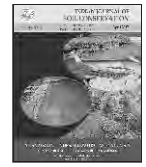
Vol. 45, No. 1, pp 60-65, 2017

Indian Journal of Soil Conservation

Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home



Impact of deficit rainfall coupled with high groundwater exploitation on water quality in semi-arid region of Karnataka

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ARTICLE INFO

Article history :

Received : June, 2015

Revised : September, 2016

Accepted : October, 2016

Key words:

Deficit rainfall,
Groundwater quality,
Semi-arid,
Watershed

ABSTRACT

A study was conducted in a semi-arid watershed spread over 442 ha located in Chitradurga district, Karnataka with a view to assess the impact of deficit rainfall coupled with high groundwater exploitation on water quality. A total of nineteen (ten and nine from upper and lower portions of the watershed, respectively) bore wells were selected, and samples were collected during the pre-monsoon seasons of 2011 and 2014. Results indicate that the groundwater is alkaline in nature with an average pH of 8.70, and average electrical conductivity of 1.28 dS m^{-1}. The general order of abundance in respect of cations is $Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$, and in respect of anions is $HCO_3^{-} > Cl^{-} > SO_4^{-2}$. Cations were observed to be higher in the upper portion of the watershed as compared to the lower portion. Increased individual ion concentration of individual ions such as Na^{+} (77%), Mg^{2+} (61%) and HCO_3^{-} (100%) in 2014 compared to 2011 can be explained in terms of the three consecutive low rainfall years coupled with higher groundwater abstraction. The dominant hydro chemical facies of the groundwater in the watershed are Mg-HCO_3-Cl and Na-HCO_3-Cl. During 2014, 21% of the samples were in the 'high salt hazard' zone, while the groundwater in 50% of the watershed indicates a potential alkalinity hazard expressed as residual sodium carbonate. These values indicate that the water should be used with caution for irrigation during years of low rainfall in order to prevent the soils from becoming salt-affected and reducing crop yields.

1. INTRODUCTION

India is the world's largest groundwater user, in terms of both absolute volumes pumped and total number of users. There are some 20 million wells, a number that is increasing at approximately one million yr^{-1}; the majority of these are equipped with electrical pumps (Scott and Shah, 2004). Around 40% of India's agricultural output is contributed from areas irrigated by groundwater. However, overuse of groundwater is associated with significant risks (IMWI, 2010). Over-abstraction of groundwater without significant recharge results in the decline in water levels (Shah *et al.*, 2000; Mali and Singh, 2016), and as per reports (GoI, 2012) as such the country is headed towards a serious crisis of groundwater due to overuse and quality deterioration.

Besides the problems of availability of sufficient groundwater, water quality issues (Milovanovic, 2007; Adhikary and Biswas, 2011) and the deterioration-causing factors (Jain, 2009) need significant attention. Therefore, regular monitoring the quality of ground water (Jang *et al.*, 2013) and assessing the risks involved in the use of water (Smith, 2001) are as important as assessing its quantity. Groundwater quality is a function of aquifer characteristics, nutrient and pollutant enrichment, withdrawals and recharge. Understanding groundwater chemistry and periodic monitoring of water quality parameters are essential to determine its use for irrigation. This applies particularly to the semi-arid regions characterized by low to medium rainfall with high coefficient of variation. Over-exploitation, coupled with low recharge deteriorates groundwater quality (Lashkari *et al.*, 2013; Pophare *et al.*, 2014). The composition of ground water varies spatially and temporally, and various studies have been carried out in the Deccan region of India on groundwater characteristics (Subramani *et al.*, 2005; Jeevanandam *et al.*, 2006). Some studies have reported the beneficial effect of water harvesting on the groundwater recharge and quality in the country (Sharma and Dubey, 2013), and particularly in the semi-arid Deccan (Adhikari *et al*., 2013; 2015). The immediate consequence of this positive impact, along with availability of subsidized to free electricity for agriculture, easy access to technology and credit availability has been a steep rise in the number of bore wells in watersheds and over-extraction of groundwater for irrigation and drinking in semi-arid regions (Anantha and Raju, 2008). The present study was conducted in a semi-arid watershed in Karnataka which has witnessed a drastic increase in the number of bore wells in the last decade coupled with the occurrence of low rainfall. An attempt was, therefore, made to assess the impact of defect rainfall and over-draft of groundwater on its quality and probable implications for irrigation in a watershed located in the semi-arid zone.

2. MATERIALS AND METHODS

Study Area

The study area (Fig. 1) is a watershed (Netranahalli), in Molakalmuru *taluk* of Chitradurga district (14°37'50" to 14°38'47"N latidute and 76°42'46" to 76°44'51" E longitude) in Karnataka at an altitude range between 550 and 570 above msl. The watershed lies in the valley of the Tunga and Bhadra rivers which form a part of the Krishna basin. The climate of the region is characterized as arid to semi-arid with an average annual rainfall of 542.9 mm, with a coefficient of variation of 31%. About 80% of the rainfall is received from September to November. Rainfall distribution is highly erratic and about 10-15% of rain water is lost as runoff. A study in a nearby semi-arid watershed has pointed out that the threshold value of rainfall for ensuring 1 mm potential recharge is 61 mm, and that potential recharge is only 3% of annual rainfall received (Adhikari *et al*., 2013).t-cost ratio and soil nutrients over years was identified.

Methodology

The watershed, with a total area of 442 ha, was divided into two, roughly equal portions (upper and lower) for the estimation based on the survey numbers of land holdings. A total of nineteen (ten and nine from upper and lower portions, respectively) bore wells were selected, and samples were collected as per standard procedures (water from each bore well was collected in a 500 ml poly-propylene bottle after running the pump for 15-20 minutes followed by addition of 4% toluene for storage) during June, 2014 before the onset of monsoon and analyzed. The quality parameters of the water samples were compared with those obtained from the same bore wells during June, 2011 (pre-monsoon). The analysis was carried out immediately after the collection of water samples at the Centre's laboratory. The parameters analyzed as per standard procedures for irrigation water (APHA, 1995) were - pH, EC, important cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}), and anions such as carbonate (CO_3^{2-}), bi-carbonate (HCO_3^{-}), chloride (Cl^{-}) and sulphate (SO_4^{2-}). The pH and EC were measured by a Systronics pH meter, while SO_4^{2-} was determined by spectrophotometer, Na and K, by using flame photometer. Ca^{2+}, Mg^{2+}, HCO_3^{-}, CO_3^{2-} and Cl^{-} were determined by titrimetric analysis. Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Residual Sodium Carbonate (RSC), Permeability Index (PI), Magnesium Hazard (MH) and Kelly's ratio were analyzed by the procedure adapted by Saxena (1990).

3. RESULTS AND DISCUSSION

The chemical composition of ground water collected from the upper and lower portions of the watershed during 2011 is presented in Table 1. The groundwater is alkaline in nature with an average pH of 8.52 and electrical conductivity of 1.32 dS m^{-1}. The general order of abundance in respect of cationic concentration (meq l^{-1}) is $Mg^{2+} > Na^{+} > Ca^{2+} > K^{+}$, and in respect of anions is $HCO_3^{-} > Cl^{-} > SO_4^{2-}$. The Mg^{2+}/Ca^{2+} ratio in the watershed averaged 2.47, which is typical of a semi-arid region (Chhabra, 1996). Cations were generally observed to be higher in the upper portion of the watershed as compared to the lower portion, which can be explained in terms water movement from upper portion of the watershed to the lower portion indicating the connectivity of the

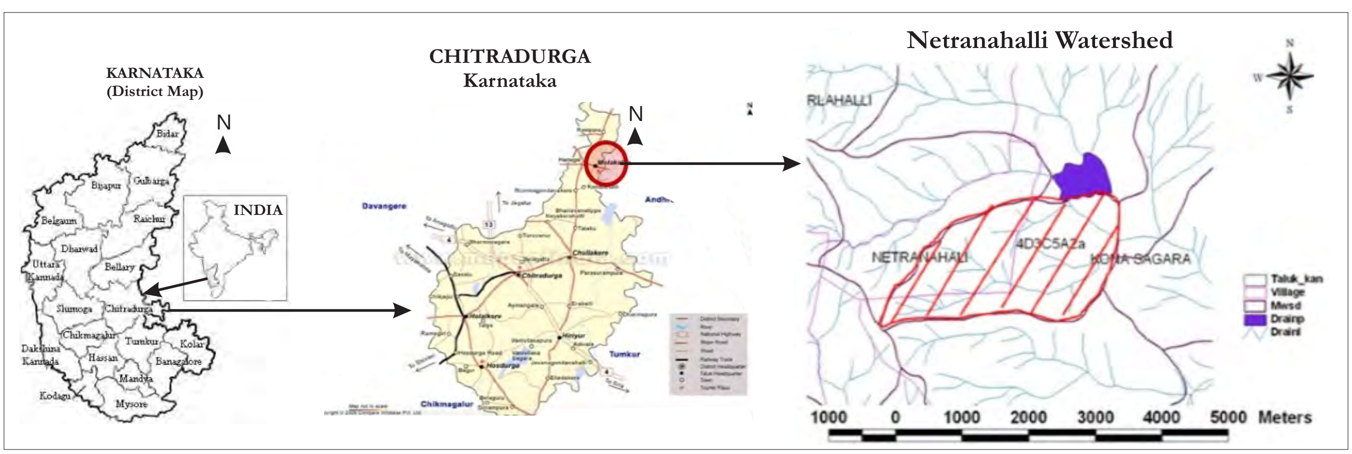


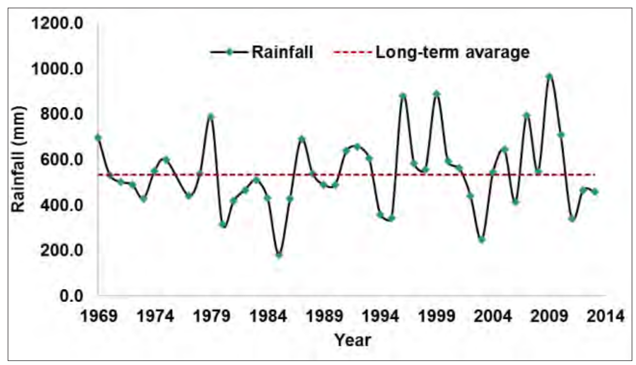
Fig. 1. Location of the study area

Table: 1
Chemical composition of groundwater in the upper and lower portions of the watershed in 2011

Parameter	Upper			Lower		
	Range	Mean	SD ±	Range	Mean	SD±
pH	8.15-8.82	8.51	0.21	8.28-8.70	8.53	0.14
EC (dS m^{-1})	0.85-2.00	1.30	0.41	0.49-2.00	1.35	0.54
TDS (mg l^{-1})	544-1280	833	259	493-1222	809	275
Ca^{2+} (mg l^{-1})	48-112	76.0	19.1	32-104	58.7	24.8
Mg^{2+} (mg l^{-1})	70-125	94.7	18.5	82-115	88.8	14.8
Na^{+} (mg l^{-1})	128-201	155	25.5	112-177	143	24.6
K^{+} (mg l^{-1})	8.01-18.0	11.5	3.0	7.57-12.07	10.0	1.51
Co_3- (mg l^{-1})	ND	-	-	ND	-	-
HCO_3- (mg l^{-1})	439-659	571	70	439-683	556	76
So_4^{2-} (mg l^{-1})	52-114	76	21.0	68-145	108	25.6
Cl^- (mg l^{-1})	185-554	320	138	114-433	256	129

ND = Not detected

watershed. Any attempt of groundwater recharge is, therefore, expected to benefit the lower portion of the watershed in terms of improving water quality because of movement of water within the aquifer. Considering this, two groundwater recharge structures were constructed in the watershed. However, the amount of recharge could not be effectively assessed during the study period owing to the low rainfall received during the study period, *i.e.* from 2011 to 2013. The annual rainfall recorded during 2011, 2012 and 2013 were 338.5, 466.1 and 458.9 mm, respectively against the long-term average of 534 mm (Fig. 2). This, coupled with higher groundwater abstraction reduced the water availability for irrigation in the area. It is clear from Fig. 3 that there has been a decline in ground water table by 16 m between 2010 and 2014. The decline has been compounded by an exorbitant rise in the number of bore wells in the whole area. There were only 112 bore wells in the watershed prior to the implementation of project (2007), which sky-rocketed to 468 during 2014, with about 60% of the wells either failing or not yielding due to poor rainfall. The decline in the groundwater levels resulted in decline in its quality during the same period. The composition of groundwater in respect of the 19 samples collected and analysed in 2014 (Table 2) shows an increase in concentration of all the major cations and anions. The pattern of dominance of cations and anions is similar to that of the samples collected in 2011. The diagnostic chemical characteristics of water solutions in hydrologic systems has been determined with the application of the concept of hydro-chemical facies (Back, 1966), which enables convenient subdivision of water compositions by identifiable categories and reflects the effect of chemical processes occurring between the minerals within the subsurface rock units and the groundwater. Statistical distribution diagrams such as Piper trilinear (Piper, 1944) is used to gain better insight into the hydro-chemical processes operating in the groundwater system. The relative proportions of cations and anions, as plotted in Piper trilinear diagrams (Fig. 3) indicate that the dominant hydro-chemical facies of the groundwater in the



Data source: *CGWB (Groundwater brochure of Chitradurga); Groundwater Office, Chitradurga*

Fig. 2. Rainfall pattern in Molakalmuru taluk of Chitradurga district

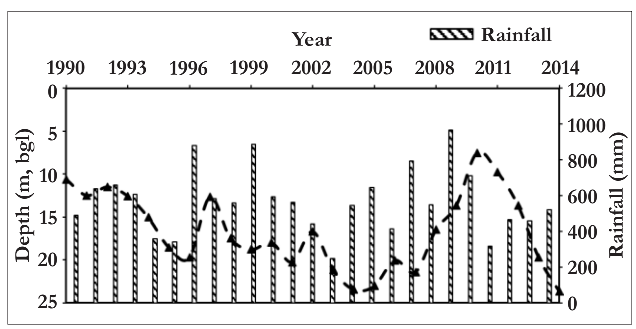


Fig. 3. Change in groundwater table over time in Molakalmuru Taluk, Chitradurga

watershed are Mg-HCO_3-Cl and Na-HCO_3-Cl. The chemistry controlling the groundwater composition is a combination of carbonate dissolution, silicate weathering and dissolution of chlorides from the salt-bearing strata. Water chemistry differs depending on the source of water, the degree to which it has been evaporated, the types of rock and mineral it has encountered, and the time it has been in contact with reactive minerals (Arshid, 2011).

On closely examining Fig. 4 (a and b), it can be inferred that during 2011, after the good rainfall years of 2009 and 2010, there was heterogeneity among the water samples and

Table: 2
Chemical composition of groundwater in the upper and lower portions of the watershed in 2014

Parameter	Upper			Lower		
	Range	Mean	SD ±	Range	Mean	SD±
pH	8.50-9.08	8.69	0.19	8.53-8.87	8.71	0.12
EC (dS m^{-1})	1.15-2.19	1.58	0.37	0.89-2.28	1.43	0.39
TDS (mg l^{-1})	736-1402	1010	237	570-1459	917	251
Ca^{2+} (mg l^{-1})	82-165	124	29.9	77.2-129	95.5	20.3
Mg^{2+} (mg l^{-1})	127-181	152	17.6	110-146	124	10.9
Na^{+} (mg l^{-1})	181-350	275	57.4	161-327	228	52.0
K^{+} (mg l^{-1})	10.9-21.5	15.1	3.29	8.58-13.7	11.0	1.72
Co_3- (mg l^{-1})	ND	-	-	ND	-	-
HCO_3- (mg l^{-1})	964-1293	1144	119	744-994	866	93.8
So_4^{2-} (mg l^{-1})	66-110	80.4	18.5	70-163	111	31.9
Cl^- (mg l^{-1})	221-572	341	123	147-481	289	114

ND = Not detected

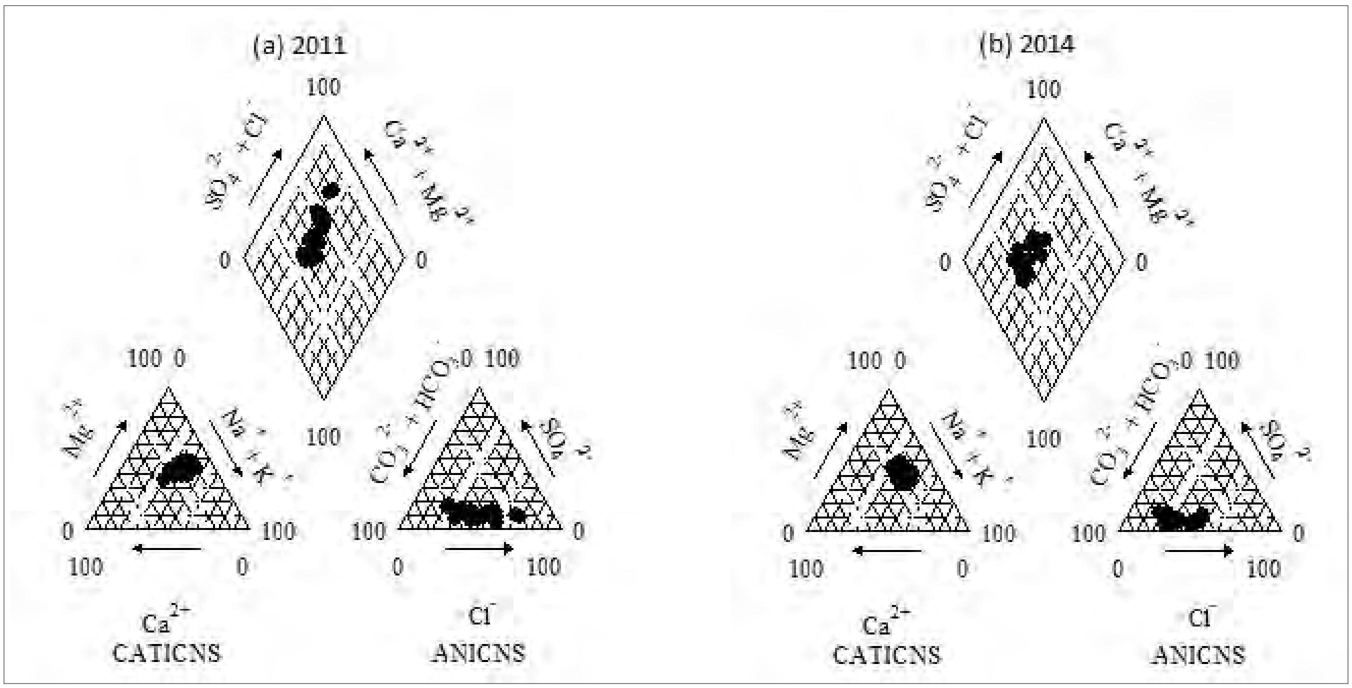


Fig. 4. Piper tri-linear diagram depicting the concentration of ions in groundwater (N = 19)

the points are scattered. Following three consecutive low rainfall years, the points are clustered together, which shows the uniform increase in concentration of ions, particularly of sodium as compared to calcium and magnesium. While the average concentration of sodium increased by 77% in the upper portion of the watershed during the three years, magnesium and calcium ions increased by 66 and 60%, respectively. The relative abundance of former ions as compared to the latter could be attributed to both silicate weathering coupled with the substitution of Na^+ by Ca^{2+} and Mg^{2+} on the exchange sites of the rock strata. The main mechanism controlling the chemistry of groundwater as indicated by the Gibb's plot (Fig. 5) is the 'evaporation', leading to the abundance of soluble salts in the depleting groundwater. This also indicates the limited capacity of the aquifer, which unless adequately recharged, may further degrade the quantity and quality of irrigation water. This is also evident by the failure of several wells and the increased density of deep bore wells over the years in the study area.

Farmers of the watershed mostly depend on groundwater, particularly during the *rabi* season for providing life-saving irrigation to crops. In order to assess the suitability of groundwater for irrigation, the sodium, salinity and alkalinity hazards were computed (Table 3). The parameters for the classification of groundwater were: salinity hazard represented by the EC values of the samples, individual ionic hazards, sodicity hazard represented by sodium percentage and sodium adsorption ratio, and alkalinity hazard represented by pH and residual sodium carbonate. The pH of only 31% of the samples was below the safe level of 8.4 in

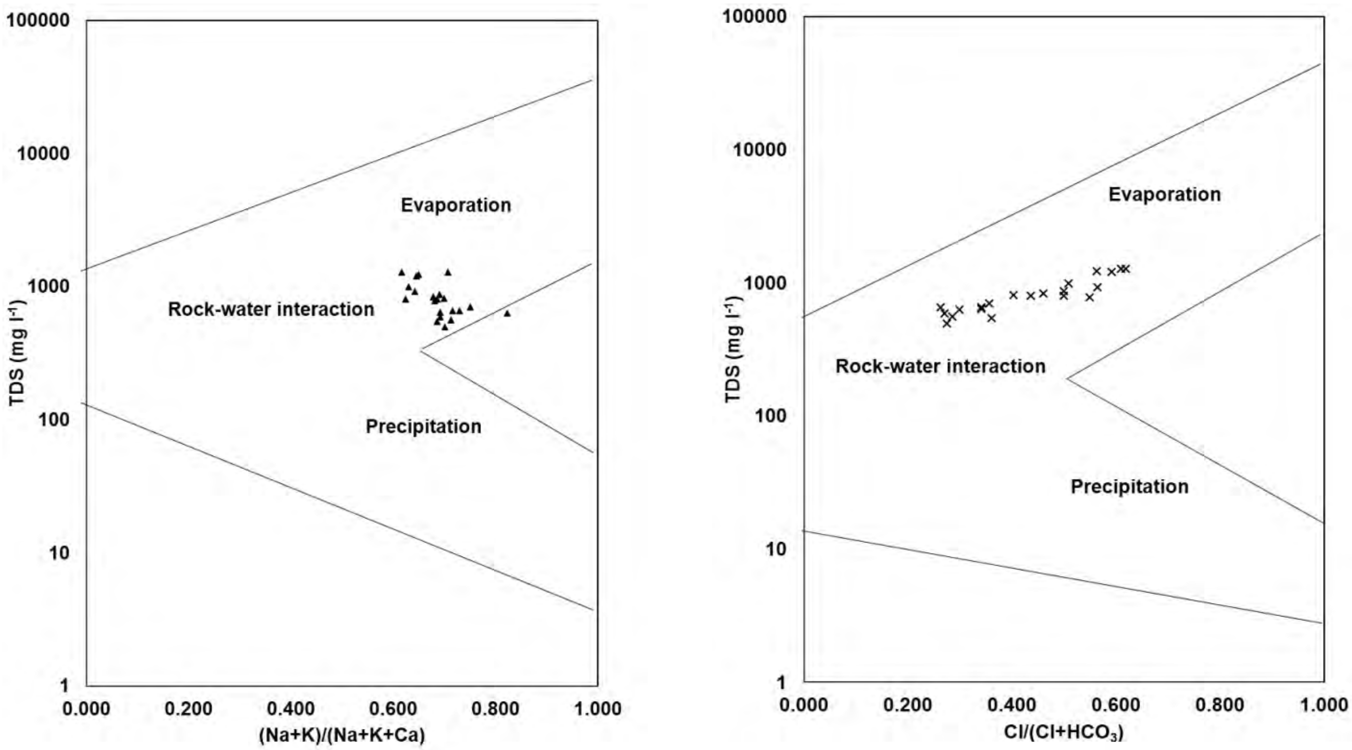


Fig. 5. Gibb's Plots for the water samples of Netranahalli watershed

Table: 3
Characterization of groundwater of the study area for irrigation (threshold values were compiled from Richards, 1954; Chhabra, 1996; Hopkins *et al.*, 2007)

Parameter	Defines/Affects	No. of samples (N = 19)							
pH	Soil pH	2011	2014	2011	2014	2011	2014	2011	2014
		Good (6.5-8.4)		Poor (> 8.4)					
		6	2	13	17				
Electrical conductivity (dS m^{-1})	Salt Hazard	Slight (<0.75) - C_2		Moderate (0.75-2.00) - C_3		High (2.00-3.00) - C_4		Very high (>3.00) - C_5	
		5	0	14	15	0	4	0	0
Sodium (% of total cations)	Sodium hazard	Safe (0-30%)		Marginal (30-60%)		Unsafe (> 60%)			
		3	0	16	19	0	0		
Chloride (mg l^{-1})	Chloride hazard	Safe (< 70)		Slight (70-140)		Moderate (140-350)		High (> 350)	
		0	0	2	0	13	11	4	8
Sodium Adsorption ratio	Alkalinity hazard	Nil (< 10) - S_1		Slight (10-18) - S_2		Moderate (18-26) - S_3		High (> 26) - S_4	
		19	19	0	0	0	0	0	0
Residual sodium carbonate (meq l^{-1})	Bicarbonate hazard	Safe (< 1.25)		Marginal (1.25-2.5)		Unsafe (> 2.5)			
		17	10	2	9	0	0		

2011, while in 2014, the number of samples with safe pH value was only 11%. About 26 and 74% of the samples were found to be in the C_2 and C_3 categories during 2011. Continuous drought-like situations in the study area increased the salinity hazard potential of the groundwater samples, with 79 and 21% of the samples categorized under C_3 and C_4 categories.

It has been mentioned earlier that the sodium ion abundance (ratio of sodium to calcium and magnesium) in the groundwater samples increased from 2011 to 2014. While 84% of the samples were in the marginal category in terms of sodium percentage during 2011, all the samples were in the marginal zone during 2014. Rainfall aberrations, however, did not affect the sodium adsorption ratio of the samples even after three years, indicating that the groundwater would not immediately pose any threat to the soil in terms of sodicity.

The groundwater of the study area is rich in both chloride and magnesium ions. Magnesium in excess of calcium ions in irrigation water is considered detrimental to soil health, as the former behaves like sodium in higher concentrations and has the potential to cause soil sodicity (Chhabra, 1996). Magnesium ratio below a threshold value of 50% $[(Mg^{2+})/(Mg^{2+}+Ca^{2+})*100]$ in irrigation water is considered as safe. However, all the samples in the study area have a magnesium ratio in excess of 50% suggesting potential magnesium hazard. Similar is the case with chloride ions. Most of the samples have moderate to high potential to damage chloride sensitive crops in the area if groundwater is used indiscriminately. High evaporation and accumulation of anions, particularly bicarbonate ions increased the alkalinity hazard of the groundwater. About 50% of the samples analysed during 2014 were in the marginal range in terms of suitability for irrigation.

4. CONCLUSIONS

The groundwater of the study area was found to be suitable for irrigation; however, its quality deteriorated under deficit rainfall situations, which was occurred for three consecutive years, coupled with the high levels of groundwater extraction for drinking and irrigation. During 2011, 26 and 74% of the water samples were categorized under C_2S_1 and C_3S_1, respectively, while in 2014, 79% and 21% of the samples were classified under C_3S_1 and C_4S_1, respectively. Characterization of groundwater based on different parameters mostly indicates individual ion toxicity (Mg^{2+} and Cl^-) and salinity hazards in the event of continuous usage of water for irrigation. Fortunately, most of the soils in the watershed are course textured, with high infiltration rates, which favour lesser impact of poor quality saline water. However, the groundwater should be used with caution for irrigation during years of low rainfall, particularly in the upper portion of the watershed in order to prevent the soils from becoming salt-affected and reduce crop yields. The alarming rise in the number of bore wells, most of which either fail or stop yielding water within a few years in the study area is a cause of concern. Both low rainfall and groundwater exploitation by farmers have resulted in deterioration in groundwater quality, which call for urgent technological and policy interventions.

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