al. 2013; Singh et al. 2013, 2015). The suitability of groundwater for irrigation depends on the nature of the mineral elements in the water and their impacts on both the soil and plants (Richards 1954; Singh et al. 2009).

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The excess of salts affects plant's growth by redressing the uptake power of plant due to complex changes arouse out of the osmotic processes (Todd 1980).

Generally, water quality parameters (major cations as Na^+, Ca^{2+}, Mg^{2+}, K^+) and anions Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, NO_3^-) and heavy metals are indicators of drinking water use, while water quality indices such as sodium adsorption ratio (SAR), sodium percentage (SSP; %Na), residual sodium carbonate (RSC), residual alkalinity (RA), Kelly's ratio (KR) [or Kelly's index (KI)], permeability index (PI), chloroalkaline indices (CAI1 and CAI2), potential salinity (PS), magnesium hazard (MH) (or magnesium adsorption ratio; MAR), total dissolved solids (TDS) and total hardness (TH) based on primary water quality parameters are frequently used to determine quality of water for irrigation (Singh et al. 2013, 2015; Gautam et al. 2015).

In the present study, forty-four groundwater samples collected from bore wells were analyzed and assessed for temporal variation and change in water quality index over a period of time. Most of the bore wells are from agricultural areas.

The relation between irrigation and groundwater resources is highly interlinked. This paper describes the groundwater quality status for irrigation purpose using water quality index (SAR, %Na, RSC, PI, MH, CAI1 and CAI2 CR, TDS, TH, Gibb's 1 and 2) based on primary parameters (such as K^+, Ca^{2+}, Cl^-, Na^+, Mg^{2+}, NO_3^-, SO_4^{2-} and HCO_3^-). Further, the classification was performed based on Soltan method and estimation of groundwater source based on meteoric genesis index. Therefore, the aim of the study was to determine suitability of goundwater for irrigation.

Study area

Kanchipuram district of Tamil Nadu (India) state lies between 11°00′ and 12°00′ north latitudes and 77°28′–78°50′ east longitudes (North East coast of Tamil Nadu) and on the banks of the Vegavathi River, a tributary of the Palar River (Fig. 1a). The study area has an elevation of 83.2 m above mean sea level. The land around study area is flat and slopes toward the south and east. It is bound by Bay of Bengal in the east.

Agriculture is the main occupation of the people with 47% of the population engaged in it. Paddy is the major crop cultivated in this district. Industrial developments occupy around 65 ha (160 acres), where most of the handloom spinning, silk weaving, dyeing and rice production units are located. 89.06 ha (220.1 acres) are used for transport and communications infrastructure, including bus stands, roads, streets and railways lines. Groundnuts, sugarcane, cereals and millets and pulses are the other major crops (Table 1). The soil in the region is mostly clay, with some loam, clay and sand (Table 1). The total forest area in the district is 23,586 ha, and it spreads in the interior region

and around the district. In this forest area, there are 366.675 ha of reserved land. Totally, 76.50 metric tonnes lands are cultivated in fuelwood and 8.039 tonnes in cashew.

The pre-monsoon rainfall is almost uniform throughout the district. The coastal regions get more rains rather than the interior regions. This district is mainly depending on the seasonal rains, and the distress conditions prevail in the event of the failure of rains. Northeast and southwest monsoons are the major donors with 54% and 36% contribution each to the total annual rainfall. During normal monsoon, the district receives a rainfall of 1213.3 mm (Table 1).

Materials and methods

The data related to groundwater quality have been acquired from Chennai Water Metro Board/Central Ground Water Board (CGWB) during pre- and post-monsoon seasons. Totally, 44 samples were collected during May 2005 (pre-monsoon) and sampling activity was repeated during January 2006 (post-monsoon) of period 2005–2013. Well coordinates have been collected using a handheld GPS device (eTrex Legend® HCx, having 10-m accuracy).

Development of rainfall datasets using satellite datasets

The precipitation data of the entire study area have been derived from daily precipitation data provided by the NOAA climate prediction center and were downloaded from the site ftp://ftpprd.ncep.noaa.gov/pub/cpc/fews/S.Asia/. The need of satellite-estimated precipitation arises because of the non-dependable and poorly spatially distributed ground rainfall data (Rawat and Tripathi 2016; Rawat et al. 2012a; b, 2016). Daily precipitation satellite data have been converted into monthly precipitation data (Fig. 1b) by simply sum of per day rainfall of particular month (Rawat and Tripathi 2016; Rawat et al. 2012c, d, 2016).

Irrigation indices

Sodicity

Sodic soils are characterized by a disproportionately high concentration of sodium (Na^+) in their cation exchange complex. Sodicity is the effect of irrigation water and can alter the chemical and physical properties of the soil due to an accumulation of Na^+. Excess of Na^+ can affect plants in three ways: (1) by degrading soil structure after each rainfall and irrigation due to crust formation which reduces water movement (permeability) and aeration in the soil; (2) toxic effects when absorbed by leaves/roots; and (3) K^+ and Ca^{2+}
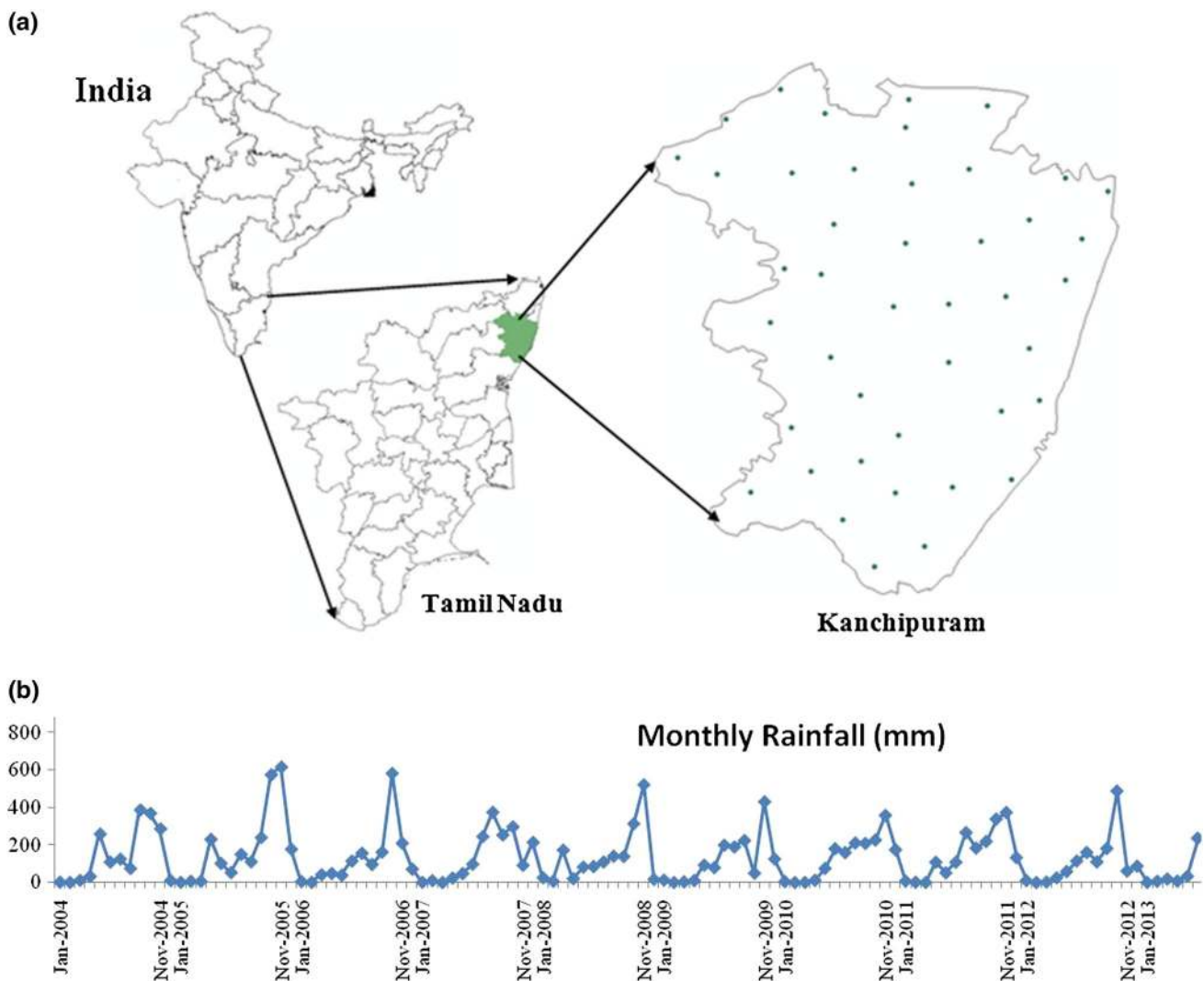
Fig. 1 **a** Study area map with 44 sampling locations. **b** Graphical representation of rainfall variability in the study area during 2005–2013

deficiencies may arise if the soil or irrigation water has a high concentration of Na^+. Therefore, evaluation of the sodicity hazard of irrigation water is important.

Sodium adsorption ratio (SAR)

The SAR is a relative ratio of Na^+ ions to Ca^{2+} and Mg^{2+} ions present in the water sample. The SAR is used to estimate the potential of Na^+ to accumulate in the soil primarily (water movement) at the expense of Ca^{2+}, Mg^{2+} and K^+ as a result of regular use of sodic water. It is formulated as Eq. (1):

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}} \tag{1}$$

where Na^+, Ca^{2+} and Mg^{2+} are in meq/l.

On the basis of SAR range, irrigation water can be classified into four classes as SAR < 10 (ideal or excellent), 10–18 (good), 18–26 (doubtful) and > 26 (unsuitable).

SAR also influences percolation time of water in the soil. Therefore, the low value of SAR of irrigation water is desirable.

Residual sodium carbonate (RSC)/residual alkalinity (RA)

RSC represent as the amount of sodium carbonate ($NaCO_3$) and sodium bicarbonate ($NaHCO_3$) present in the irrigation water if the concentration of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions exceeds the concentrations of Ca^{2+} and Mg^{2+} ions (Raghunath 1987), precipitation of Ca^{2+} and Mg^{2+}. If the carbonates are less than alkaline earths ($Ca^{2+} + Mg^{2+}$), it outlined the residual $NaCO_3$ which is absent. Generally, RSC is expressed as milliequivalents

Table 1 General information about the study area (Source: www.kanchi.tn.nic.in)

Total area	4393.37 km^2
Net sown area	1364.89 km^2
Net irrigation area	1236.28 km^2
Forest area	426.57 km^2
Poromboke area	1553.47 km^2
Town area	82.57 km^2
Number of panchayat villages	648
Summer temperature	21.1–36.6 °C
Winter temperature	19.8–28.7 °C
Rainfall	1133.0 mm actual, 1213.3 mm normal
Major crops	Rice (145,966 ha), sugarcane (7586 ha), groundnut (28,766 ha), gingelly (912 ha), pulses (2966 ha), cotton (53 ha), millets and cereals (1217 ha)
Soil types	Read loam (Kanchipuram, Uthiramerur blocks), lateritic soil (plateaus in the district), black soil (spread in all blocks), sandy coastal alluviam (Thiruporur and St. Thomas Mount) and red sandy soil (Kancheepuram and urban blocks)

per liter (meq/l) of $NaCO_3$. An excess of CO_3^{2-} and HCO_3^- causes precipitation of soil Ca^{2+} and Mg^{2+} impairing the soil structure as well as potentially activating soil sodium. On the basis of RSC range, sodium hazard has been classified into three classes as follows: RSC < 1.25 (low), 1.25–2.5 (medium) and > 2.5 (high). RSC is expressed as Eq. (2):

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

A high range of RSC in irrigation water means an increase in the adsorption of sodium on the soil. Water having RSC > 5 has not been recommended for irrigation because of damaging effects on plant growth. Generally any source of water in which RSC is higher than 2.5 is not considered suitable for agriculture purpose, and water < 1.25 is recommended as safe for irrigation purpose. A negative value of RSC reveals that concentration of Ca^{2+} and Mg^{2+} is in excess. A positive RSC denotes that Na^+ existences in the soil are possible. RSC calculation is also important in context to calculate the required amount of gypsum or sulfuric acid per acre-foot in irrigation water to neutralize residual carbonates effect.

Percent sodium (%Na) or sodium hazard

The %Na is also used in classifying water for irrigation purpose. Na^+ is important parameter and helps in categorization of any source of water for irrigation uses. Na^+ makes chemical bounding with soil to reduce water movement capacity of the soil (Ayers and Westcot 1985). Percent Na^+ concentration is a factor to assess its suitability for irrigation purposes

(Wilcox 1948). Na^+ reacts with CO_3^{2-} and forms alkaline soils, while Na^+ reacts with chloride and forms saline soils. Sodium-affected soil (alkaline/saline) retards crop growth (Todd 1980). If concentration of Na^+ in irrigation water is high, then the ions tend toward the clay particles, by removing Ca^{2+} and Mg^{2+} ions through a base-exchange reaction. This exchange process in soil reduces water movement capacity. In this condition, air and water cannot move freely or restricted during wet conditions, and such soils have become hard when dry (Collins and Jenkins 1996; Saleh et al. 1999). The %Na values are calculated as Eq. (3):

$$\%Na = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \tag{3}$$

(all the ion concentrations are expressed in meq/l).

The classification of water is based on %Na as excellent (< 20%), good (20–40%), permissible (40–60%), doubtful (60–80%) and unsuitable (> 80%) (Khodapanah et al. 2009).

Kelly's ratio (KR) or Kelly's index (KI)

Kelly (1940) and Paliwal (1967) introduced another factor to assess quality and classification of water for irrigation purpose based on the concentration of Na^+ against Ca^{2+} and Mg^{2+}. It can be calculated using Eq. (4)

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \tag{4}$$

(all the ion concentrations are expressed in meq/l).

KR/KI > 1 indicates an excess level of Na^+ in waters. Therefore, water with a KI ≤ 1 has been recommended for

irrigation, while water with KI ≥ 1 is not recommended for irrigation due to alkali hazards (Ramesh and Elango 2012; Karanth 1987).

Permeability index (PI)

The permeability index (PI) is an indicator to study the suitability water for irrigation purpose. Water movement capability in soil (permeability) is influenced by the long-term use of irrigation water (with a high concentration of salt) as it is affected by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- ions of the soil. PI formula has been developed by Doneen (1964), to assess water movement capability in the soil as the suitability of any kind of source of water for irrigation, and it is formulated as Eq. (5):

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \tag{5}$$

(all the ion concentrations are expressed in meq/l).

According to Doneen (1964), PI can be categorized in three classes: class I (> 75%, suitable), class II (25–75%, good) and class III (< 25%, unsuitable). Water under class I and class II is recommended for irrigation.

Magnesium hazard (MH) or magnesium adsorption ratio (MAR)

Usually, alkaline earths (Ca^{2+} and Mg^{2+}) are in an equilibrium state in groundwater. Both Ca^{2+} and Mg^{2+} ions are linked with soil friability and aggregation, but both are also essential nutrients for the crop. The high value of Ca^{2+} and Mg^{2+} in water can increase soil pH (therefore soil converting it to saline nature of the soil; Joshi et al. 2009), resulting in decrease in the availability of phosphorous (Al-Shammiri et al. 2005). Excess concentration of magnesium in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield (Gowd 2005; Singh et al. 2013; Gautam et al. 2015). According to agriculturists, excess amount of Mg^{2+} ions in waters damage the soil quality which causes low crop production (Ramesh and Elango 2012; Narsimha et al. 2013). Szabolcs and Darab (1964) projected MH values for irrigation water, and it is calculated using Eq. (6):

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \tag{6}$$

(all the ion concentrations are expressed in meq/l).

MH > 50 is not recommended for irrigation purposes (Khodapanah et al. 2009).

Potential salinity (PS)

PS is another water quality parameter-based index (Doneen 1964) for categorization of water for agriculture use. PS < 3 meq/l is an indication of the suitability of water for irrigation. The temporal distribution of PS of the study area is produced for pre- and post-monsoon seasons using following Eq. (7):

$$PS = Cl^- + 0.5 \times SO_4^{2-} \tag{7}$$

Chloroalkaline indices (CAI1 and CAI2)

Information about coming changes in chemical composition of the groundwater during underground travel is also vital (Sastri 1994). The chemical reaction in which ion exchange between the groundwater and the aquifer occurs during the movement and rest condition of water. It can be analyzed through the chloroalkaline indices. The CAI1 and CAI2 are evaluated (Schoeller 1977) and expressed by Eqs. (8 and 9):

$$CAI1 = \frac{Cl^- - (Na^+ + K^+)}{Cl^-} \tag{8}$$

$$CAI2 = \frac{Cl^- - (Na^+ + K^+)}{(SO_4^{2-} + CO_3^{2-} + HCO_3^- + NO_3^-)} \tag{9}$$

The CAI1 and CAI2 indices may be negative or positive depending on the exchange process of Na^+ and K^+ from the rock with Mg^{2+} and Ca^{2+} present in water and vice versa. If a direct exchange process (DEP) happens between Na^+ and K^+ in water with Mg^{2+} and Ca^{2+} in rocks, then CAI ratio will be positive. If a reverse exchange process occurs (Na^+ and K^+ in water with Mg^{2+} and Ca^{2+} in rocks), then CAI ratio will be negative.

Corrosivity ratio (CR)

The corrosivity ratio is giving the information about water supply. Any source of water with CR < 1 is recommended to the transport of any source of water in any kind of pipes, whereas CR > 1 shows corrosive nature of water, means not to be transported through metal pipes (Balasubramanian 1986; Shankar et al. 2011; Aravindan 2004). The CR can be estimated using an Eq. (10):

$$CR = \frac{\left(\frac{Cl^-}{35}\right) + 2\left(\frac{SO_4^{2-}}{96}\right)}{\left(\frac{CO_3^{2-} + HCO_3^-}{100}\right)} \tag{10}$$

(all ions are in ppm).

The rate of corrosion depends upon some physical parameters like pressure, temperature and rate of flow of water. In addition to the higher value of Cl^- and SO_4^{2-} also increases the corrosion rate.

Total dissolved solids (TDS)

In natural water total dissolved solids contains of minerals, nutrients that have dissolved in water, and also includes major ions, i.e. Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} and PO_4^{3-}. Weathering or dissolution of soil and rocks generates ions in water (Singh et al. 2013). After evaporation of water, accumulation of salt at the root zone makes obstacle and plants are not capable of sucking water from soil resulting in moisture stress (Modi 2000). For irrigation, the TDS has been classified as TDS < 450 mg/l and is preferred for irrigation and TDS > 450–2000 mg/l is slight to moderate and TDS > 2000 mg/l is unsuitable for agricultural purpose (FAO 2006).

Total hardness (TH)

Water hardness is a result of existence of divalent metallic cations (Ca^{2+} and Mg^{2+}), and it can be calculated as the sum of Ca^{2+} and Mg^{2+} concentration as meq/l equivalent to $CaCO_3$ (Todd 1980) and expressed by (Eq. 11):

$$TH = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+} \tag{11}$$

The high value of TH is due to encrustation on water supply systems (pipes) for distribution. Moderate value of TH is useful for plumbing system from corrosion. Total hardness classified as 100 mg/l provides good control over corrosion and is the usually acceptable limit. TH is usually classified (EPA 1986) as soft (0–60 mg/l), moderately hard (60–120 mg/l), hard (120–180 mg/l) and very hard (> 180 mg/l).

Classification of groundwater

Soltan (1998) suggested the classification of different sources of water facies based on the concentration (meq/l) of particular ion. Soltan (1999) suggested a new classification method based on base-exchange indices, and it can be calculated using Eq. (12)

$$r_1 = \frac{Na^+ - Cl^-}{SO_4^{2-}} \tag{12}$$

The groundwater of the study area can be categorized as Na^+–HCO_3^- type if $r_1 > 1$ and Na^+–SO_4^{2-} type if $r_1 < 1$.

The groundwater has also been categorized based on meteoric genesis index, which was calculated (Soltan 1999) using Eq. (13).

$$r_2 = \frac{(K^+ + Na^+) - Cl^-}{SO_4^{2-}} \tag{13}$$

If the value of $r_2 < 1$ it means the groundwater is of deep meteoric percolation (DMP) type, and if the value of $r_2 > 1$ it means the groundwater is of shallow meteoric percolation (SMP) type.

Result and discussion

Irrigation indices

Figure 2a, b shows the fluctuation of SAR value during pre- and post-monsoon season and Tables 2 and 3 show 9-year statistics. Tables 2 and 3 revealed that SAR value ranges from 0.25 to 69.09 and 0.24 to 78.37 in pre- and post-monsoon, respectively. The average value of SAR for 9 years was reported as 18.74 and 17.49 which are the nearest average value (18.93 and 19.17 and 17.30 and 17.40) of 2010 and 2011 (pre-monsoon) and 2006 and 2008 (post-monsoon). According to individual year statistics, 2007 and 2012 have lowest average value of SAR (15.92 and 15.91) during post-monsoon. It is due to good amount of rainfall (Fig. 1b, 7- and 8-month rainfall out of 12 during 2007 and 2012, respectively). The same year's range of SAR was also lowest (1.05–46.14 and 1.94–67.93). Similarly, Table 3 shows 32 wells (15 excellent, 31.82 percent + 17 good, 38.64 percent), and 32 wells (19 excellent, 43.18 percent + 13 good, 39.55 percent) fall under excellent and good category during the years 2007 and 2012 (post-monsoon). The rainfall affects SAR value of the year 2006 (pre-monsoon). The 2007 post-monsoon saw a good amount of rainfall as 70.45 percent (19 excellent + 12 good) wells have reported normal SAR limit, whereas in 2011 pre-monsoon, majority of water went as runoff (less amount of infiltration into groundwater); hence, in 2012 pre-monsoon, only 21 wells (17 excellent + 4 good) fell under safe limit of SAR. From Fig. 2a, during pre-monsoon well nos. 4, 12, 21, 27, 34 and 40 were cross the higher (> 26) limit of SAR, respectively, 9, 7, 6, 7, 3 and 7 time (year) out of 9 years, and it highlights that these wells are not appropriate for pre-monsoon irrigation. From Fig. 2b, these same wells have higher SAR value as > 26 (limit) with 7, 6, 4, 3, 0 and 8 times out of 8 years during post-monsoon. Therefore, these wells (4, 12, 21, 27 and 40) were unsuitable during the study period (2005–2013).

The RSC value ranges from − 0.10 to 6.87 with an average value of 1.76 over 2005–2013 during pre-monsoon (Table 2), while during post-monsoon RSC value ranges from − 4.73 to 5.04 (for 8 years) with 1.48 8-year average (Table 3). From Table 4 in years 2011 and 2012, wells (47.73% and 65.91%, respectively) fall under the good limit
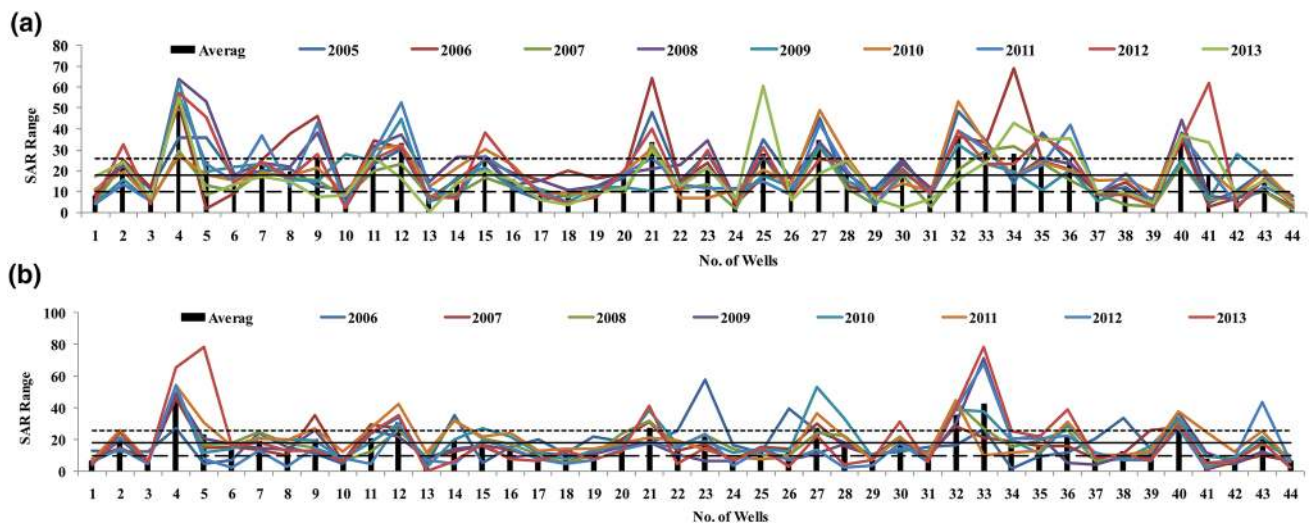
Fig. 2 a Nine-year (2005–2013) temporal representation of SAR value during pre-monsoon. b Nine-year (2006–2013) temporal representation of SAR value during post-monsoon

(< 1.25) due to good amount of monthly rainfall during 2010 and 2011 (above 200 mm), which provide higher rate of infiltration rather than runoff. Similarly, during post-monsoon of year 2013, highest no. of wells (59.09%, Table 5) falls under the good limit (< 1.25) of RSC. It shows during 2013 factor (HCO_3^-, CO_3^{2-}, Ca^{2+} and Mg^{2+}) which govern RSC were less in groundwater due to slow leaching from rock to groundwater. Effect of rainfall over RSC can be easily understood from Fig. 3a, b, well nos. 2, 4, 5, 12, 21, 25, 32, 35 and 41 most of the time of year come under beyond of the unsuitable limit during pre-monsoon, but after rainfall or due to rainfall effect these well's RSC range reduces. In Fig. 3b, some wells (6, 24, 32, 36 and 44) having negative RSC values due to excess concentration of Ca^{2+} and Mg^{2+}. A high range of RSC in groundwater indicates an increase in the adsorption of sodium in soil (Eaton 1950) during irrigation from such type of bore well. It is observed that well nos. 2, 4, 5, 12, 21, 25, 32, 35 and 41 fall under unsuitable category for irrigation purpose because of RSC value > 2.5 meq/l is harmful for plants growth.

From Tables 2 and 3, 9-year average of %Na found 55.04 (with min = 3.27 and max = 87.59) and 54.38 for pre- and post-monsoon, respectively, and both values are under the permissible limit for irrigation. Individual yearwise study shows the years 2006 (during pre-monsoon) and 2011 (during post-monsoon) average value of %Na [60.05 (pre-monsoon) and 57.30 (post-monsoon)] was high during the study period. Statistical analysis (Tables 2, 3) of %Na does not show much variation in %Na values yearwise, and also Tables 2 and 3 revealed that all the year wise statistical values (AV, Me, Mo, Mi, Ma and SD) showing most no. of wells falls under acceptable limit of %Na. From Table 4, it is clear that majority of percent of wells come under excellent,

good and permissible category, but the doubtful category also reports the good percent of total no. of wells during the pre-monsoon years 2006, 2010 and 2011, respectively, 45.45, 45.45 and 59.09%. It may be due to low rainfall and leads to slow dilution process. Table 5 shows the doubtful category (except years 2006 and 2010) during post-monsoon and explain rainfall effect over %Na. Figure 4a, b also explains the effect of rainfall over groundwater quality in the context of %Na. Only well no. 33 showing a negative effect of rainfall, it may be due to more leaching of Na^+ from the rock into the water. Overall, Fig. 4b represents dilution in %Na with respect to Fig. 4a during the study period 2005–2013. Based on Fig. 4a, b, majority of wells come in the good and permissible category of irrigation water.

Kelly's ratio (KR)/Kelly's index (KI) is an indicator to asses irrigation water suitability and it is free from the effect of K^+ parameter, which purely depends on Ca^{2+}, Mg^{2+} and Na^+. Its classification bin (only two classes) is also easier than %Na classification bin (four classes). From Tables 2 and 3, average value of KR/KI during the study period was 1.39 and 1.34 for pre- and post-monsoon, respectively, with a range of 0.03–6.66 and 0.03–12.31. Statistical analysis of KR has revealed that majority of wells falls in unsuitable category during pre-monsoon. Except for year 2007 KR varies from 0.03–3.63 with average KR was found 0.92 (Table 2) during pre-monsoon. After analysis of post-monsoon KR value, it was found that there was very less effect of rainfall over KR because after rainfall average value of KR (Table 3) comes under the suitable range due to dilution process. Table 4 denotes that during the pre-monsoon study period more than 52 percent wells in the study area come under the suitable category (KR < 1) of irrigation except the years 2005 and 2007. Table 5 does not take into

Table 2 Statistics of each index during pre-monsoon

	2005	2006	2007	2008	2009	2010	2011	2012	2013	N YA
SAR										
AV	19.25	21.15	13.88	21.13	17.17	18.93	19.17	20.66	17.34	18.74
Me	15.51	17.10	11.48	18.30	15.50	17.79	14.88	20.41	14.29	15.80
Mo	10.42	7.00	7.30	6.51	28.25	8.41	3.77	2.48	8.07	12.73
Mi	2.09	1.83	1.13	5.43	3.81	5.79	3.77	2.48	0.25	0.25
Ma	48.49	69.09	32.42	63.78	62.60	53.23	55.81	61.95	60.63	69.09
SD	12.70	15.61	9.01	13.22	11.39	10.86	13.81	14.95	13.67	13.01
RSC										
AV	1.82	1.74	1.64	2.00	1.64	1.88	1.75	1.61	1.78	1.76
Me	1.61	1.65	1.49	1.86	1.63	1.83	1.43	0.98	1.52	1.59
Mo	1.27	0.31	0.27	1.23	1.00	0.61	2.19	0.46	0.40	1.27
Mi	0.10	−0.10	0.27	0.15	0.02	0.01	0.04	0.01	0.32	−0.10
Ma	6.42	5.21	3.85	4.90	3.67	5.07	5.58	6.87	5.62	6.87
SD	1.29	1.08	0.96	1.23	0.91	1.10	1.22	1.53	1.26	1.18
%Na										
AV	57.42	60.05	46.98	58.50	53.11	55.75	57.66	55.64	50.22	55.04
Me	56.09	62.30	47.60	58.56	55.87	58.65	59.86	55.86	53.84	56.02
Mo	55.17	87.59	45.24	44.78	61.92	48.81	33.33	53.83	39.04	44.78
Mi	20.35	22.73	10.47	30.41	26.26	35.17	27.93	29.26	3.27	3.27
Ma	85.94	87.59	81.90	86.02	85.86	84.94	86.46	79.10	86.95	87.59
SD	15.17	16.53	16.44	13.87	14.56	12.53	14.61	12.51	18.49	15.45
KR/KI										
AV	1.55	1.55	0.92	1.57	1.26	1.33	1.36	1.66	1.29	1.39
Me	1.18	1.29	0.76	1.15	1.06	1.17	1.10	1.18	0.89	1.06
Mo	1.18	1.17	0.76	0.76	1.56	0.91	0.28	0.28	0.64	1.17
Mi	0.16	0.09	0.09	0.38	0.27	0.49	0.28	0.27	0.03	0.03
Ma	5.78	5.43	3.63	5.35	6.00	5.17	4.26	5.56	6.66	6.66
SD	1.28	1.12	0.71	1.13	1.15	0.84	1.00	1.39	1.21	1.12
PI										
AV	62.41	62.75	51.18	63.47	57.54	60.90	59.33	61.27	57.16	59.56
Me	60.39	65.35	51.36	60.39	58.50	61.39	61.95	58.68	55.37	59.47
Mo	63.75	71.79	53.76	56.75	65.34	60.00	33.49	40.11	47.32	63.75
Mi	25.08	18.03	18.61	36.51	29.13	39.39	33.49	30.75	12.10	12.10
Ma	99.42	88.55	87.43	89.75	90.09	90.42	86.56	91.24	94.69	99.42
SD	14.89	15.79	15.68	13.55	13.76	11.58	14.99	17.85	16.70	15.36
MH										
AV	51.99	49.90	44.98	42.90	37.33	32.83	35.76	44.10	38.32	42.01
Me	46.46	50.92	47.58	42.75	35.02	32.02	33.33	39.84	37.11	39.46
Mo	33.33	22.22	39.13	50.00	33.33	20.93	33.33	37.79	37.79	33.33
Mi	21.05	14.02	4.65	16.67	11.96	13.16	5.51	18.55	17.28	4.65
Ma	82.98	92.98	72.88	75.56	69.36	59.49	79.66	74.81	68.35	92.98
SD	17.60	18.96	14.04	13.70	12.70	10.60	15.63	16.10	11.82	15.87
PS										
AV	2.36	2.66	2.43	2.70	2.63	2.59	2.78	2.36	2.13	2.52
Me	1.94	2.09	1.95	1.86	1.91	1.52	2.04	1.91	1.35	1.85
Mo	0.94	0.39	0.80	0.56	4.89	2.18	3.74	0.38	1.04	1.23
Mi	0.25	0.37	0.40	0.47	0.36	0.40	0.41	0.38	0.15	0.15
Ma	7.78	8.99	7.30	11.31	9.54	10.83	12.32	9.99	6.58	12.32
SD	1.94	2.14	1.78	2.35	2.13	2.43	2.51	1.84	1.68	2.10
CIA1										
AV	−0.040	−0.107	0.233	−0.033	0.129	−0.122	0.120	0.122	0.092	0.04

Table 2 (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	N YA
Me	0.102	0.206	0.391	0.166	0.279	0.079	0.176	0.226	0.295	0.22
Mo	0.415	− 3.080	0.367	0.143	0.344	0.047	0.267	− 0.107	0.345	− 0.11
Mi	− 2.438	− 3.080	− 2.256	− 2.043	− 1.258	− 2.120	− 0.930	− 1.800	− 3.339	− 3.34
Ma	0.814	0.826	0.908	0.775	0.764	0.784	0.802	0.795	0.951	0.95
SD	0.688	0.859	0.588	0.641	0.513	0.722	0.377	0.520	0.743	0.65
CIA2										
AV	0.18	0.12	0.24	0.17	0.25	0.13	0.19	0.23	0.16	0.19
Me	0.04	0.09	0.16	0.08	0.14	0.03	0.05	0.16	0.10	0.09
Mo	0.31	0.00	0.00	0.00	0.00	0.00	0.06	− 0.03	0.15	0.31
Mi	− 0.25	− 1.16	− 0.22	− 0.26	− 0.23	− 0.30	− 0.33	− 0.28	− 0.27	− 1.16
Ma	1.45	1.87	1.33	1.16	1.74	1.74	1.60	1.98	1.05	1.98
SD	0.37	0.48	0.33	0.35	0.45	0.42	0.37	0.42	0.29	0.39
CR										
AV	2.16	2.25	1.67	1.72	1.78	1.89	1.67	1.97	1.08	1.80
Me	1.15	1.28	1.16	0.99	1.05	1.00	1.05	1.52	0.97	1.06
Mo	1.75	0.00	0.00	0.00	0.00	0.00	0.76	0.71	1.37	1.75
Mi	0.18	0.19	0.15	0.23	0.24	0.14	0.31	0.24	0.13	0.13
Ma	23.80	19.42	13.25	13.90	12.74	19.72	8.42	14.55	3.52	23.80
SD	3.77	3.36	2.26	2.31	2.20	3.23	1.71	2.40	0.69	2.59
TDS										
AV	719.91	762.27	729.77	798.89	764.43	794.98	798.43	705.86	674.92	749.94
Me	622	664	587	710	636	618	678	646.5	605	648.50
Mo	253	222	269	206	1277	240	378	682	387	262.00
Mi	233	222	235	206	237	238	221	188	113	113.00
Ma	3314	2734	2955	2727	2999	2608	2481	2412	1405	3314.00
SD	516.81	463.87	463.43	491.76	493.54	499.44	511.18	431.89	349.15	468.70
TH										
AV	328.09	329.60	400.67	352.33	376.13	360.33	342.38	307.56	338.62	385.21
Me	277.40	272.70	338.20	279.25	306.65	289.90	253.35	239.41	272.07	282.35
Mo	118.30	51.40	143.80	113.30	540.30	121.90	255.20	109.89	224.76	190.70
Mi	64.20	51.40	133.30	111.50	86.00	121.90	103.30	109.89	94.87	51.40
Ma	1495.60	1277.80	1337.60	1167.00	1340.80	1116.60	1419.60	1178.30	1147.04	1495.60
SD	238.18	220.09	238.06	239.84	251.92	240.26	232.99	203.95	207.48	340.52
r_1										
AV	− 0.89	− 0.78	− 1.79	− 1.17	− 1.48	− 0.52	− 1.54	− 0.86	− 1.07	− 1.12
Me	− 0.54	− 0.71	− 1.29	− 0.59	− 0.88	− 0.38	− 1.11	− 0.94	− 0.99	− 0.82
Mo	− 1.50	− 0.15	− 0.63	− 0.17	− 0.88	− 0.10	− 0.61	− 0.85	− 0.52	− 0.80
Mi	− 10.42	− 6.78	− 12.11	− 13.27	− 10.73	− 9.10	− 12.09	− 8.78	− 14.06	− 14.06
Ma	7.20	10.50	8.30	2.37	2.61	3.00	7.25	9.22	14.25	14.25
SD	2.38	2.32	3.04	2.93	2.53	1.77	2.79	2.57	4.63	2.87
r_2										
AV	0.15	− 0.12	− 1.34	− 0.95	− 1.14	− 0.28	− 0.77	− 0.40	− 0.45	− 0.59
Me	− 0.20	− 0.35	− 0.99	− 0.28	− 0.53	− 0.20	− 0.30	− 0.58	− 0.82	− 0.50
Mo	− 1.42	3.78	− 0.55	− 0.12	− 0.82	− 0.05	− 0.28	0.15	− 0.52	− 0.55
Mi	− 10.17	− 6.26	− 10.56	− 17.14	− 10.27	− 9.00	− 17.91	− 8.70	− 13.03	− 17.91
Ma	16.50	10.50	8.80	3.26	2.83	4.50	14.00	12.00	18.88	18.88
SD	3.71	2.45	2.98	3.53	2.63	1.89	3.87	3.09	5.46	3.43

Av average, *Me* median, *Mo* mode, *Mi* minimum, *Ma* maximum, *SD* standard deviation, *NYA* nine-year average

Table 3 Statistics of each index during post-monsoon

	2005	2006	2007	2008	2009	2010	2011	2012	2013	N YA
SAR										
AV		17.30	15.92	17.40	15.74	19.24	19.56	15.91	18.87	17.49
Me		15.15	14.43	16.25	12.03	16.47	16.46	13.47	13.21	14.53
Mo		4.59	5.75	6.86	5.21	8.20	12.02	8.52	6.61	21.23
Mi		1.63	1.05	3.64	4.17	2.72	6.39	1.94	0.24	0.24
Ma		57.57	46.14	49.49	71.17	53.70	54.05	67.93	78.37	78.37
SD		11.21	9.40	10.13	12.43	11.86	11.29	13.69	18.59	12.57
RSC										
AV		1.18	1.99	1.88	1.68	1.79	1.08	1.46	0.86	1.48
Me		1.38	1.81	1.93	1.56	1.89	1.23	1.43	.77	1.51
Mo		1.46	2.90	1.60	0.40	1.08	1.05	0.51	0.34	1.71
Mi		−4.73	−1.43	−2.42	−2.85	−1.54	−3.36	−3.31	−3.47	−4.73
Ma		3.79	5.04	4.56	4.89	3.92	3.74	4.28	3.81	5.04
SD		1.56	1.35	1.44	1.33	1.22	1.26	1.53	1.21	1.41
%Na										
AV		55.79	51.60	54.37	52.20	56.97	57.30	53.35	53.44	54.38
Me		57.65	50.84	53.42	52.40	57.35	56.96	53.82	54.62	54.25
Mo		38.71	42.86	42.86	40.00	61.90	59.55	48.79	38.50	42.86
Mi		15.28	30.43	33.54	29.48	25.52	35.00	25.36	10.60	10.60
Ma		85.60	79.22	83.71	88.10	83.56	83.45	89.89	92.49	92.49
SD		15.40	13.00	12.61	14.11	13.06	12.51	15.29	18.84	14.48
KR/KI										
AV		1.34	1.11	1.24	1.21	1.39	1.44	1.24	1.76	1.34
Me		1.11	0.94	1.01	0.88	1.18	1.20	0.89	0.79	0.98
Mo		0.53	0.72	0.67	0.59	0.82	1.42	0.91	0.62	1.00
Mi		0.15	0.08	0.29	0.35	0.16	0.53	0.12	0.03	0.03
Ma		4.83	3.56	4.38	7.34	4.49	4.56	8.58	12.31	12.31
SD		1.01	0.78	0.88	1.19	0.93	0.93	1.43	2.49	1.31
PI										
AV		59.72	57.29	59.31	57.08	62.08	61.63	55.63	57.25	58.75
Me		60.64	56.09	57.88	54.12	62.73	61.23	57.22	51.88	57.96
Mo		47.27	56.02	49.21	51.43	58.33	68.03	59.08	48.72	47.27
Mi		30.26	25.48	36.50	30.56	20.85	36.64	16.95	19.69	16.95
Ma		89.38	87.11	89.42	92.00	91.82	89.01	96.08	99.19	99.19
SD		14.24	13.32	12.58	13.81	13.17	12.46	16.13	19.15	14.53
MH										
AV		66.37	34.99	34.66	48.28	39.70	40.97	39.11	42.30	43.30
Me		64.31	36.14	32.63	46.78	41.46	37.99	37.79	39.61	41.03
Mo		53.85	31.25	42.03	33.33	16.00	33.33	28.83	33.29	33.33
Mi		38.64	0.85	11.69	22.87	1.64	15.29	13.78	4.82	0.85
Ma		86.44	68.75	74.63	72.17	80.00	71.76	70.85	77.74	86.44
SD		13.14	12.98	12.71	14.19	17.97	14.33	13.61	17.98	17.49
PS										
AV		2.54	2.51	2.52	2.20	2.62	2.91	2.30	2.08	2.46
Me		2.27	1.77	1.54	1.63	1.63	2.04	1.50	1.32	1.67
Mo		4.03	0.72	0.51	0.50	0.49	0.99	0.70	0.67	0.66
Mi		0.21	0.21	0.35	0.38	0.34	0.74	0.32	0.00	0.00
Ma		7.98	11.80	13.26	9.33	12.68	12.29	8.65	7.26	13.26
SD		1.94	2.56	2.69	1.75	2.68	2.41	2.17	1.87	2.28
CIA1										
AV		0.13	−0.03	−0.04	0.16	−0.11	0.31	−0.01	0.23	0.08

Table 3 (continued)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	N YA
Me		0.25	0.22	0.15	0.20	−0.01	0.31	0.21	0.27	0.21
Mo		0.00	0.14	−1.00	0.19	−0.41	0.38	0.21	0.45	0.00
Mi		−1.44	−1.73	−1.68	−1.54	−1.82	−0.48	−2.09	−1.26	−2.09
Ma		0.85	0.78	0.79	0.83	0.82	0.81	0.76	0.86	0.86
SD		0.54	0.70	0.59	0.46	0.63	0.25	0.64	0.44	0.56
CIA2										
AV		0.39	0.17	0.20	0.26	0.18	0.46	0.19	0.34	0.27
Me		0.12	0.07	0.05	0.09	0.00	0.19	0.08	0.20	0.09
Mo		0.00	0.00	0.05	0.00	−0.07	0.00	0.08	0.29	0.00
Mi		−0.28	−0.21	−0.28	−0.22	−0.26	−0.18	−0.47	−0.75	−0.75
Ma		4.36	1.88	3.07	2.73	3.25	6.34	2.54	3.21	6.34
SD		0.87	0.39	0.59	0.58	0.60	1.01	0.54	0.63	0.68
CR										
AV		2.38	1.16	1.34	1.48	1.42	2.42	1.83	2.34	1.80
Me		1.27	0.91	0.69	0.99	0.82	1.49	0.95	1.17	1.07
Mo		0.00	0.00	1.24	0.00	0.50	0.00	1.15	1.09	1.24
Mi		0.20	0.09	0.14	0.21	0.15	0.43	0.20	0.00	0.00
Ma		14.82	6.25	9.50	10.82	8.01	16.74	14.78	17.97	17.97
SD		3.06	1.21	1.79	1.85	1.66	3.03	2.99	3.23	2.49
TDS										
AV		738.43	761.91	766.02	670.43	781.98	782.84	714.77	616.77	729.14
Me		664.5	593	603.5	553	627	609	537	499	596.00
Mo		215	593	279	330	258	258	243	664	321.00
Mi		170	175	195	204	258	258	243	98	98.00
Ma		2436	2614	2427	1800	3087	2562	2373	2520	3087.00
SD		480.37	523.41	502.77	377.54	563.96	523.82	470.45	424.95	484.92
TH										
AV		371.79	394.39	375.78	347.94	362.58	356.49	346.27	292.95	356.02
Me		289.85	295.85	274.40	282.30	265.35	255.05	272.03	241.96	269.28
Mo		130.20	96.00	155.60	118.30	137.80	109.20	199.70	254.57	254.57
Mi		114.70	96.00	106.00	118.30	132.20	109.20	99.80	69.82	69.82
Ma		1646.40	1517.00	1514.60	1298.50	1250.20	1356.40	1358.00	1397.71	1646.40
SD		289.80	311.99	291.19	231.76	271.30	271.20	260.32	223.61	269.12
r_1										
AV		−1.98	−0.92	−1.44	−1.65	−0.85	−1.96	−0.81	−2.07	−1.46
Me		−1.14	−0.66	−0.42	−0.73	−0.30	−1.21	−0.66	−1.58	−0.75
Mo		−1.36	−0.15	−0.28	−0.25	0.27	−1.21	−0.39	−4.83	−0.25
Mi		−14.00	−8.98	−14.40	−14.29	−14.88	−10.89	−8.35	−14.40	−14.88
Ma		2.67	4.47	2.43	2.05	2.53	0.84	3.77	8.80	8.80
SD		3.36	2.40	3.83	2.91	2.74	2.12	1.70	3.73	2.95
r_2										
AV		−1.23	−0.47	−1.34	−1.42	−0.66	−1.91	−0.45	−1.84	−1.17
Me		−0.67	−0.46	−0.18	−0.33	0.01	−0.99	−0.39	−1.21	−0.46
Mo		0.00	−0.12	−0.18	−0.17	0.39	−1.14	−0.33	−4.82	0.00
Mi		−8.00	−8.98	−19.84	−17.86	−19.75	−20.74	−9.91	−16.00	−20.74
Ma		3.50	9.90	3.07	2.75	2.68	1.18	4.10	8.82	9.90
SD		2.80	2.88	4.88	3.36	3.442308	3.329189	1.99	3.84	3.42

Av average, *Me* median, *Mo* mode, *Mi* minimum, *Ma* maximum, *SD* standard deviation, *NYA* nine year average

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Table 4 Classification of fixed bore wells water during pre-monsoon within the study area for irrigation based on %Na, SAR, MH, KR RSC, TDS (Wilcox 1948; Kelly 1940; Todd 1980; USSL 1954)

Index	Range	Class	No. of samples (with %) under different classes per year								
			2005	2006	2007	2008	2009	2010	2011	2012	2013
SAR	< 10	Exc.	14, 31.82	13, 29.55	19, 43.18	11, 25	13, 29.55	11, 25	11, 25	17, 38.64	17, 38.64
	10–18	Go.	11, 25	11, 25	12, 27.27	10, 22.73	13, 29.55	11, 25	11, 25	04, 9.10	10, 22.73
	18–26	Dou.	08, 18.18	9, 20.45	07, 15.91	10, 22.73	12, 27.27	13, 29.45	11, 25	9, 20.45	07, 15.91
	> 26	UnSu.	11, 25	11, 25	6, 13.64	13, 29.55	06, 13.64	09, 20.45	11, 25	14, 31.82	10, 22.73
RSC/RA	< 1.25	Go.	16, 36.36	14, 31.82	13, 29.55	16, 36.36	18, 40.91	12, 27.27	21, 47.73	29, 65.91	17, 38.62
	1.25–2.5	Dou.	17, 38.64	9, 20.45	23, 52.27	16, 36.36	16, 36.36	22, 50	14, 31.82	7, 15.91	19, 43.18
	> 2.5	UnSu.	11, 25	21, 47.73	08, 18.18	12, 27.27	10, 22.73	10, 22.73	09, 20.45	08, 18.18	08, 18.18
%Na	> 20	Exce.	01, 2.27	01, 2.27	04, 9.09	00, 00	00, 00	00, 00	00, 00	00, 00	00, 00
	20–40	Go.	06, 13.64	04, 9.09	07, 15.91	02, 4.54	09, 20.45	04, 9.09	04, 9.09	03, 6.82	13, 29.55
	40–60	Perm.	21, 47.73	15, 34.09	22, 50	22, 50	23, 52.27	19, 43.18	16, 36.36	26, 59.09	17, 38.64
	60–80	Dou.	13, 29.55	20, 45.45	10, 22.73	17, 38.64	10, 22.73	20, 45.45	20, 45.45	15, 34.09	10, 22.73
	> 80	UnSu.	03, 6.82	04, 9.09	01, 2.27	03, 6.82	02, 4.55	01, 2.27	04, 9.09	00, 00	02, 4.55
KR/Kl	< 1	Su.	19, 43.18	31, 70.45	13, 29.55	25, 56.82	24, 54.55	24, 54.55	23, 52.27	23, 52.27	24, 54.55
	> 1	UnSu.	25, 56.82	13, 29.55	31, 70.45	19, 43.18	20, 45.45	20, 45.45	21, 47.73	21, 47.73	20, 45.45
PI	> 75%	Su.	09, 20.45	08, 18.18	02, 4.55	08, 18.18	03, 6.82	05, 11.36	06, 13.64	11, 25	06, 13.64
	25–75%	Go.	34, 77.27	35, 79.55	38, 86.36	36, 81.82	41, 93.18	39, 88.64	38, 86.36	33, 75	37, 84.09
	< 25%	UnSu.	01, 2.27	01, 2.27	04, 9.09	00, 00	00, 00	00, 00	0, 00	00, 00	1, 2.27
MAR/MH	< 50	Su.	25, 56.82	23, 52.27	30, 68.18	34, 77.27	36, 81.82	40, 90.91	42, 95.45	26, 59.09	37, 84.09
	> 50	UnSu.	19, 43.18	21, 47.73	14, 31.82	10, 22.73	8, 18.18	4, 9.09	6, 13.64	18, 40.91	7, 15.91
PS	< 3	Su.	33, 75	28, 63.64	30, 68.18	31, 70.45	28, 63.64	31, 70.45	31, 70.45	32, 72.73	30, 68.18
	> 3	UnSu.	11, 25	16, 36.36	16, 36.36	13, 29.55	16, 36.36	13, 29.55	13, 29.55	12, 27.27	14, 31.82
CAI1	− tiv	REP	17, 38.64	17, 38.64	8, 18.18	17, 38.64	13, 29.55	17, 38.64	14, 31.82	14, 31.82	11, 25
	+ tiv	DEP	27, 61.36	27, 61.36	36, 81.82	27, 61.36	31, 70.45	27, 61.36	30, 68.18	30, 68.18	33, 75
CAI2	− tiv	REP	19, 43.18	17, 38.64	8, 18.18	17, 38.64	13, 29.55	17, 38.64	14, 31.82	14, 31.82	11, 25
	+ tiv	DEP	25, 56.82	27, 61.36	36, 81.82	27, 61.36	31, 70.45	27, 61.36	30, 68.18	30, 68.18	33, 75
CR	< 1	Su.	12, 27.27	18, 40.91	20, 45.45	23, 54.27	21, 47.73	21, 47.73	19, 43.18	20, 45.45	25, 56.82
	> 1	UnSu.	32, 72.73	26, 59.09	24, 54.55	21, 47.73	23, 54.27	23, 54.27	25, 56.82	24, 54.55	19, 43.18
TDS	< 450	Best	13, 29.55	12, 27.27	13, 29.55	14, 31.81	16, 36.36	14, 31.81	15, 34.09	16, 36.36	18, 40.91
	450–2000	Mode	30, 68.18	31, 70.45	30, 68.18	29, 65.91	27, 61.36	29, 65.91	28, 63.64	27, 61.36	26, 59.09
	> 2000	Hazard	01, 2.27	01, 2.27	01, 2.27	01, 2.27	01, 2.27	01, 2.27	01, 2.27	01, 2.27	00, 00
TH	< 75	Soft	1, 2.27	2, 4.55	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0	0, 0
	75–150	Mode	3, 6.82	3, 6.82	6, 13.64	3, 6.82	2, 4.55	5, 11.36	3, 6.82	5, 11.36	3, 6.82
	150–300	Hard	23, 52.27	24, 54.54	11, 25.00	23, 52.27	21, 47.73	19, 43.18	24, 6.82	25, 56.82	24, 6.82
	> 300	V. Hard	17, 38.64	15, 34.09	27, 61.36	18, 40,91	21, 17.73	20, 45.45	17, 38.64	14, 31.82	17, 38.64
r_1	< 1	Na^+–SO_4^{2-}	42, 95.45	43, 97.73	41, 93.18	41, 93.18	41, 93.18	40, 90.91	43, 97.73	40, 90.91	40 90.91
	> 1	Na^+–HCO_3^-	02, 4.55	01, 2.27	03, 6.82	03, 6.82	03, 6.82	04, 9.09	01, 2.27	04, 9.09	04, 9.09
r_2	< 1	DMP	38, 86.36	38, 86.36	40, 90.91	36, 81.82	41, 93.18	39, 88.64	37, 84.09	39, 88.64	34, 77.27
	> 1	SMP	6, 13.64	6, 13.64	4, 9.09	08, 18.18	3, 6.82	05, 11.36	07, 15.91	05, 11.36	10, 22.73

After "," the values are given in %

Exc excellent, *Go* good, *Dou* doubtful, *UnSu* unsuitable, *Perm* permissible, *Su* suitable, *REP* reverse exchange process, *DER* direct exchange process, *Mode* moderate, *DMP* deep meteoric percolation, *SMP* shallow meteoric percolation

account rainfall effect over KR because no regular patterns were found for KR. The comparison of pre-monsoon and post-monsoon shows that KR of pre-monsoon shows more a number of wells come under suitable category after rainfall. Due to rainfall, leaching of Na^+ from rock to water is more

in comparison with Ca^{2+} and Mg^{2+} that is why after rainfall more no. of wells come under unsuitable class (Table 5). Figure 5a, b shows frequency of some wells under suitable and unsuitable class during the study period. KR index is alkali hazard indicator. If KR value is high, then the use of

Table 5 Classification of fixed bore wells water during post-monsoon within the study area for irrigation based on %Na, SAR, MH, KR RSC, TDS (Wilcox 1948; Kelly 1940; Todd 1980; USSL 1954)

Index	Range	Class	No. of samples (with %) under different classes per year							
			2006	2007	2008	2009	2010	2011	2012	2013
SAR	<10	Exc.	10, 22.73	14, 31.82	12, 27.27	15, 34.09	09, 20.45	08, 18.18	19, 43.18	20, 45.45
	10–18	Go.	17, 22.73	17, 38.64	12, 27.27	15, 34.09	15, 34.09	15, 34.09	13, 29.55	08, 18.18
	18–26	Dou.	08, 18.18	04, 9.09	10, 22.73	10, 22.73	10, 22.73	11, 25.00	06, 13.64	07, 15.91
	>26	UnSu.	09, 20.45	09, 20.45	10, 22.73	04, 9.09	10, 22.73	10, 22.73	06, 13.64	09, 20.45
RSC/RA	<1.25	Go.	18, 40.91	10, 22.73	10, 22.73	14, 31.82	11, 25	20, 45.45	18, 40.91	26, 59.09
	1.25–2.5	Dou.	14, 31.82	18, 40.91	18, 40.91	20, 45.45	11, 25	18, 40.91	17, 38.64	14, 31.82
	>2.5	UnSu.	09, 20.45	16, 36.36	16, 36.36	10, 22.73	22, 50	06, 13.64	09, 20.45	04, 9.09
%Na	>20	Exce.	01, 2.27	00,0 0	00, 00	00,00	00, 00	00, 00	00, 00	02, 4.55
	20–40	Go.	07, 15.91	09, 20.45	07, 15.91	09, 20.45	04, 9.09	05, 11.36	12, 27.27	12, 27.27
	40–60	Perm.	16, 36.64	25, 56.82	25, 56.82	23, 52.27	21, 47.73	20, 45.45	19, 43.18	15, 34.09
	60–80	Dou.	17, 38.64	10, 22.73	9, 20.45	11, 25.00	16, 36.36	16, 36.36	09, 20.45	10, 22.73
	>80	UnSu.	3, 6.82	00, 00	03, 6.82	01, 2.27	03, 6.82	03, 6.82	04, 9.09	05, 11.36
KR/Kl	<1	Su.	18, 40.91	28, 63.64	22, 50	18, 40.91	16, 36.36	16, 36.36	28, 63.64	25, 56.82
	>1	UnSu.	26, 59.09	16, 36.36	22, 50	26, 59.09	28, 63.64	28, 63.64	16, 36.36	19, 43.18
PI	>75%	Su.	05, 11.36	05, 11.36	05, 11.36	07, 15.91	05, 11.36	07, 15.91	03, 6.82	09, 20.45
	25–75%	Go.	39, 88.64	39, 88.64	39, 88.64	37, 84.09	38, 86.36	33, 75	40, 90.91	33, 75
	<25%	UnSu.	00, 00	00, 00	00, 00	00, 00	01, 2.27	00, 00	01, 2.27	02, 4.55
MAR/MH	<50	Su.	06, 13.64	40, 90.91	06, 13.64	25, 56.82	34, 77.27	33, 75	33, 75	30, 68.18
	>50	UnSu.	38, 86.36	4, 9.09	38, 86.36	19, 43.18	10, 22.73	11, 25	11, 25	14, 31.82
PS	<3	Su.	17, 38.64	13, 29.55	11, 25	10, 22.73	14, 31.82	14, 31.82	10, 22.73	34, 77.27
	>3	UnSu.	27, 61.36	31, 70.45	33, 75	34, 77.27	30, 68.18	30, 68.18	34, 77.27	10, 22.73
CAI1	−tiv	REP	10, 22.73	14, 31.82	15, 34.09	11, 25	22, 50	3, 6.82	17, 38.64	8, 18.18
	+tiv	DEP	34, 77.27	30, 68.18	29, 65.91	33, 75	22, 50	41, 93.18	27, 61.36	36, 81.82
CAI2	−tiv	REP	10, 22.73	14, 31.82	15, 34.09	11, 25	22, 50	3, 6.82	17, 38.64	8, 18.18
	+tiv	DEP	34, 77.27	30, 68.18	29, 65.91	33, 75	22, 50	41, 93.18	27, 61.36	36, 81.82
CR	<1	Su.	16, 36.36	29, 65.91	25, 56.82	23, 52.27	24, 54.55	8, 18.18	27, 61.36	18, 40.91
	>1	UnSu.	28, 63.64	15, 43.09	19, 43.18	21, 47.73	20, 45.45	36, 81.82	17, 38.64	26, 59.09
TDS	<450	Best	12, 27.27	11, 25	14, 31.82	14, 31.82	15, 34.09	9, 20.45	17, 38.64	18, 40.91
	450–2000	Mode	30, 68.18	31, 70.45	28, 63.64	30, 68.18	27, 61.36	33, 75	26, 59.09	25, 56.82
	>2000	Hazard	02, 4.55	02, 4.55	02, 4.55	00, 00	02, 4.55	02, 4.55	01, 2.27	01, 2.27
TH	<75	Soft	0, 0	0, 0	0, 0	0, 0	0, 0	0,0	0, 0	1, 2.27
	75–150	Mode	6, 13.64	3, 6.82	4, 9.09	5, 11.36	4, 9.09	2, 4.55	2, 4.55	8, 18.18
	150–300	Hard	17, 38.64	24, 54.55	20, 45.45	23, 52.27	23, 52.27	23, 52.27	25, 56.82	23, 52.27
	>300	V. Hard	21, 47.73	17, 38.64	20, 45.45	16, 36.36	17, 38.64	19, 43.18	17, 38.64	12, 27.27
r_1	<1	Na^+–SO_4^{2-}	42, 95.45	38, 86.36	40, 90.91	41, 93.18	41, 93.18	44, 100	42, 95.45	39, 88.64
	>1	Na^+–HCO_3^-	02, 4.55	06, 13.64	04, 9.09	03, 6.82	03, 6.82	00, 00	02, 4.55	05, 11.36
r_2	<1	DMP	40, 90.91	38, 86.36	36, 81.82	41, 93.18	39, 88.64	40, 90.91	37, 84.09	39) 88.64
	>1	SMP	04, 9.09	06, 13.64	08, 18.18	03, 6.82	05, 11.36	04, 9.09	07, 15.91	05, 11.36

After "," the values are given in %

Exc excellent, *Go* good, *Dou* doubtful, *UnSu* unsuitable, *Perm* permissible, *Su* suitable, *REP* reverse exchange process, *DER* direct exchange process, *Mode* moderate, *V* very, *DMP* deep meteoric percolation, *SMP* shallow meteoric percolation

pure gypsum is recommended to reduce the effect of Na^+ ion.

From Tables 2 and 3, average value of PI during the study period was 59.56% and 58.75% for pre- and post-monsoon, respectively, which was under good class (25–75%) with range from 12.10 (unsuitable, PI < 25%, water movement freedom is less in soil) to 99.42% (suitable, PI > 75%, water movement freedom is high in soil) and 16.95 (unsuitable, PI < 25%) to 99.19% (suitable, PI > 75%), respectively, in pre- and post-monsoon. The pre-monsoon PI of 2007
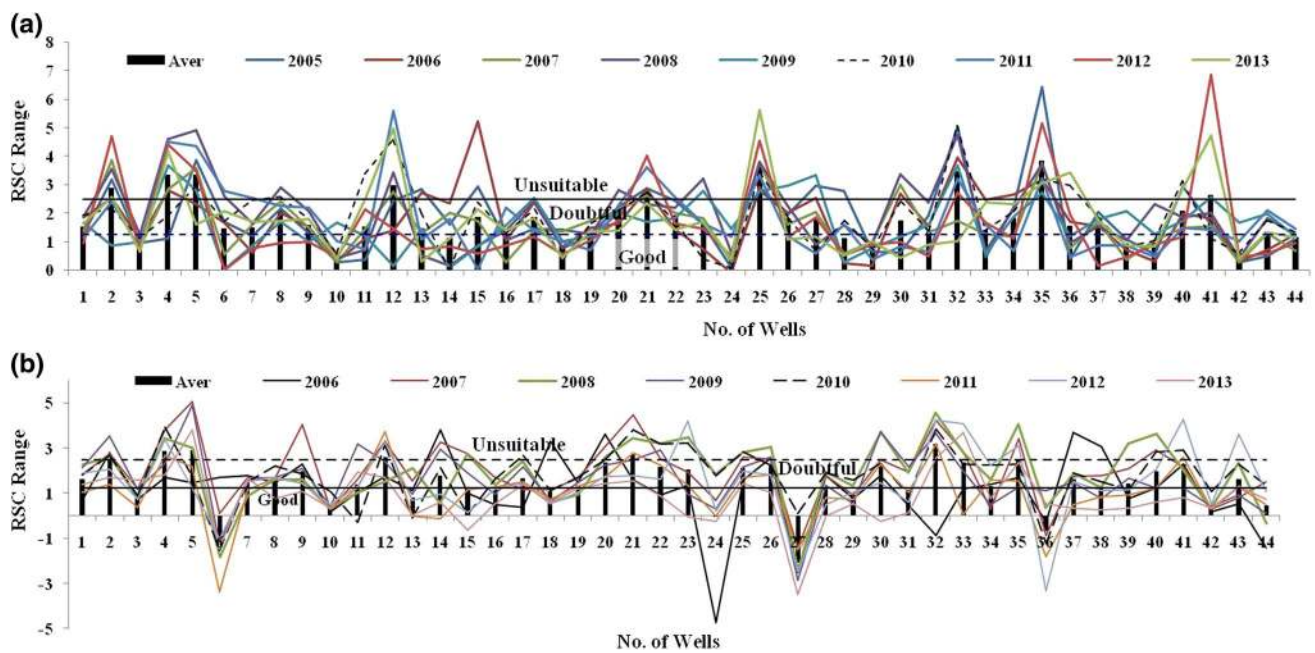
Fig. 3 a Nine-year (2005–2013) temporal representation RSC value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation RSC value during post-monsoon
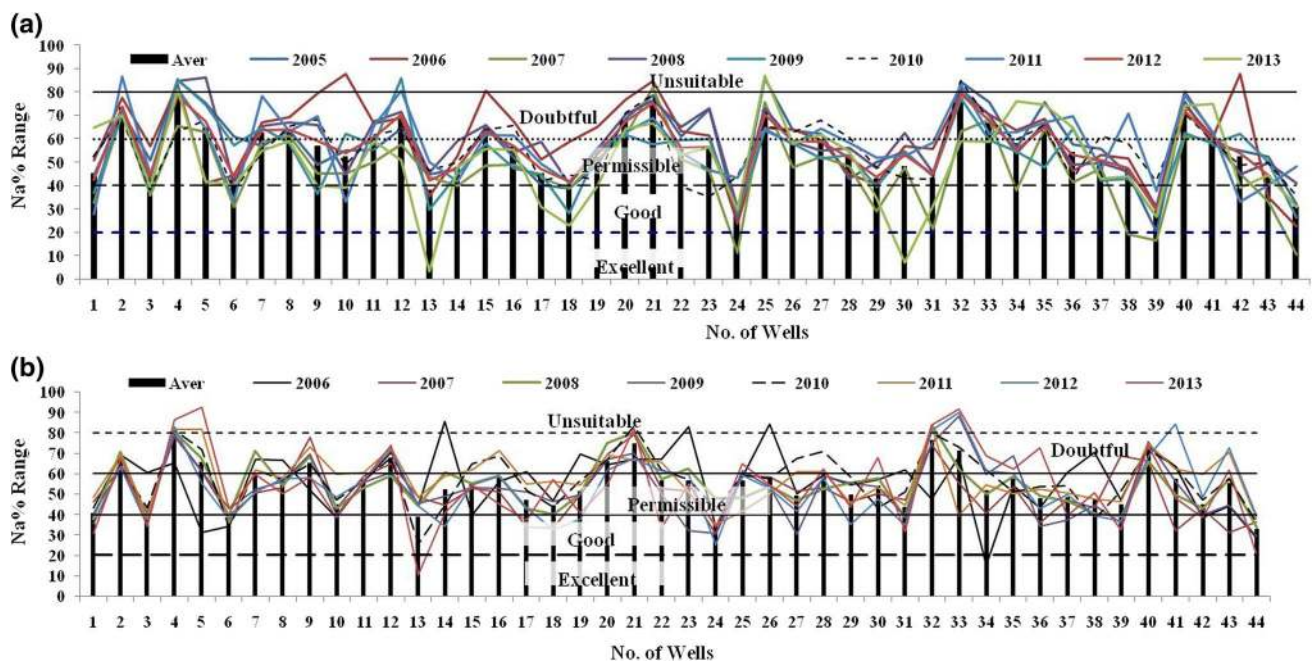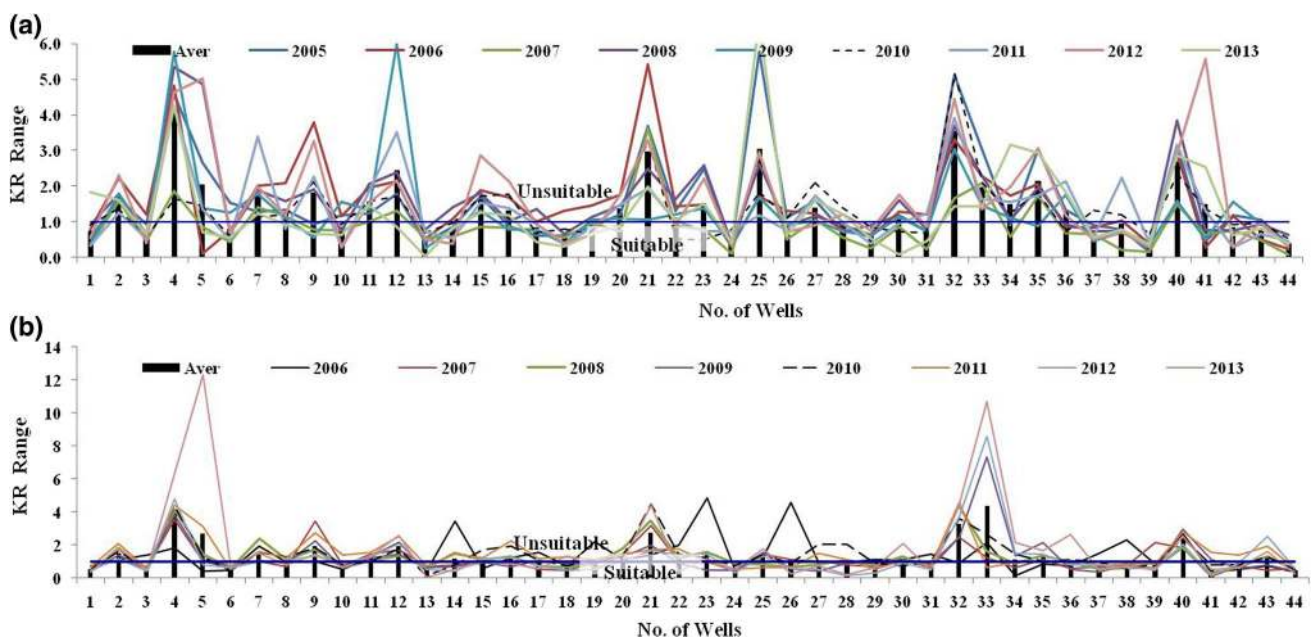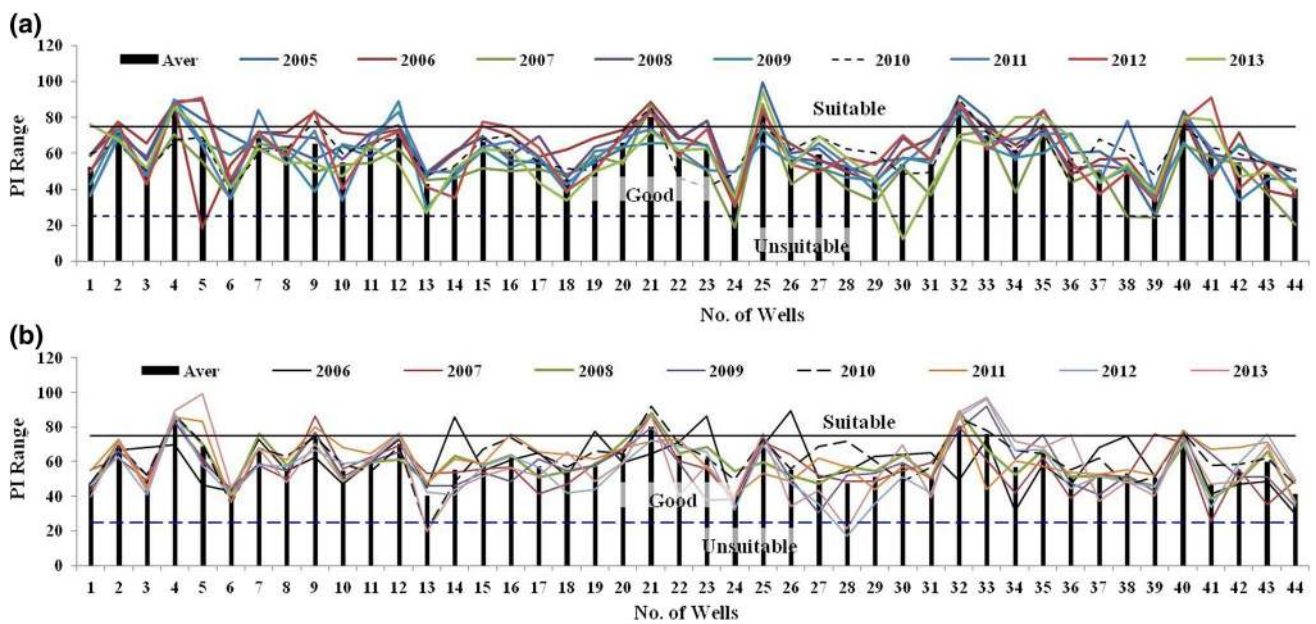

Fig. 4 a Nine-year (2005–2013) temporal representation of %Na value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of %Na value during post-monsoon

(Table 2) shows that the average value of PI was lowest, 51.18% (suitable); similarly, post-monsoon PI of year 2007 (57.29%) and 2009 (57.08%) was also reported low (Table 3). From Tables 2 and 3, the effect of rainfall over PI is not showing much significance. However, Tables 4 and

5 show the effect of rainfall over PI. It suggests that the no. of wells falls in unsuitable class during pre-monsoon (before rainfall) converted into suitable class after rainfall (post-monsoon). From Tables 4 and 5, it is the clear that the effect of rainfall over PI was more during the study period

because after post-monsoon most no. of wells found under the suitable and good category. Figure 6a, b is capable of representing a category of particular no. of wells at the particular time of year like well nos. 12, 25 and 40 during pre-monsoon which come under the unsuitable category more than two times, but after post-monsoon these wells come under good class due to rainfall effect only. The soil permeability is affected by the extensive use of irrigation water as it is influenced by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- contents of the water (Gautam et al. 2015).

MH/MAR is Mg^{2+} and Ca^{2+} based index, and it also represents in percent and contains only two classes MH < 50% and MH > 50%, suitable and unsuitable, respectively. On the basis of Tables 2 and 3, average values of MH during the study period were 42.01 and 43.30% for pre- and post-monsoon, respectively, with range 4.46–92.98% (pre-monsoon) and 0.85–86.44% (post-monsoon). Long-term (nine-year) average of MH showing majority of wells falls under suitable category of irrigation water. The average MH shows unsuitable limit for 2005 (pre-monsoon) and 2006 (post-monsoon) (Tables 2, 3). Table 4 shows that more than 52 percent (even 95.45% during 2011) wells in each year during pre-monsoon were in suitable (MH < 50%) category, while this pattern was not shown during post-monsoon, and each year no. of wells (which come under < 50% category during pre-monsoon) fluctuate but never come equal or more than to no. of wells during pre-monsoon. This fluctuation during post-monsoon clearly indicates some degree of leaching process of Mg^{2+} (from rock to groundwater) after rainfall

(Singh et al. 2012). Figure 7a shows magnitude of MH for well nos. 2, 7, 12, 14, 43, 43 which were high during post-monsoon, but from Fig. 7b, after rainfall magnitude of MH for same wells was reduced but not below the < 50% MH range. Overall, according to MH index 52% wells fall in suitable category of water for irrigation during pre-monsoon, but due to rainfall or Mg^{2+} leaching process the no. of well reduces from suitable category during post-monsoon. The year 2006 of post-monsoon elaborates that majority of wells were not unsuitable for irrigation.

If MH < 50, then it is considered as safe, and if it is greater than > 50, then it is unsafe for irrigation use. In the analyzed groundwater samples, 61.36% of the sample lies in the unsafe (MH value > 50) and remaining 38.63% in the safe region in the pre-monsoon season. In post-monsoon season, 68.18% are unsafe and remaining 31.81% suitable for irrigation uses. According to MH computation, majority of groundwater samples are not suitable for irrigation purpose.

PS index (Doneen 1964) is Cl^-, and SO_4^{2-} dominant index. From Tables 2 and 3 (in context of PS), the long-term averages 2.52 (< 3) and 2.46 (< 3) of PS were found under suitable category during pre- and post-monsoon with much differences in minimum and maximum (12.17 and 13.26, pre- and post-monsoon, respectively). Each year's during pre- and post-monsoon, average PS value was under suitable class (PS < 3). But each year (in both the monsoon) maximum value of PS was also found which was beyond of suitable limit that means few no. of wells must have come under > 3 limit of PS. It is clear from analysis of Tables 4 and 5, a clear signature of increasing and decreasing pattern

Fig. 5 a Nine-year (2005–2013) temporal representation KR/KI value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation KR/KI value during post-monsoon
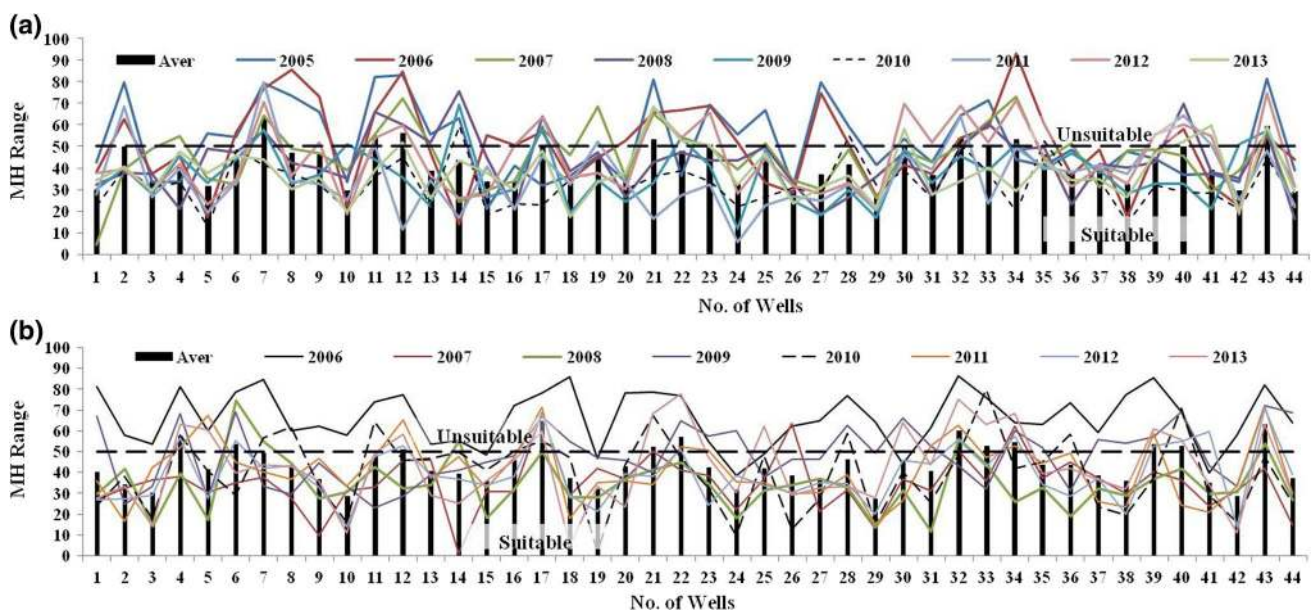
Fig. 6 a Nine-year (2005–2013) temporal representation of PI value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of PI value during post-monsoon

is observed in no. of wells during per- and post-monsoon, respectively. This happens due to the effect of rainfall. Figure 8a, b shows characteristic of PS for particular no. of wells during the study time period. Well nos. 6, 9, 11, 14, 21, 27, 28, 30, 34, 36 and 43 have a high value of PS, but after rainfall well nos. 6, 11, 14, 27, 28, 34, 36 and 43 remain constant with the unsuitable condition of water for

irrigation. Overall on the basis of PS analysis, it was found that most no. of wells (more than 63.64%) in the study area were suitable for irrigation during pre-monsoon, but during post-monsoon, more than 61.36% wells were found unsuitable for irrigation (except the year 2013).

The CAI1 and CAI2 indexes indicate the direction of reaction (DRP or ERP) between groundwater and aquifer.

Fig. 7 a Nine-year (2005–2013) temporal representation of MH value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of MH value during pre-monsoon

From Tables 2 and 3 (in references of CAI1 and CAI2), according to long-term (nine-year) average value during pre- and post-monsoon CAI1 (0.02 and 0.04) and CAI2 (0.19 and 0.27), it was found that most of the year DRP happens between groundwater and aquifer in the study area over the study period. From Tables 4 and 5, it is clear that during the study period most no. of wells (more than 61.36 percent and max. 81.82%) come under DRP condition except the year 2010 during post-monsoon, 50% show DRP, and remaining 50% show ERP. Almost equal no. of wells were same for CAI1 and CAI2 during pre- and post-monsoon; therefore, CAI1 and CAI2 indexes show supporting nature to each other. Figures 9a, b and 10a, b reveal the supporting nature, magnitudes may be not same, but naturewise [negative (−, ERP) and positive (+, DRP)], they are same.

CR is Cl^- dominant index similar to PS, CAI1 and CAI2. Hence, it suggests the same nature of water. Well nos. 6, 12, 13, 14, 15, 24, 27, 36 and 44 show almost same increasing nature of these indexes (Figs. 8a, d, 9a, b, 10a, b, 11a, b), but magnitude is different). CR can be used as an economical index in point of irrigation supply system because on the basis of CR it can be decided that irrigation water could be transported by PVC plastic (low cost) pipes or metallic pipes (cost effective). Knowledge of CR index is crucial when irrigation drainage is long. When irrigation water is low in open drainage system, there is a chance of contamination. The supply of irrigation water through the pipes is recommended (may be metallic or PVC plastic pipes) on the basis of CR values of irrigation water.

The fluctuations in TDS are shown in Fig. 12a, b while its statistics is given in Tables 2, 3. According to Tables 2 and 3, average value of TDS was found 749.94 and 729.14 mg/l for pre- and post-monsoon, respectively. While during both seasons average values fall under the moderate category (450–2000 mg/l). Tables 4 and 5 give the information about TDS fluctuation binwise. From Table 4, maximum no. of wells fall under best (TDS < 450 mg/l) and moderate category, while each year during pre-monsoon one well comes under hazard category (> 2000 mg/l, Table 4). Similarly, during post-monsoon most no. of wells distributed under best and the moderate bin (Table 4), while each year one or two wells come under hazard category. Tables 4 and 5 clearly reveal that during pre- and post-monsoon most no. of wells come under moderate class only. From Fig. 12a, b, it is clear that particular well no. 27 comes under hazard category during both seasons and almost same time of year (2006, 2007, 2008, 2010, 2011 and 2013), while well nos. 24, 34 and 36 fall under hazard category during post-monsoon which may be increasing salt concentration after rainfall due to weathering of salt from rocks. On the basis of TDS analysis, we found all wells water was suitable for irrigation (except well no. 27) during pre-monsoon, but after rainfall some salt concentration increases which influences TDS value of some wells; therefore, some treatment is required in particular wells water before using water for irrigation.

Water hardness is represented by TH, and it is Ca^{2+} and Mg^{2+} dominate index. From Tables 2 and 3 (in context of
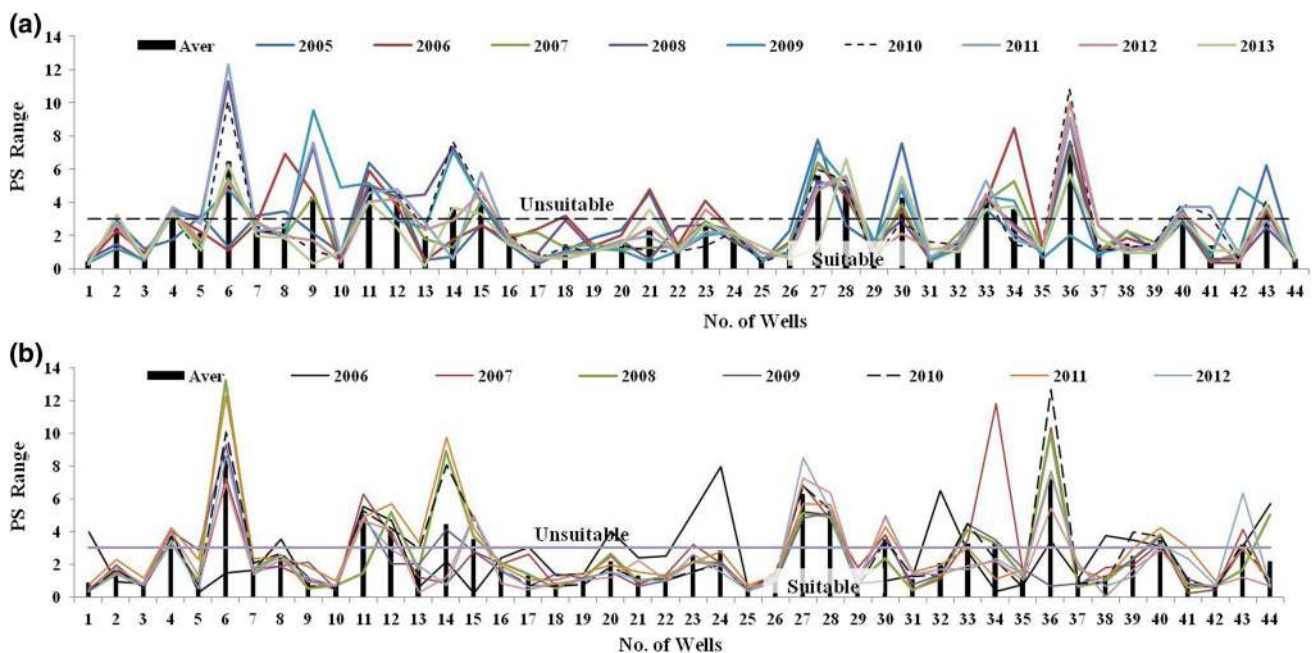
Fig. 8 **a** Nine-year (2005–2013) temporal representation of PS value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of PS value during post-monsoon
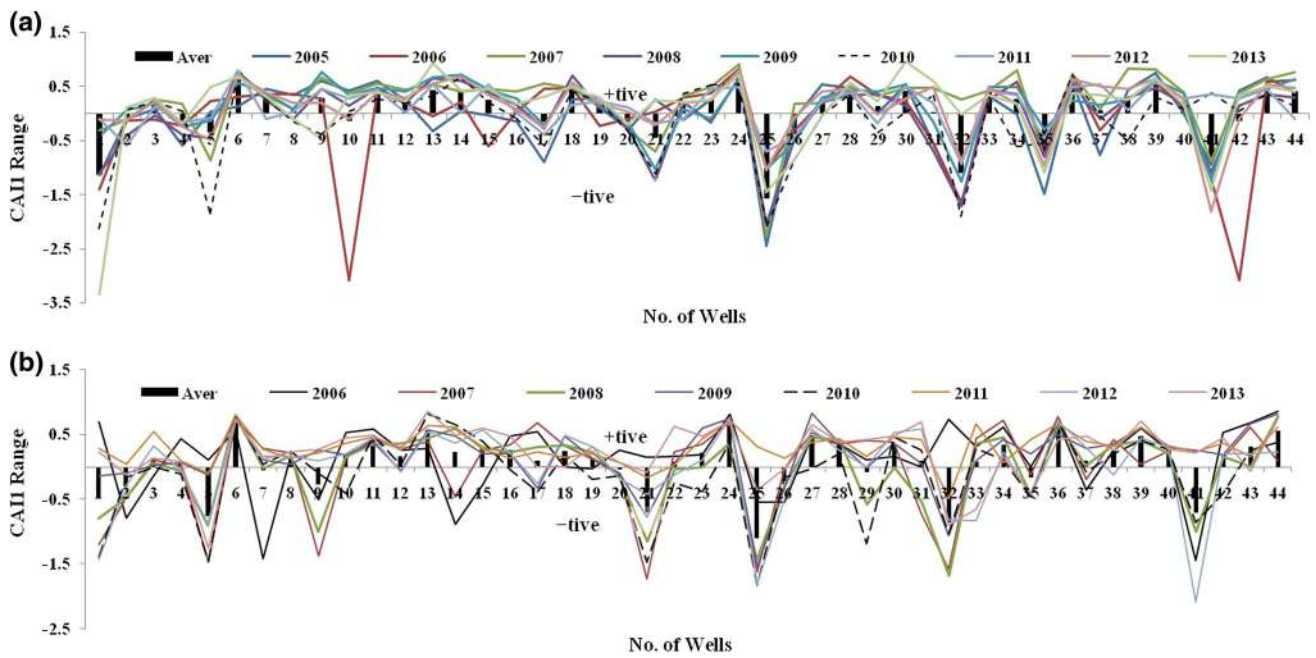
Fig. 9 a Nine-year (2005–2013) temporal representation of CIA1 value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of CAI1 value during post-monsoon
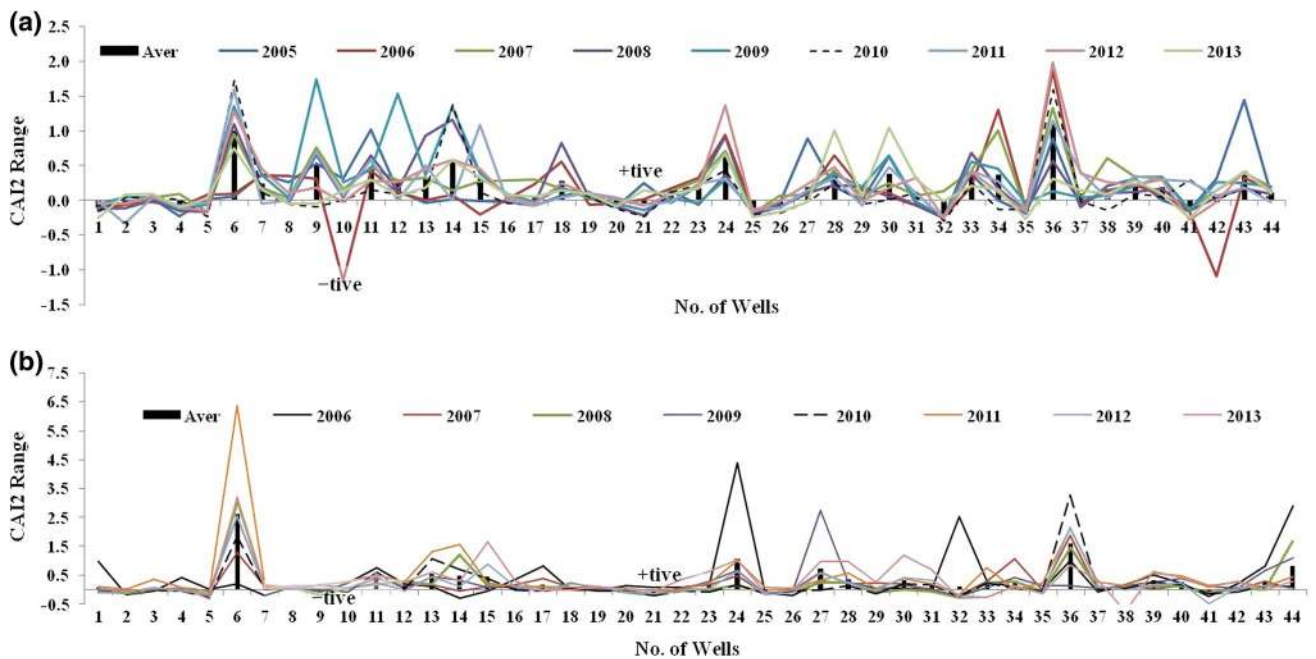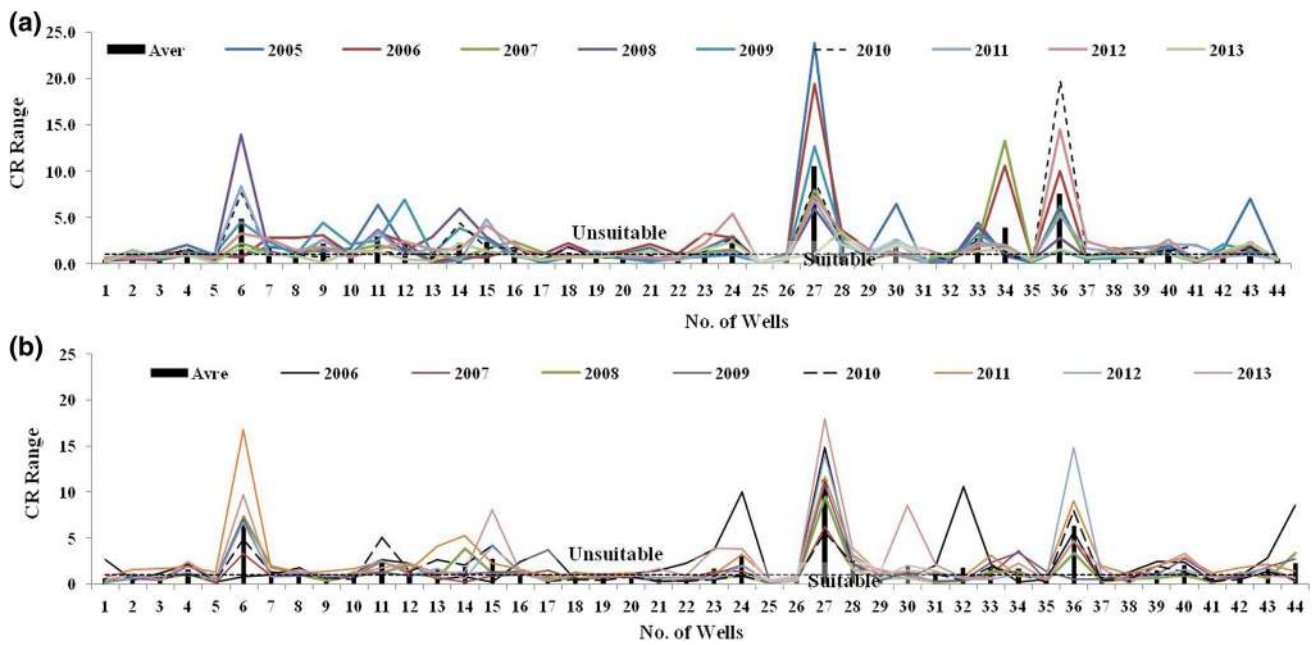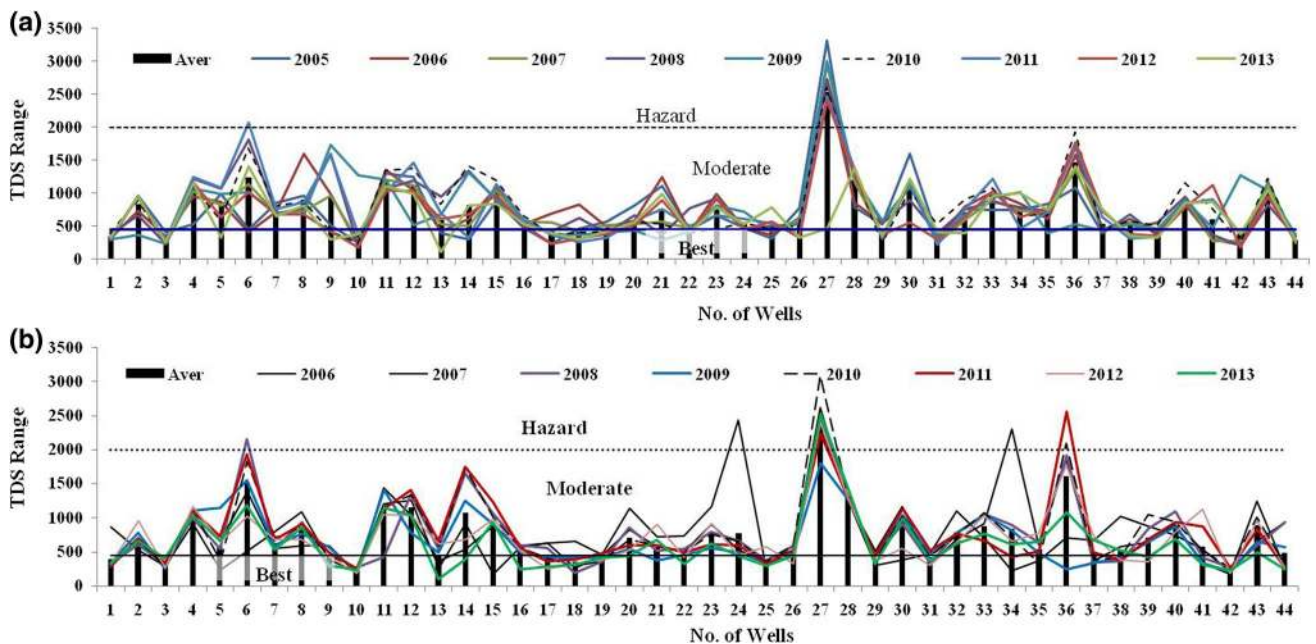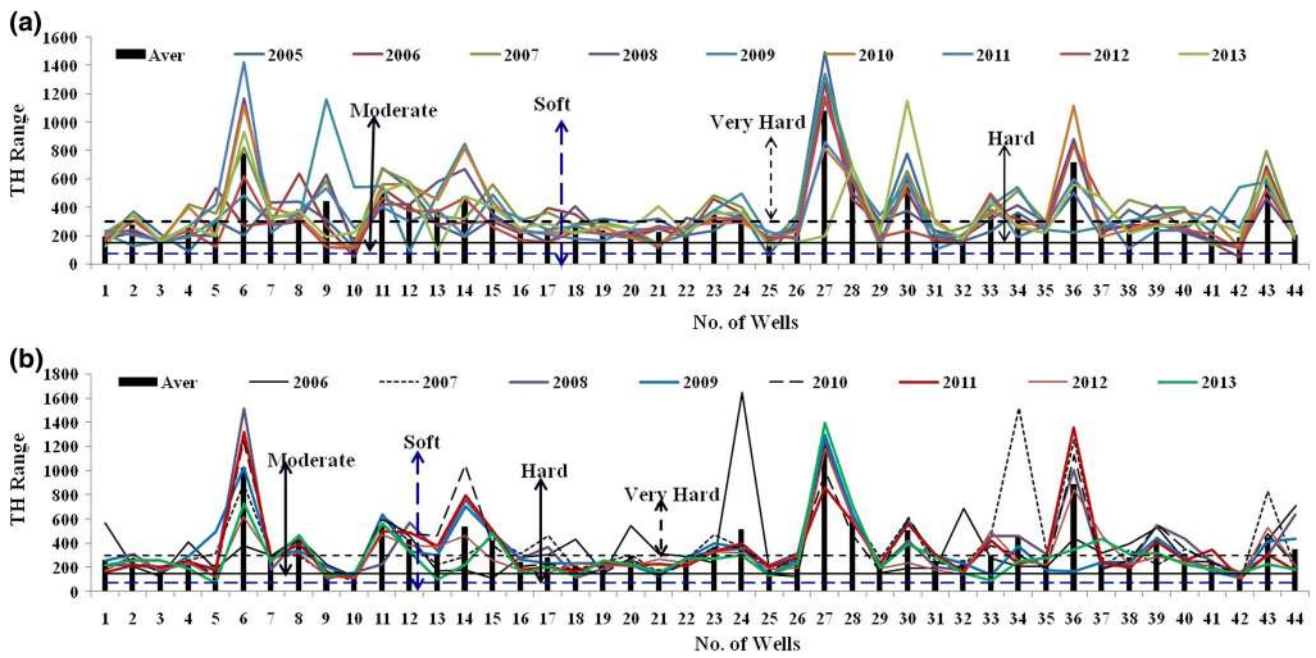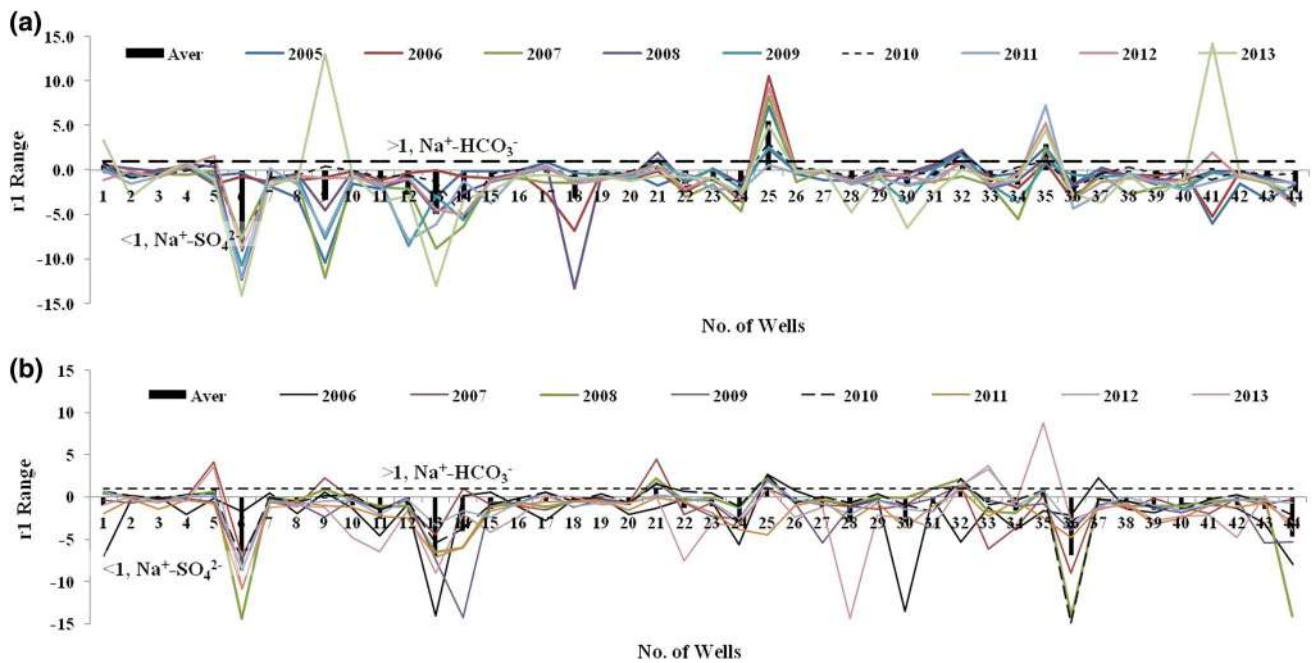

Fig. 10 a Nine-year (2005–2013) temporal representation of CAI2 value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of CAI2 value during post-monsoon

TH), we found that average value of TH for study time period was 385.21 and 356.02 mg/l during pre- and post-monsoon, average value of TH shows that most no. wells in the study area were very hard (TH > 300 mg/l) condition for long time period. However, TH ranged from 51 to 1495.60 mg/l

(Table 2) and 69.82–1646.40 mg/l (Table 3) during pre- and post-monsoon, respectively, and has revealed that maximum TH limit of 1495.60 (pre-monsoon) and 1646.40 (post-monsoon) mg/l were so high from TH > 300 mg/l (hazard condition). However, Tables 4 and 5 present the number of wells
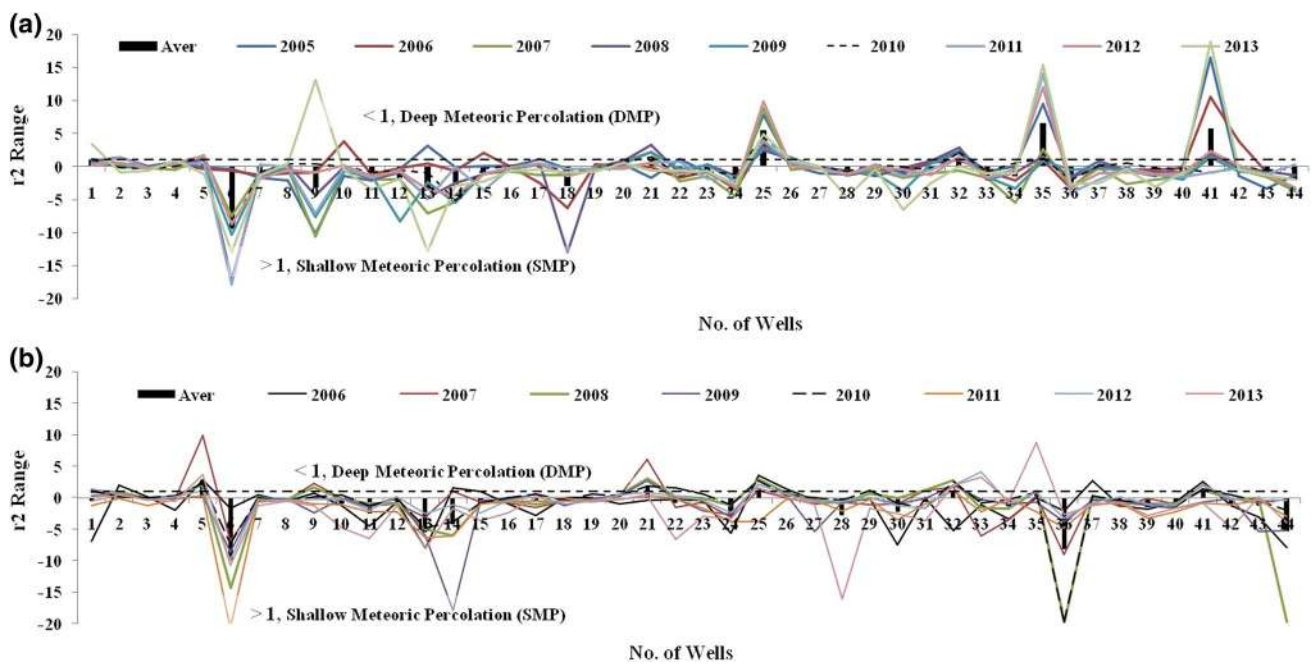
Fig. 11 a Nine-year (2005–2013) temporal representation of CR value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of CR value during post-monsoon

and their class during the study period. Table 4 shows that during the study period (pre-monsoon) the study area has faced a shortage of soft and moderate classes of water for irrigation. On the basis of Table 4, no. of wells are classified into two classes as hard (150–300 mg/l) and very hard

(TH > 300 mg/l). Few wells fall in moderate categories, and in soft categories, no well falls. Similarly, during post-monsoon, most no. of wells come under two classes, hard and very hard (Table 5). Figure 13a, b, shows characteristic of each well during pre- and post-monsoon. Figure 13a reveals

Fig. 12 a Nine-year (2005–2013) temporal representation of TDS value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of TDS value during post-monsoon

Fig. 13 **a** Nine-year (2005–2013) temporal representation of TH value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of TH value during post-monsoon

Fig. 14 **a** Nine-year (2005–2013) temporal representation of r_1 value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation of r_1 value during post-monsoon

that the well nos. 6, 14, 27 30, 36 and 43 show abnormal jump from 300 mg/l with respect to other wells during pre-monsoon. Similarly, Fig. 13b shows the same thing for well nos. 6, 14, 27, 36 and 43 during post-monsoon. Overall rainfall not shows any effect over TH.

Finally, industrial fixed wells are discriminated on the basis of Soltan (1998) index r_1. Index r_1 suggests water type (Na^+–HCO_3^- and Na^+–SO_4^{2-}). From Tables 2 and 3 (r_1), during study time period average water type was Na^+–SO_4^{2-} because the average value of r_1 belongs to less

Fig. 15 **a** Nine-year (2005–2013) temporal representation r_2 value during pre-monsoon. **b** Nine-year (2006–2013) temporal representation r_2 value during post-monsoon
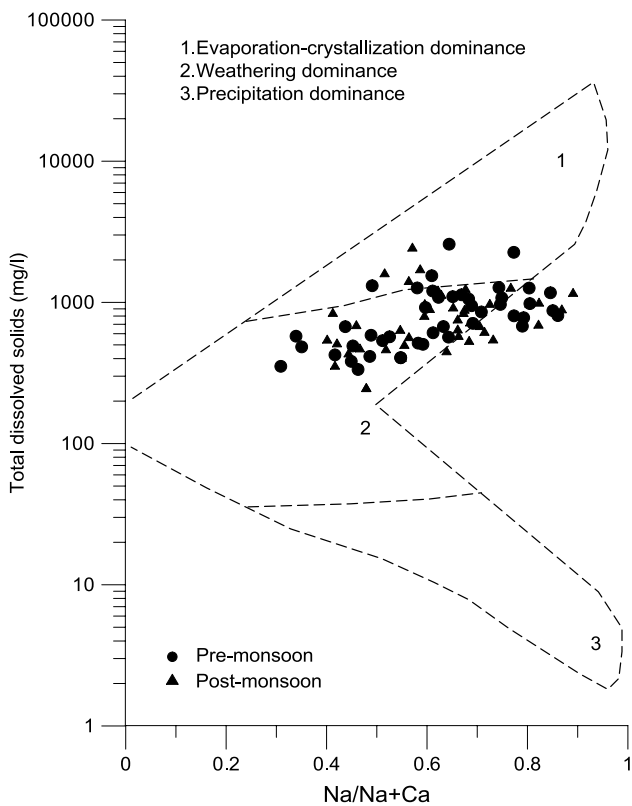
Fig. 16 Gibbs diagram shows that in both the pre-monsoon and post-monsoon seasons water–rock/soil interaction is responsible for the chemical composition of the groundwater in the study area
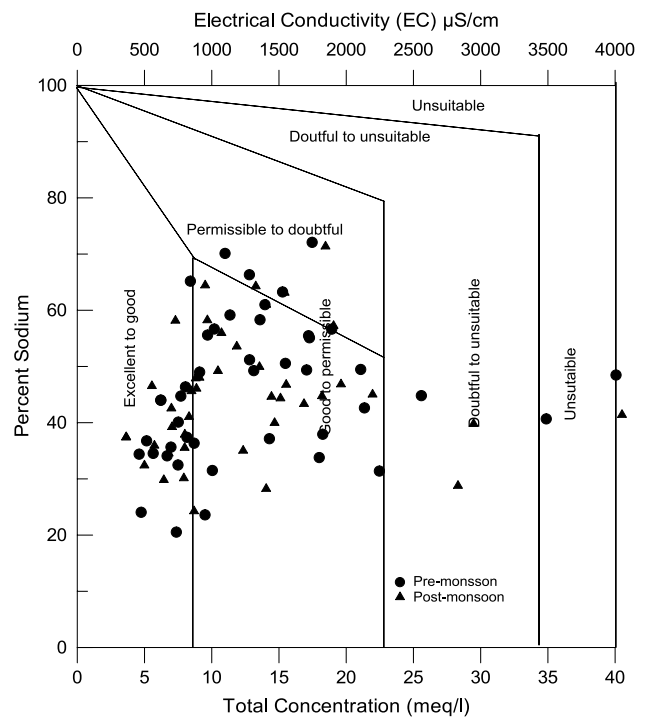
Fig. 17 Wilcox diagram shows the water suitability for irrigation use

than 1 (− 1.12 and − 1.46, pre- and post-monsoon, respectively). In yearwise average, water type was also found as Na^+–SO_4^{2-} (in both sessions); however, few r_1 value was reported greater than 1 (because maximum value of r_1 during
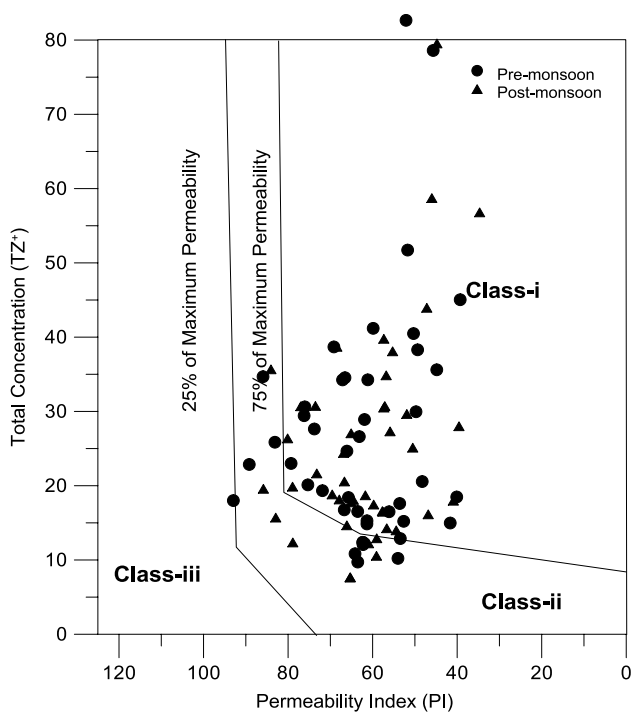
Fig. 18 Doneen ([1964](#)) classified irrigation water based on the permeability index

pre- and post-monsoon was 14.25 and 8.80, respectively), and water type is Na^+–HCO_3^-. Figure [14](#)a, b shows that water type did not change. Only magnitude of r_1 changed during pre- and post-monsoon; therefore, rainfall effect came over the magnitude of r_1 but not the type of water.

Soltan ([1998](#)) also suggested another index (r_2) for classification of water system based on the yield of K^+, Na^+, Cl^- and SO_4^{2-} ions in water. On the basis of r_2, no. of well water was categorized as DMP ($r_2 < 1$) and SMP ($r_2 > 1$); according to average value of r_2 (-0.59 and -1.17, pre- and post-monsoon, respectively) during the study period, the no. of well's water was categorized as DMP (Tables [2](#), [3](#), in context of r_2). Whoever some wells (max 18%) show SMP nature also (Tables [4](#), [5](#)). From Fig. [15](#)a, b, only the magnitude of r_2 was fluctuated not nature of water (DMP/SMP).

The Gibbs diagram (Gibbs [1970](#); Fig. [16](#)) is a commonly used method to establish the relationship of water composition and aquifer lithological characteristics. Three distinct fields of the evaporation–crystallization, weathering/rock–water interaction and precipitation dominance are shown in the boomerang-shaped Gibbs diagram. The distribution of the sampling points elucidates that the major ion chemistry of the groundwater seems to be controlled by chemical weathering of rock forming minerals and anthropogenic activities (Singh et al. [2012](#); Gautam et al. [2015](#)).

The Wilcox ([1948](#)) diagram elucidates sodium percentage and electrical conductivity to classify groundwater (Fig. [17](#)),

which can be divided into five divisions (excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable). As per the Bureau of Indian Standard (BIS), maximum sodium of 60% is recommended for irrigation water (Gautam et al. [2015](#)). Doneen ([1964](#)) classified irrigation water based on the permeability index (Fig. [18](#)). The soil permeability is affected by the extensive use of irrigation water as it is influenced by Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- content of the water (Gautam et al. [2015](#)).

Conclusion

The study area is under stress due to rock element reactions with groundwater (and influences geochemistry of groundwater), and some effects of land-use change (especially where the aquifer is unconfined) are due to urbanization, sea (saline) water interference (study area near of sea) and aquifer refreshing, and over-exploitation. The hydro-geochemical index-based study reveals that the groundwater is hard to very hard. The groundwater of the study area is more influenced by rock–water interaction, sea water, dominance and evaporation (due to high temperature) dominance field. The r_1 and r_2 indexes show that groundwater is Na^+–SO_4^{2-} and deep meteoric percolation (DMP) type. Based on the indexes [SAR, SSP (or %Na), RSC (or RA), KR, PI, CAI, PS, MH, TDS and TH] groundwater majority of the wells is falling under moderate to the unsuitable category of water for irrigation purposes. Thus, the use of groundwater for irrigation (without treatment) in the study area will damage crops and reduces production. However, more saline or salt-tolerable crops could be grown with a good irrigation system to stop soil salinization [also use lime/gypsum treatment to bout permeability of the soils (base-exchange process)]. The outcomes of this study show that index-based irrigation water quality can be useful in decision-making processes such as identifying no. of suitable wells for irrigation systems and prevent the damage of crops and production. It is also suggested that regular monitoring of irrigation water quality and pollution is essential to help farmers and the concerned department for making irrigation policy to the state government. This would be helpful in developing the suitable management plan and sustainable utilization of groundwater in irrigation. To recover the good quality of groundwater, the Government, semi-government and non-government organization (NGO) should make available and support to design the artificial recharge structures and rainwater harvesting structures in the study area.

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