J. Earth Syst. Sci. (2020)129 52
https://doi.org/10.1007/s12040-019-1312-5

Source rock weathering and groundwater suitability for irrigation in Purna alluvial basin, Maharashtra, central India

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MS received 26 April 2019; revised 15 September 2019; accepted 18 October 2019

Purna alluvial basin is characterized by low to high level groundwater salinity having adverse effect in a large area, however, the basin still lacks one-time data of any season regarding hydrogeochemistry and quality assessment for drinking and irrigation purposes. The present work is aimed to determine various weathering indices and estimation of groundwater quality for irrigation purpose. The interpretations are based on the study of total 158 samples, collected from dug wells (60) and bore wells (98) during both pre- and post-monsoon periods of the year 2009. The plots between Ca+Mg *vs.* SO_4+HCO_3, Na *vs.* Cl and Na *vs.* HCO_3 reveal that most of the samples fall below the equiline that indicates prevalence of silicate weathering. The USSL diagram (Wilcox diagram) demonstrates higher concentration of points in the fields of C2S1 and C3S1 for both the aquifers, indicating high salinity and low to medium sodium water; however, a few sample points positioned in C3S4 and C4S4 fields indicate high salinity but medium to high sodium. The values of Na%, RSC, Kelley ratio and magnesium ratio for most of samples exhibit doubtful to unsuitable categories of groundwater for irrigation from both the aquifers during pre- and post-monsoon periods. The vast data bank generated for entire basin is significant for government and non-government organizations for future planning and management.

Keywords. Ionic ratio; groundwater quality; irrigation; Purna alluvial basin; Maharashtra.

1. Introduction

Groundwater, a major natural resource of central India including the basin area under study, contributes largely to the need of domestic and irrigational requirements of the region (Tiwari *et al.* 1996; CGWB 1998; Srivastava and Parimal 2014). Certain areas in the basin, particularly in the northern hilly terrain, caters their irrigation water requirement through dam water facility, otherwise, groundwater is the only source in the rest of the basin area. In last five decades, there has been a multifold increase in the demand of groundwater for irrigation purposes particularly, in the rural areas (CGWB 1998; TERI 2017). A major part of the basin, particularly in the central portion, experiences medium to high level salinity in the groundwater which is a matter of socio-economic concern because of its adverse affect on society at large (Adyalkar 1963; Muthuraman and Padhi 1996; Srivastava and Parimal 2015). Generally, the groundwater quality of a region primarily depends on the atmospheric precipitation, surface water, host rock lithology and subsurface geochemical processes (Todd 1980; Raghunath 1987; Hem 1991; Drever 1997; Goyal *et al.* 2010). Similarly, the

Published online: 22 January 2020

chemistry of the same is largely controlled by the dissolution of minerals of the aquifer through which the water flows (Lakshmanan *et al.* 2003; Nagaraju *et al.* 2014; Al-Kalbani *et al.* 2017).

The main objective of the present study is to interpret silicate and carbonate weathering of the source rock and quality assessment of the groundwater from both shallow and deep aquifers for irrigation purpose. In the study area, agriculture is a major economic activity for the livelihood which depends largely on bore well irrigation as the monsoon in this region is normally low and erratic. Considering the same, assessment of groundwater has been given emphasis, hence, its suitability for irrigation has been focused and evaluated on the basis of various established parameters, i.e., SAR, RSC, EC, MR and KR. Plots of spatial distribution of both SAR and EC values in the basin area provide their local and regional trends that is helpful for cultivators in selecting the suitable crop for higher yield.

2. Study area

The catchment of the Purna river covering an area of about 18,514 km^2 in the northeastern part of Maharashtra is bounded by the longitudes 75°56′25″–77°56′46″E and latitudes 20°08′31″–21°40′30″N (figure 1). The peripheral part of the basin is mostly covered by the basalt of Deccan Trap while the alluvial tract occupy mostly the central part covering an area of 6,090 km^2, of which, 2,726 km^2 central part is marked by saline groundwater (Siddiqui 2004; Kale 2009). The northern and southern parts of the basin area are bounded by Gawailgarh Hill Range and low lying Ajanta Hill Range, respectively. Its eastern margin coincides with the plains of the Wardha river basin whereas, western margin merges to Tapi basin. The basin area falls in subtropical climate zone and experiences very hot summers and moderately cold winters. The rainy season starts in mid-June and ends in mid-September, with high peaks in July and August. The rainfall is uneven as the northern high altitude part receives comparatively more than the plain areas with overall average of 770 mm (Kale 2009; Srivastava and Kale 2018).

3. Geology and hydrogeology

The basin is represented dominantly by alluvium in the center and basalt on the peripheral areas that serve as major water bearing formations (Kale 2009; Tiwari *et al.* 2010; Srivastava and Parimal 2015). The basin is drained by the Purna river, a major tributary of Tapi. The drainage pattern of Purna river and its tributaries are mostly controlled by lithology and relief factor, i.e., the low to medium attitude basaltic terrain in the north is characterized by dendritic pattern of drainage, whereas, subparallel to parallel in the alluvium plain (Kale 2009; Srivastava and Kale 2018). The basalt of the Deccan trap forms the Satpura hills in north and in the hilly slopes of Narnala and Chikhaldara Fort (Adyalkar 1963; Tiwari *et al.* 1996). Successive flows in these areas are mostly horizontal or, may show low dip of 5° to 10° towards the north. In the south of Satpura hills, east–west trending Bazada zone exists consisting dominantly of matrix-supported boulders, cobbles and pebbles (Srivastava *et al.* 2009; Srivastava and Kale 2018). The Alluvial that lies in central part of the basin, consists mainly of consolidated to semi-consolidated beds of gravel, sands, silts and clays of Quaternary age (Adyalkar 1963; Tiwari *et al.* 1996, 2010; Srivastava and Kale 2018).

Groundwater in the basin area occurs at both shallow and deep levels. On the basis of bore hole data, the aquifers are categorized into three types, i.e., pebbles in sandy-matrix, coarse sand with pebbles, and medium to fine sands including clays (Adyalkar 1996; Siddiqui 2004; Srivastava *et al.* 2009). The shallow aquifer is unconfined in nature, consisting mainly of coarse-grained sand and gravels, the deep aquifer are semi-confined to confined in nature represented by admixture of medium sand and clay (Srivastava *et al.* 2009). Dug wells are mostly 15–40 m bgl deep having diameter range of 2–10 m, whereas, bore wells are 70–100 m bgl deep, rarely up to 120 m bgl having diameter range up to 150 mm.

4. Materials and method

A total of 158 samples were collected from both dug wells (60) and bore wells (98) of the alluvial part of the basin (figure 1). Sampling has been carried out twice in the year, i.e., in the months of May (pre-monsoon) and October (post-monsoon) for the year 2009. In case of bore wells, samples have been taken after pumping off the stagnant water from those wells, which were not in continuous use (APHA 2005). Similarly, the dug wells in continuous use were chosen for sampling. In general, the dug wells have a depth range of

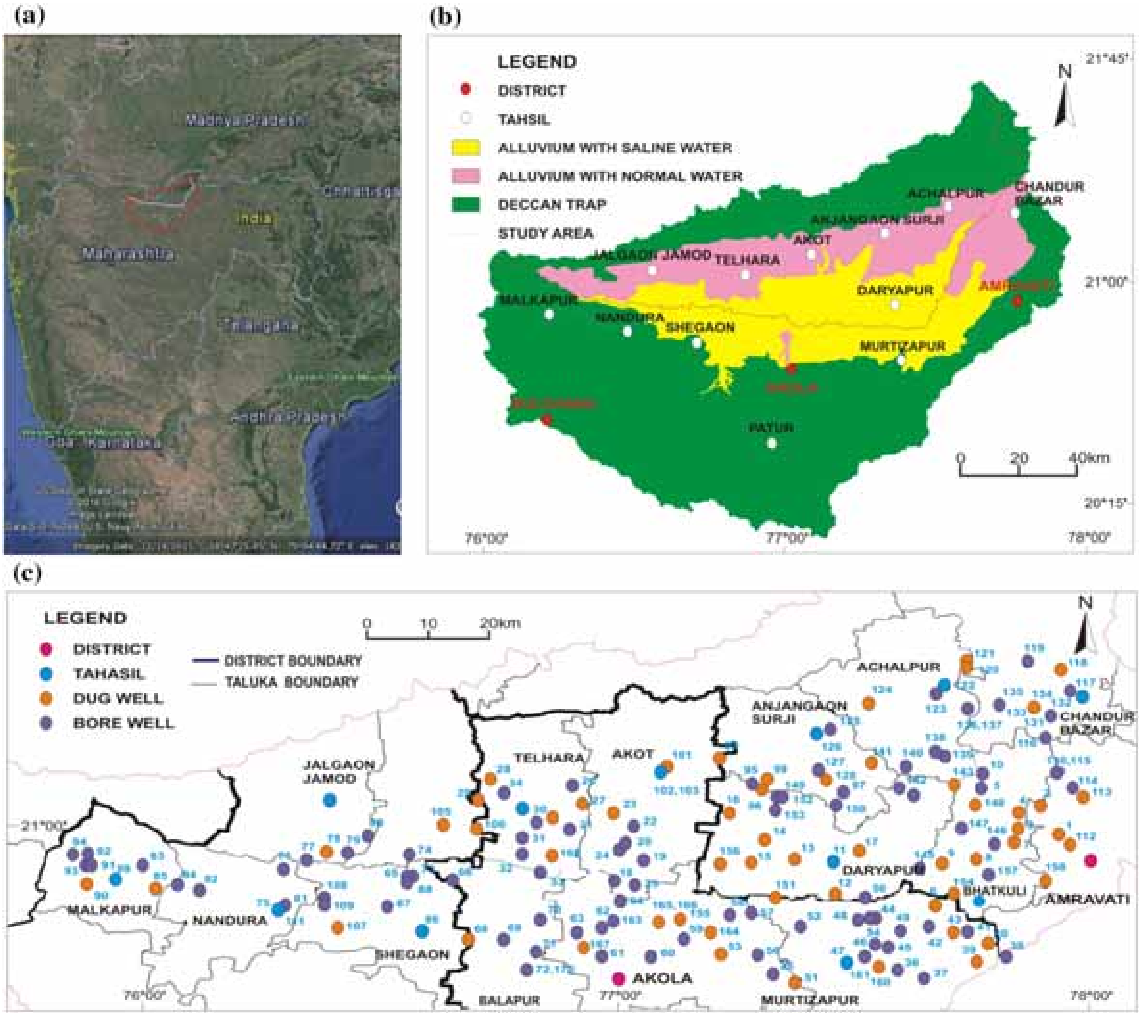

Figure 1. (**a**) Location of Purna river basin in regional set-up, (**b**) spatial distribution of major lithologies, normal and saline groundwater zones in the basin area (Kale 2009), and (**c**) location of the sampling sites (modified after Srivastava and Parimal 2015).

15–20 m bgl whereas, 70–90 m bgl for bore wells. Pre-cleaned, acid washed polythene bottles were used to collect the water for further analysis as per the procedure laid down by APHA (1992). The pH and EC were measured *in-situ* using portable meters. Alkalinity (Al), calcium (Ca), chloride (Cl) and total hardness (TH) were determined by respective volumetric titration methods. Magnesium (Mg) is obtained by subtracting calcium value from the total hardness, whereas, bicarbonate (HCO_3) was obtained by the numerical calculation of pH and phenolphthalein alkalinity values. Sodium (Na) and potassium (K) were determined by using flame photometer, whereas, SO_4 and NO_3 by UV-VIS spectrophotometer. Total dissolved solids (TDS) concentration was calculated from EC following Hem (1991). The values of various parameters were later used to find out various ratios, i.e., sodium absorption ratio (SAR), sodium percentage (Na%), residual sodium carbonate (RSC), Kelley ratio (KR) and magnesium ratio (MR) of groundwater using various formula as proposed by USSL (1954) and Doneen (1962), respectively. Table 1(a and b) shows the geographical coordinates of the sampling sites and values obtained for various physical and chemical parameters including various irrigation parameters.

5. Results and discussion

5.1 *Ionic relations and sources of major components*

Various ionic ratios provide an idea of the carbonate and silicate weathering in the host sediments that also affect the chemical composition of groundwater (Elango and Kannan 2007; Li *et al.* 2016; Vasu *et al.* 2017). The scatter diagram of

Table 1(a). *Values of cations and anions in mili equivalent per litter (meq/l) from bore wells in pre- and post-monsoon periods of the year 2009.*

Sl. no.	Village name	Longitude	Latitude	EC		Ca		Mg		Na		HCO_3		Cl		SO_4		Na%		SAR		RSC		KR		MR	
				Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	114) Shirala	77°44'45.35"	21°7'22.71"	4050	780	4.0	7.2	1.9	0.4	12.2	13.5	17.6	24.4	1.7	2.2	2.4	0.9	67.2	63.9	10.0	9.8	11.7	16.8	2.1	1.8	32.4	5.3
2	130) Jalta	77°53'44.91"	20°59'46.02"	1590	2400	4.9	22.4	23.1	4.2	28.7	26.5	51.2	48.8	22.2	16.2	2.9	2.8	50.6	49.9	10.8	10.3	23.2	22.2	1.0	1.0	82.6	15.9
3	5) Purna Nagar	77°34'40.12"	21°06'17.43"	6080	670	4.0	3.8	2.8	2.3	14.3	7.0	22.0	13.2	3.2	2.3	1.5	1.2	67.8	53.3	11.0	5.6	15.2	7.1	2.1	1.1	41.2	38.2
4	115) Saur	77°39'54.68"	21°7'47.28"	1400	1160	3.6	2.6	0.6	3.1	17.0	28.7	19.5	34.9	4.5	5.1	1.0	2.1	80.2	83.2	16.6	23.9	15.4	29.1	4.1	5.0	13.5	54.2
5	144) Ashti	77°38'42.14"	21°3'14.79"	3730	1320	3.6	3.6	3.2	2.8	32.6	29.1	29.3	41.5	4.0	3.7	3.0	1.0	82.7	81.9	25.0	23.0	22.5	35.1	4.8	4.6	47.1	43.7
6	145) Madhalpur	77°38'12.47"	21°4'45.94"	1670	3220	7.6	7.8	5.6	5.3	30.4	50.9	24.4	44.9	23.6	25.1	2.1	2.4	69.7	79.6	16.8	28.2	11.2	31.9	2.3	3.9	42.4	40.5
7	147) Khalar	77°38'45.20"	20°50'53.63"	1300	1710	10.7	12.7	4.5	3.4	13.5	14.8	24.4	29.8	8.8	9.7	3.3	2.4	47.0	47.9	6.9	7.4	9.2	13.7	0.9	0.9	29.5	20.9
8	154) Sayat	77°33'17.52"	20°53'34.74"	2520	1320	2.6	2.5	3.0	3.2	22.6	21.3	24.4	19.5	9.7	10.4	0.8	2.5	80.0	78.8	19.1	17.9	18.8	13.8	4.0	3.7	54.3	56.4
9	157) Nimbha	77°37'48.43"	20°55'9.88"	900	2120	3.0	7.1	6.8	2.0	43.0	33.0	29.3	36.6	18.4	17.5	1.0	2.3	81.5	78.5	27.6	22.0	19.5	27.6	4.4	3.7	69.7	22.1
10	10) Shinganapur	77°29'03.42"	20°56'53.57"	2300	6100	2.9	3.0	2.9	2.6	15.2	13.0	19.5	14.6	1.9	2.6	3.1	2.5	72.5	69.6	12.7	10.9	13.8	9.0	2.6	2.3	50.0	46.5
11	116) Kharwadi	77°42'56.93"	21°11'6.32"	620	1110	2.4	6.8	4.2	1.6	10.9	14.3	14.6	25.4	3.0	3.6	0.9	1.2	62.4	63.1	8.5	9.9	8.1	17.0	1.7	1.7	63.4	19.0
12	117) Madan	77°43'55.73"	21°16'59.5"	430	710	2.0	2.4	2.4	2.4	3.0	2.6	7.3	7.8	0.6	0.6	0.4	1.0	40.8	35.1	2.9	2.4	2.9	3.0	0.7	0.5	54.6	50.0
13	119) Shirasgaon Kasba	77°40'51.52"	21°19'49.62"	450	420	4.9	4.8	1.6	1.8	0.7	0.7	7.3	7.6	0.8	0.6	0.5	0.4	9.1	8.9	0.5	0.5	0.8	0.9	0.1	0.1	24.7	27.8
14	132) Shahpur	77°48'21.41"	21°16'25.39"	850	660	4.0	2.9	1.1	3.9	14.3	7.0	14.6	18.1	8.0	1.0	0.6	0.2	72.9	50.5	12.7	5.3	9.5	11.3	2.8	1.0	21.9	57.6
15	135) Talegaon Mohana	77°37'6.85"	21°14'27.39"	670	450	1.0	2.3	3.0	2.6	4.3	5.2	7.3	9.8	1.0	1.2	0.3	0.2	51.9	51.1	4.3	4.7	3.3	4.8	1.1	1.1	74.0	53.2
16	136) Tondgaon	77°33'41.3"	21°15'5.71"	600	630	0.7	4.1	1.0	2.7	7.0	4.8	9.8	11.2	1.1	1.4	0.4	0.2	80.3	41.3	10.7	3.7	8.1	4.4	4.1	0.7	57.2	40.0
17	122) Partawada	77°31'3.80"	21°17'53.34"	420	800	5.3	5.6	3.0	4.1	5.7	5.1	14.6	12.2	3.1	2.4	0.6	0.5	40.4	34.6	3.9	3.3	6.3	2.5	0.7	0.5	36.4	42.2
18	125) Pathrot	77°21'54.17"	21°12'49.61"	1630	1430	1.2	2.4	2.9	4.6	1.3	1.5	4.9	8.5	0.8	0.9	0.3	0.8	24.1	17.7	1.3	1.1	0.8	1.5	0.3	0.2	70.6	65.9
19	129) Yersuni	77°30'46.90"	21°06'31.47"	900	700	2.2	2.2	2.6	3.5	15.7	26.1	20.0	29.3	2.3	3.0	3.0	2.3	76.4	81.8	14.3	21.7	15.2	23.5	3.3	4.5	55.0	61.1
20	138) Rajna	77°31'28.31"	21°09'15.45"	870	720	1.6	3.0	3.4	2.0	11.3	11.3	15.1	17.1	0.9	0.8	1.3	2.0	69.4	69.1	10.2	10.1	10.2	12.0	2.3	2.2	67.7	39.7
21	139) Wasni Khurd	77°32'38.49"	21°09'35.65"	800	710	1.3	5.2	3.8	0.8	9.1	8.7	11.0	12.2	4.0	1.7	0.1	0.3	63.8	59.1	8.1	7.1	5.9	6.2	1.8	1.4	75.0	13.3
22	140) Yewata	77°29'41.94"	21°08'25.98"	1450	720	0.9	2.6	5.0	3.9	6.1	5.7	12.2	14.6	1.1	0.8	0.2	0.2	50.7	46.6	5.0	4.4	6.3	8.2	1.0	0.9	85.1	60.5
23	142) Asadpur	77°28'57.57"	21°05'9.422"	1380	570	12.1	7.0	1.5	6.9	15.2	15.7	17.6	29.3	7.2	5.8	2.3	2.1	52.7	53.0	8.2	8.4	3.9	15.4	1.1	1.1	11.2	49.8
24	143) Yelki	77°33'50.92"	21°06'19.96"	320	230	6.6	2.2	4.1	2.6	9.1	7.4	6.3	9.8	61.9	3.8	1.2	0.4	46.1	60.6	5.6	6.7	-4.3	5.0	0.9	1.5	38.4	53.3
25	11) Daryapur	77°20'30.53"	20° 55'31.75"	3900	2960	1.7	2.1	1.8	5.9	0.7	0.8	5.6	7.3	0.8	0.9	0.3	0.3	16.3	8.9	0.7	0.6	2.1	-0.7	0.2	0.1	52.3	74.0
26	95) Itki	77°18'22.17"	21°00'23.30"	1630	1320	1.5	1.6	1.0	1.6	60.4	56.1	29.3	43.9	28.8	21.2	2.1	0.5	96.0	94.5	76.7	62.3	26.8	40.7	24.3	17.3	38.8	50.6
27	153) Amla	77°27'39.49"	20°52'37.06"	1900	5980	1.7	2.1	0.7	0.5	30.9	31.7	22.2	29.3	6.3	6.3	2.8	1.9	92.7	92.4	39.8	39.7	19.8	26.7	12.9	12.4	30.9	18.7
28	97) Chincholi	77°23'54.44"	21°04'32.83"	980	560	2.7	2.4	2.6	4.0	10.9	12.0	15.9	19.5	4.0	2.6	0.5	0.4	66.9	65.0	9.4	9.5	10.5	13.1	2.0	1.9	49.3	62.5
29	98) Sategaon	77°14'36.91"	21°06'44.62"	750	420	0.8	1.6	4.0	4.0	10.9	7.4	13.7	12.2	5.2	4.1	0.3	0.2	69.3	56.8	9.9	6.2	8.9	6.6	2.3	1.3	83.3	71.4
30	127) Takarkheda	77°20'32.88"	21°08'47.58"	720	870	2.2	2.4	3.8	3.2	5.2	6.5	12.2	12.2	0.8	1.0	0.3	0.3	46.4	53.7	4.3	5.5	6.2	6.6	0.9	1.2	64.0	57.2
31	149) ChincholiShengne	77°17'8.79"	21°04'34.61"	1220	1900	2.2	4.2	5.4	1.9	11.7	13.9	14.6	19.5	4.8	1.7	2.7	0.6	60.7	69.2	8.5	11.2	7.0	13.4	1.5	2.3	70.5	31.1
32	150) Pimpalgaon	77°22'29.29"	21°03'33.50"	2290	1500	2.4	2.2	3.3	2.6	30.4	27.0	24.4	29.3	12.2	8.0	2.5	2.8	84.1	84.5	25.5	24.4	18.7	24.4	5.4	5.5	57.8	54.1

Table 1(a). *(Continued.)*

33	155) Umbri	77°16'09.8"	21°02'8.02"	2000	8840	4.0	3.4	3.4	2.6	31.7	34.8	19.5	26.8	24.0	22.4	3.2	0.7	81.1	85.3	23.4	28.6	12.2	20.9	4.3	5.9	45.6	43.2
34	17) Hingni Buzrug	76°49'59.91"	21°06'03.20"	9710	2620	37.6	14.4	2.4	4.0	78.3	84.8	20.5	11.2	112.0	108.0	4.9	2.4	66.1	82.1	24.7	39.5	-19.5	-7.2	2.0	4.6	6.0	21.7
35	19) Kavasa	77°03'13.35"	20°57'47.92"	2000	260	6.3	5.0	3.4	5.0	1.5	1.4	11.2	9.8	2.4	3.0	0.4	2.5	13.4	12.1	1.0	0.9	1.6	-0.2	0.2	0.1	34.8	50.4
36	20) Patsul	77°01'18.44"	20°58'0.63"	310	3010	2.5	2.4	2.3	3.0	6.5	5.7	9.3	6.3	1.5	0.9	2.8	4.2	57.4	50.7	6.0	4.8	4.5	0.9	1.4	1.0	48.3	55.9
37	21) Aalewadi	77°01'05.51"	21°59'24.53"	3500	1370	8.8	12.0	1.6	1.6	28.7	33.9	9.8	29.3	21.6	21.6	0.4	2.3	73.3	71.3	17.8	18.4	-0.6	15.7	2.8	2.5	15.4	11.7
38	22) Bolegaon	77°02'10.08"	21°02'0.85"	1060	700	0.8	3.0	3.2	2.4	14.3	28.7	19.0	38.1	2.4	7.1	1.3	1.9	78.1	84.0	14.3	24.6	15.0	32.6	3.6	5.3	80.0	44.2
39	23) Mundgaon	76°59'23.69"	21° 03'25.54"	1600	360	2.2	1.4	1.5	3.0	27.0	33.0	35.1	41.5	4.1	4.9	2.1	1.4	87.5	88.0	27.8	31.5	31.4	37.1	7.2	7.5	40.5	67.3
40	24) Chota Bazar	77°00'13.54"	20° 55'36.01"	900	830	5.7	4.8	3.1	3.3	3.0	2.8	9.8	9.8	2.6	2.6	0.4	0.3	25.4	25.6	2.0	2.0	0.9	1.7	0.3	0.3	35.4	40.6
41	102) Akot	77°03'36.97"	21°05'44.46"	570	800	2.4	5.4	3.0	2.5	3.0	8.3	9.8	18.5	0.9	3.6	0.2	0.1	35.8	51.3	2.6	5.9	4.3	10.7	0.6	1.1	55.9	31.7
42	103) Adgaon Buzrug	76°58'18.22"	21°06'51.83"	660	2020	2.0	2.4	2.2	8.4	7.0	5.0	13.2	13.7	1.0	1.2	0.4	0.5	62.0	31.6	6.8	3.0	8.9	2.9	1.6	0.5	52.8	77.8
43	28) Varud Buzrug	76°54'15.95"	21°03'02.18"	440	570	1.4	2.2	1.8	19.0	9.6	12.2	13.7	36.4	0.8	2.3	0.3	0.4	74.7	36.4	10.7	5.3	10.5	15.2	3.0	0.6	55.0	89.4
44	29) Ghodegaon	76°52'46.16"	21°02'38.29"	1320	640	15.6	0.6	4.0	9.4	13.0	13.5	29.8	13.7	11.6	14.3	0.4	2.1	39.9	57.4	5.9	8.5	10.2	3.7	0.7	1.3	20.3	94.0
45	30) Thar	76°51'41.78"	21°00'26.03"	670	1000	4.4	2.7	1.8	13.7	7.0	6.5	14.6	23.7	1.0	1.4	0.6	0.4	52.0	28.4	5.6	3.2	8.4	7.3	1.1	0.4	29.5	83.4
46	32) Umberkheda	76°53'23.81"	20°56'49.18"	900	420	1.3	2.4	6.5	25.6	35.2	30.0	41.5	39.0	12.8	13.6	3.1	2.5	81.9	51.7	25.3	11.3	33.7	11.0	4.5	1.1	83.5	91.4
47	33) Ner	76°55'44.28"	20°53'48.34"	2430	3210	4.0	3.2	0.8	2.4	33.9	29.9	34.2	24.4	13.2	14.2	2.5	3.0	87.6	84.2	31.0	25.2	29.4	18.8	7.1	5.3	16.6	42.9
48	168) Sangwi Hiware	76°56'46.52"	20°53'56.05"	3210	3330	15.3	17.5	7.0	6.6	73.9	69.6	54.7	48.8	49.6	52.4	3.1	2.9	76.5	74.1	31.3	28.4	32.3	24.7	3.3	2.9	31.5	27.5
49	169) Asadpur	77°28'57.65"	21°05'07.68"	3220	640	4.2	4.9	3.8	10.6	5.2	5.4	3.1	4.9	13.6	15.2	0.8	0.6	39.4	26.0	3.7	2.8	-4.9	-10.6	0.7	0.4	48.0	68.4
50	34) Murtijapur	77°22'09.68"	20°44'41.29"	3000	490	36.0	20.0	4.0	3.2	11.7	26.1	43.9	34.6	8.0	25.4	0.8	2.4	22.6	52.9	3.7	10.8	3.9	11.5	0.3	1.1	10.0	13.7
51	35) Malkapur	77°26'38.40"	20°44'40.02"	790	620	4.2	5.2	3.4	4.0	1.5	1.4	9.8	9.8	1.3	1.5	0.8	0.7	16.2	13.1	1.1	0.9	2.2	0.6	0.2	0.2	44.2	43.5
52	36) Jamti Buzrug	77°29'49.99"	20°43'38.86"	500	460	6.4	3.9	2.4	4.9	1.2	1.2	7.8	11.7	0.8	1.4	1.1	0.7	11.7	11.7	0.8	0.8	-1.0	2.9	0.1	0.1	27.3	55.5
53	37) Hadiyapur	77°36'53.33"	20°46'25.06"	700	570	5.5	6.0	3.0	6.4	1.4	1.1	8.8	12.7	0.8	1.7	1.4	1.4	14.1	8.3	1.0	0.6	0.3	0.3	0.2	0.1	35.8	51.6
54	40) Kholda	77°33'04.08"	20°49'26.92"	1730	1290	13.0	9.6	4.6	8.8	9.1	8.3	22.0	25.9	8.0	8.4	3.5	2.0	34.1	30.9	4.4	3.9	4.4	7.5	0.5	0.4	26.4	47.8
55	42) Hiwara	77°29'52.12"	20°49'39.99"	1610	2510	2.3	2.0	1.8	0.6	28.7	33.9	42.9	40.0	1.2	1.5	0.3	0.7	87.4	92.9	28.4	42.4	38.9	37.5	7.0	13.2	43.2	21.9
56	43) Shelubazar	77°29'01.46"	20°51'16.55"	1600	1110	3.3	3.2	2.4	2.8	5.2	1.6	8.8	9.3	1.2	0.5	1.3	0.3	47.7	20.7	4.4	1.3	3.1	3.3	0.9	0.3	42.3	46.7
57	45) Borta	77°27'44.09"	20°49'40.64"	1360	640	2.0	2.4	1.2	0.4	26.1	26.1	36.6	31.7	1.2	1.4	1.2	0.6	88.9	90.2	29.2	31.2	33.4	28.9	8.1	9.3	37.5	14.4
58	46) Brahmi Khurd	77°26'01.07"	20°47'52.81"	800	1400	2.2	3.8	3.1	7.8	10.4	8.7	18.5	24.9	0.8	0.9	1.4	1.0	66.3	42.8	9.1	5.1	13.3	13.3	2.0	0.7	59.1	67.6
59	47) Hirpur	77°24'05.29"	20°46'05.02"	810	1500	2.2	2.4	3.3	1.6	10.4	10.9	13.7	17.1	0.7	0.8	3.6	1.0	65.5	73.0	8.9	10.9	8.2	13.1	1.9	2.7	60.3	40.0
60	48) Tiptala	77°24'57.14"	20°48'05.16"	1200	4220	6.3	2.4	3.5	3.0	11.7	11.3	13.7	7.3	10.3	10.4	2.4	3.4	54.4	67.1	7.5	9.7	3.9	1.9	1.2	2.1	36.0	55.9
61	49) Khaparwada	77°25'23.46"	20°50'17.44"	1700	1060	16.0	2.4	2.4	3.2	27.8	23.0	46.8	34.2	3.2	3.0	3.5	2.3	60.1	80.1	13.0	19.5	28.5	28.6	1.5	4.1	12.9	57.2
62	50) Durgwada	77°23'28.29"	20°50'30.02"	4950	6360	2.4	4.0	25.6	20.9	47.0	24.3	48.8	31.7	21.8	13.8	1.9	2.2	62.5	49.4	17.7	9.8	20.8	6.8	1.7	1.0	91.3	83.9
63	52) Bhatora	77°17'55.22"	20°49'55.38"	2230	630	17.7	19.2	3.1	1.6	10.9	67.8	19.5	31.2	11.8	66.0	2.7	2.2	34.2	76.4	4.8	29.8	-1.3	10.5	0.5	3.3	14.9	7.6
64	53) Sawangi	77°23'53.96"	20°50'41.94"	1460	460	4.2	3.2	1.4	3.2	24.3	27.8	34.2	39.0	0.1	3.2	2.8	2.3	78.5	81.2	20.6	22.0	28.6	32.6	4.3	4.3	25.7	50.0
65	54) Virwada	77°12'48.36"	20°51'32.89"	1570	3200	2.4	3.6	0.9	1.2	23.5	23.5	30.7	31.7	2.8	3.7	0.8	2.3	87.6	82.9	25.9	21.4	27.5	26.9	7.2	4.9	26.8	25.0
66	55) Kodka	77°15'32.94"	20°44'30.93"	570	1520	3.2	3.6	2.8	2.8	7.0	6.5	12.2	12.7	1.6	3.0	2.9	0.6	53.6	50.4	5.7	5.2	6.2	6.3	1.2	1.0	46.7	43.7
67	56) Palso	77°13'51.09"	20°46'31.71"	2280	2410	4.9	3.6	1.6	3.8	29.6	30.4	41.5	43.4	5.2	5.5	2.3	2.4	81.8	80.3	23.2	22.4	35.0	36.1	4.6	4.1	24.7	51.1
68	57) Maisang	77°11'18.62"	20°51'09.14"	1400	1340	9.1	11.9	9.4	8.1	27.8	26.1	45.4	40.5	6.3	6.8	2.9	2.3	60.1	56.6	13.0	11.7	27.0	20.5	1.5	1.3	50.8	40.4

Table 1(a). *(Continued.)*

Sl. no.	Village name	Longitude	Latitude	EC		Ca		Mg		Na		HCO_3		Cl		SO_4		Na%		SAR		RSC		KR		MR	
				Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
69	59) Aapatapa	77°06'49.21"	20°48'45.60"	1000	4850	35.3	32.2	3.1	5.4	95.7	91.3	24.4	19.5	12.6	12.8	3.1	2.9	70.9	69.7	30.9	29.8	14.0	-18.1	2.5	2.4	8.1	14.4
70	61) Sukodi	76°59'20.67"	20°45'58.36"	2260	2600	6.7	9.1	10.1	2.9	27.0	26.1	26.8	33.2	13.6	12.8	2.4	2.7	61.5	68.3	13.2	15.0	10.1	21.2	1.6	2.2	60.1	24.3
71	62) Sawanga	76°59'08.59"	20°50'11.18"	1500	1600	7.4	3.2	32.6	4.0	26.1	23.5	48.8	19.5	1.7	5.9	2.9	2.4	39.1	76.5	8.3	17.5	8.8	12.3	0.7	3.3	81.6	55.6
72	63) Agar	76°57'0.52"	20°49'59.46"	1200	10000	10.0	17.6	2.0	4.0	145.2	172.2	65.9	57.6	122.0	140.0	3.1	2.4	92.2	88.5	83.8	74.1	53.9	36.0	12.1	8.0	16.7	18.5
73	65) Kajikhed	76°42'17.47"	20°55'01.89"	1820	1800	5.6	9.4	0.2	4.0	31.3	15.2	39.0	19.0	8.3	12.4	1.1	1.9	84.2	53.2	25.9	8.3	33.2	5.7	5.4	1.1	4.1	30.0
74	66) Mokha	76°44'51.22"	20°55'25.78"	1430	1600	2.6	1.9	1.6	4.1	21.7	29.1	22.9	36.6	3.7	3.8	1.7	1.5	83.8	82.8	21.3	23.8	18.8	30.6	5.2	4.9	37.6	68.0
75	67) Nimba	76°46'07.87"	20°53'13.27"	1800	1290	1.8	2.2	8.8	0.4	26.1	16.5	39.0	18.5	3.8	4.0	1.9	2.3	71.1	86.5	16.1	20.6	28.5	16.0	2.5	6.4	83.0	15.7
76	69) Zural	76°49'45.03"	20°48'24.04"	3100	2150	4.0	17.6	10.4	6.0	10.4	8.3	7.3	19.5	17.2	18.0	2.8	2.3	41.7	25.9	5.5	3.4	-7.1	-4.1	0.7	0.4	72.2	25.4
77	70) Hatrun	76°53'35.79"	20°50'48.06"	2210	1650	2.5	2.0	10.4	3.2	33.9	27.8	43.9	24.4	9.7	7.6	2.9	2.3	72.4	83.9	18.9	24.4	31.0	19.2	2.6	5.3	80.6	61.6
78	71) Khandala	76°52'43.98"	20°46'23.33"	1760	1830	4.0	11.1	3.4	3.4	17.0	17.0	23.4	24.9	7.2	11.5	0.6	2.4	69.6	53.9	12.5	8.9	16.1	10.4	2.3	1.2	45.6	23.4
79	72) Nimkarda	76°52'18.20"	20°44'59.12"	820	780	4.2	3.7	4.0	4.5	6.1	7.8	12.2	17.1	2.0	2.4	0.7	0.8	42.6	48.8	4.3	5.5	4.0	8.9	0.7	1.0	48.5	54.7
80	170) Nimkarda	76°52'9.403"	20°44'28.29"	1950	1700	5.0	5.0	1.0	2.3	23.5	21.5	34.2	31.7	2.3	1.9	2.9	2.6	79.5	74.6	19.2	16.0	28.2	24.4	3.9	3.0	16.7	31.3
81	73) Khiroda	76°41'00.70"	20°56'26.22"	1270	1080	2.2	4.0	1.5	1.6	15.7	16.1	18.5	26.8	3.2	2.8	0.3	0.8	80.5	74.1	16.1	13.6	14.8	21.2	4.2	2.9	40.5	28.5
82	74) Jastagao	76°40'48.04"	20°58'50.66"	900	8000	1.0	2.4	7.6	1.4	10.4	9.3	21.5	9.8	2.0	2.4	0.9	0.8	54.7	71.2	7.1	9.6	12.8	6.0	1.2	2.5	88.4	36.1
83	76) Khandwi	76°28'24.83"	20°50'50.60"	1700	1800	2.0	5.7	1.8	4.0	17.0	15.9	15.1	19.5	8.8	10.4	0.7	0.6	81.7	62.2	17.5	10.2	11.4	9.9	4.5	1.7	46.8	41.2
84	77) Godegaon	76°31'37.02"	20°58'02.82"	1100	980	2.4	2.4	3.5	2.0	15.7	9.6	23.4	11.7	3.6	4.0	1.0	0.9	72.5	68.3	12.9	9.1	17.5	7.3	2.6	2.2	59.5	45.5
85	79) Mudakhed	76°35'27.69"	20°58'50.89"	2340	800	4.0	3.5	2.2	3.3	15.2	11.3	9.8	12.2	13.9	2.5	1.0	2.4	71.0	62.4	12.2	8.7	3.6	5.4	2.5	1.7	35.5	48.3
86	80) Rudhana	76°36'57.47"	21°00'51.20"	620	510	4.0	4.9	1.3	5.1	2.2	2.0	6.3	9.8	1.9	2.0	0.6	0.5	29.0	16.3	1.9	1.2	1.1	-0.2	0.4	0.2	24.3	50.6
87	81) Nimgao	76°28'50.49"	20°52'13.76"	790	1400	2.2	3.6	3.6	4.3	7.8	8.3	13.2	13.2	2.3	1.3	0.8	1.2	57.2	51.0	6.5	5.9	7.3	5.3	1.3	1.0	61.6	54.0
88	82) Hingni Buzrug	76°21'34.96"	20°54'50.06"	7120	6450	2.4	2.4	1.6	4.0	10.0	9.8	16.1	17.1	1.0	1.0	0.5	0.6	71.3	60.4	10.0	7.7	12.1	10.7	2.5	1.5	39.1	61.9
89	83) Kalegaon	76°17'44.20"	20°57'26.33"	810	620	4.4	6.8	3.6	0.4	8.0	6.5	14.6	11.2	2.4	2.2	0.4	0.5	50.1	47.5	5.7	4.9	6.6	4.0	1.0	0.9	45.0	5.6
90	84) Mominabad	76°19'26.82"	20°55'26.06"	810	760	5.0	5.6	3.0	1.7	15.7	17.0	23.4	22.0	3.2	4.0	0.9	2.4	66.1	69.8	11.1	12.6	15.4	14.7	2.0	2.3	37.5	23.1
91	86) Shegaon	76°41'25.76"	20°48'00.64"	700	820	3.0	4.9	15.0	3.3	8.7	7.0	18.5	12.2	5.6	4.5	2.9	1.4	32.6	46.0	4.1	4.9	0.5	4.0	0.5	0.9	83.3	40.4
92	87) Yaulkhed	76°38'52.40"	20°52'49.67"	7370	1000	10.0	10.6	4.4	13.0	99.1	135.7	44.4	31.7	86.0	136.4	3.0	2.3	87.2	85.1	52.2	55.9	30.0	8.1	6.9	5.8	30.6	55.3
93	88) Pahurpurna	76°39'56.55"	20°54'49.99"	1250	1000	4.0	4.8	0.4	3.2	31.7	34.8	31.2	39.0	14.0	9.7	3.3	2.9	87.6	81.2	30.3	24.6	26.8	31.0	7.2	4.3	9.2	40.0
94	109) Tiwali	76°34'30.12"	20°52'41.11"	1850	9000	2.8	3.2	2.8	0.9	17.0	13.0	20.5	15.1	4.4	4.1	0.3	2.1	75.1	76.0	14.3	12.9	14.9	11.0	3.0	3.2	50.0	21.6
95	89) Malkapur	76°11'58.67"	20°53'37.18"	1640	1290	3.0	4.9	6.6	7.1	10.0	9.1	12.2	12.2	6.6	6.5	2.4	2.1	51.0	43.1	6.5	5.3	2.6	0.2	1.0	0.8	68.8	59.5
96	92) Dasarkhed	76°10'54.13"	20°158'01.8"	1300	1100	5.4	5.3	5.8	3.8	6.5	7.4	16.6	12.2	3.2	3.8	1.5	1.6	36.7	44.6	3.9	4.9	5.4	3.1	0.6	0.8	51.8	42.0
97	93) Maiswadi	76°13'27.85"	20°58'26.18"	1500	1410	6.4	5.6	20.0	8.0	7.8	8.7	26.8	19.5	6.4	6.1	0.8	1.5	22.9	39.0	3.0	4.7	0.4	5.9	0.3	0.6	75.8	58.8
98	94) Narwel	76°13'53.48"	20°58'26.22"	3100	3900	2.0	3.2	2.0	24.0	52.2	30.4	48.8	63.4	3.1	2.5	2.9	2.7	92.6	52.7	52.2	11.7	44.8	36.2	13.0	1.1	50.0	88.2
			Average	**1756**	**1861**	**5.4**	**5.5**	**4.3**	**4.5**	**20.5**	**21.3**	**22.3**	**23.1**	**10.1**	**10.8**	**1.6**	**1.5**	**60.8**	**58.7**	**14.5**	**13.9**	**12.6**	**13.0**	**2.9**	**2.6**	**46.0**	**44.7**
			Minimum	**310**	**230**	**0.7**	**0.6**	**0.2**	**0.4**	**0.7**	**0.7**	**3.1**	**4.9**	**0.1**	**0.5**	**0.1**	**0.1**	**9.1**	**8.3**	**0.5**	**0.5**	**-19.5**	**-18.1**	**0.1**	**0.1**	**4.1**	**5.3**
			Maximum	**9710**	**10000**	**37.6**	**32.2**	**32.6**	**25.6**	**145.2**	**172.2**	**65.9**	**63.4**	**122.0**	**140.0**	**4.9**	**4.2**	**96.0**	**94.5**	**83.8**	**74.1**	**53.9**	**40.7**	**24.3**	**17.3**	**91.3**	**94.0**

Table 1(b). *Values of cations and anions in mili equivalent per litter (meq/l) from dug wells in pre- and post-monsoon periods of the year 2009.*

Sl. no.	Village name	Longitude	Latitude	EC		Ca		Mg		Na		HCO_3		Cl		SO_4		Na%		SAR		RSC		KR		MR	
				Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	1) Walgaon	77°42'32.35"	21°01'01.71"	800	610	4.8	4.0	6.4	2.9	3.9	4.8	15.9	9.8	2.7	2.3	0.8	1.0	25.9	40.9	2.3	3.6	4.7	2.9	0.3	0.7	41.9	57.2
2	112) Rewsa	77°43'19.47"	21°00'16.82"	1420	1290	6.4	5.6	6.4	8.0	10.9	13.9	22.0	30.7	2.5	3.5	1.0	2.4	45.9	50.5	6.1	7.5	9.2	17.1	0.8	1.0	58.8	50.0
3	113) Pusda	77°45'12.60"	21°05'04.18"	1090	780	2.7	4.4	6.1	5.6	3.5	4.8	12.2	13.2	1.6	1.6	0.9	2.1	28.2	32.2	2.3	3.0	3.4	3.2	0.4	0.5	56.0	69.1
4	131) Rewsa	77°43'19.47"	21°00'16.82"	1190	1360	3.0	4.8	3.8	1.2	17.4	27.0	24.4	36.1	0.9	1.1	2.5	2.3	72.0	81.8	13.4	22.0	17.7	30.1	2.6	4.5	20.0	56.0
5	158) Lomtek	77°42'38.63"	20°54'28.30"	1410	1300	2.6	3.0	6.6	5.0	11.3	12.2	18.0	22.0	2.7	2.9	0.5	1.1	54.9	59.9	7.5	8.6	8.8	13.9	1.2	1.5	62.4	71.3
6	7) Khartalegaon	77°37'24.43"	21°00'03.25"	1960	1450	6.0	12.0	5.6	13.7	43.5	54.8	8.8	37.6	45.0	54.0	2.4	2.4	68.7	65.8	25.5	21.6	-2.8	11.9	3.7	2.1	53.3	48.3
7	8) Maispur	77°34'11.35"	20°58'04.14"	4190	1450	2.0	3.6	5.6	3.2	20.9	26.1	17.1	36.1	6.3	5.5	3.0	2.1	73.2	79.3	15.1	20.0	9.5	29.3	2.7	3.8	47.1	73.7
8	9) Kholapur	77°30'46.13"	20°57'29.14"	1450	3750	1.8	22.4	27.0	1.7	31.3	33.9	24.4	34.6	29.6	31.2	2.9	2.4	51.1	57.1	11.7	13.8	-4.4	10.6	1.1	1.4	6.9	93.6
9	146) Darapur	77°30'21.44"	20°57'34.53"	2020	1580	7.5	8.1	2.7	2.4	13.5	16.5	17.1	18.3	9.6	11.0	3.0	1.9	56.9	61.1	8.5	10.2	6.9	7.8	1.3	1.6	22.9	26.7
10	148) Sakhari	77°37'40.23"	20°33'50.63"	1840	1260	1.0	1.0	1.4	1.2	30.4	23.5	31.7	31.7	0.9	1.0	0.4	1.0	92.3	90.8	39.3	31.4	29.3	29.5	12.7	10.5	53.6	60.0
11	6) Aasegaon Purna	77°34'27.90"	21°07'53.78"	1130	2500	4.2	2.0	1.8	4.3	8.7	7.8	12.2	9.8	1.6	1.4	1.7	4.4	59.1	55.5	7.1	6.3	6.2	3.5	1.4	1.3	68.3	30.7
12	118) Brhamanwada	77°43'46.54"	21°19'23.36"	600	400	2.2	2.5	2.1	7.8	1.0	1.2	3.7	8.5	1.2	1.8	0.5	0.5	19.4	10.3	1.0	0.7	-0.7	-1.7	0.2	0.1	75.8	48.2
13	120) Talpapur	77°33'10.41"	21°19'1.45"	620	310	2.1	2.2	2.2	6.6	1.0	1.1	2.4	9.8	0.6	0.8	0.6	0.5	18.7	11.0	1.0	0.7	-1.9	1.0	0.2	0.1	74.5	51.8
14	121) Kharpi	77°34'11.33"	21°20'8.74"	1930	610	2.4	2.5	2.0	6.4	1.2	1.2	4.9	10.5	1.1	1.0	0.4	0.4	21.0	12.0	1.1	0.8	0.5	1.6	0.3	0.1	72.1	45.5
15	133) Shahpur	77°48'21.41"	21°16'25.39"	800	850	4.0	3.4	1.6	3.8	13.9	13.0	24.4	24.4	1.0	1.2	0.4	0.5	71.2	64.3	11.8	9.7	18.8	17.2	2.5	1.8	52.2	28.5
16	134) Kural	77°40'42.54"	21°13'38.17"	560	710	4.0	3.6	0.8	4.1	5.7	5.9	9.8	16.6	0.5	0.7	0.2	0.4	53.7	43.3	5.2	4.3	5.0	8.9	1.2	0.8	53.1	16.6
17	137) Tondgaon	77°33'41.3"	21°15'5.71"	960	520	2.0	2.6	1.6	5.0	4.8	3.5	7.3	11.2	1.2	1.2	0.5	0.4	57.0	31.3	5.0	2.5	3.7	3.6	1.3	0.5	65.3	44.4
18	123) Achalpur	77°30'40.47"	21°15'23.26"	550	410	2.3	2.5	1.0	4.3	1.5	1.6	6.1	7.3	0.6	0.8	0.0	0.5	31.5	19.1	1.7	1.2	2.8	0.5	0.5	0.2	63.5	29.3
19	124) Tawalar	77°25'34.15"	21°14'27.72"	570	480	1.4	1.6	2.2	6.1	3.0	3.0	5.6	11.2	0.8	0.9	0.6	0.2	45.8	28.4	3.2	2.2	2.0	3.5	0.8	0.4	79.2	62.2
20	141) Kakada	77°25'48.31"	21°08'49.68"	2000	1530	7.1	2.2	2.8	1.9	10.9	15.7	15.9	24.9	2.8	1.4	0.3	0.3	52.2	79.0	6.9	15.4	6.0	20.7	1.1	3.8	46.1	28.3
21	12) Sanglud	77°17'19.22"	20°58'33.11"	3900	2200	20.1	16.0	6.3	5.3	40.4	37.8	30.5	50.8	27.3	22.0	4.8	3.9	57.9	60.3	15.7	16.4	4.1	29.5	1.5	1.8	25.1	23.9
22	13) Yavada	77°13'54.67"	21°00'22.24"	2530	2000	4.6	10.0	3.5	2.8	30.4	23.5	20.0	26.8	15.6	10.5	3.5	2.2	78.7	64.6	21.3	13.1	11.8	14.0	3.7	1.8	21.9	43.2
23	14) Ghodchindi	77°13'15.55"	20°57'45.92"	2100	1870	4.4	5.6	4.4	4.8	32.2	26.1	29.3	29.3	7.1	10.9	2.6	3.4	78.4	71.4	21.7	16.2	20.5	18.9	3.7	2.5	46.1	50.0
24	15) Wadaner Gangai	77°10'43.20"	20°03'35.51"	1910	1230	8.1	13.6	2.6	0.8	16.1	17.0	19.5	33.7	7.2	5.9	2.6	2.2	59.1	53.9	9.8	8.9	8.8	19.3	1.5	1.2	5.4	24.6
25	151) Samda	77°16'11.15"	20°54'37.5"	1400	690	3.1	1.0	3.4	5.5	13.5	113.5	12.2	29.3	11.2	10.4	2.6	2.3	67.5	94.5	10.6	88.6	5.7	22.7	2.1	17.3	84.2	51.8
26	152) Thilori	77°22'46.79"	20°54'32.97"	730	1800	2.6	2.6	4.2	1.8	10.9	10.0	17.6	14.6	1.8	1.8	2.1	2.4	59.7	66.3	8.3	9.4	10.8	10.2	1.6	2.2	41.1	62.3
27	156) Pimplud	77°11'35.00"	20°57'18.29"	6320	2300	2.4	15.2	3.3	3.2	9.1	7.4	6.1	12.2	28.0	13.6	2.8	3.1	60.3	28.7	7.7	3.4	0.4	-6.2	1.6	0.4	17.3	57.8
28	96) Kumbhargaon	77°17'57.55"	21°03'32.19"	3010	1230	5.3	5.1	1.6	2.1	11.3	12.2	12.9	19.5	2.8	2.4	1.7	2.2	62.0	62.8	8.6	9.1	6.0	12.3	1.6	1.7	29.0	23.2
29	99) AdgaonKhade	77°16'52.36"	21°07'28.88"	650	310	2.8	3.4	2.4	3.0	6.5	5.9	13.4	14.6	0.8	1.0	0.2	0.3	55.5	47.5	5.7	4.6	8.2	8.2	1.3	0.9	46.9	46.2
30	100) Karla	77°10'40.11"	21°09'1.12"	470	280	3.2	2.6	2.4	3.0	1.1	1.0	7.8	6.1	1.0	0.8	0.3	0.3	16.7	15.5	1.0	0.9	2.2	0.4	0.2	0.2	53.5	42.9

Table 1(b). *(Continued.)*

Sl. no.	Village name	Longitude	Latitude	EC		Ca		Mg		Na		HCO_3		Cl		SO_4		Na%		SAR		RSC		KR		MR	
				Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
31	126) AnjangaonSurji	77°18'41.79"	21°09'54.00"	480	540	2.0	3.2	2.8	6.6	1.7	1.7	3.9	7.3	6.4	0.7	0.4	0.4	26.0	14.4	1.5	1.1	-0.9	-2.4	0.4	0.2	67.2	58.3
32	128) Kapustalni	77°21'43.77"	21°06'25.42"	990	1060	3.8	1.5	4.5	2.9	10.9	7.8	22.0	13.7	2.4	1.1	0.3	0.2	56.8	64.0	7.6	7.5	13.7	9.3	1.3	1.8	65.5	54.4
33	18) Dharel	77°02'08.75"	20°54'59.59"	3180	900	4.2	12.0	7.9	1.6	44.3	31.3	51.2	29.3	20.8	22.0	1.8	2.3	77.6	69.1	25.4	17.0	39.1	15.7	3.6	2.3	11.7	65.1
34	101) Akoli Jahgir	77°7'0.49"	21°09'10.77"	410	560	2.4	2.3	3.3	5.2	1.5	1.6	7.3	8.8	1.0	0.9	0.0	0.1	21.1	17.2	1.3	1.2	1.6	1.3	0.3	0.2	69.2	57.8
35	26) Shirsoli	76°57'02.89"	21°04'50.12"	900	890	2.7	2.8	3.6	9.2	13.0	24.3	14.6	24.4	7.4	7.7	2.2	2.2	66.9	66.9	10.4	14.1	8.3	12.4	2.1	2.0	76.7	56.9
36	27) Pathrdi	76°56'11.11"	21°01'37.68"	2190	1860	11.5	12.0	2.0	18.0	17.4	17.0	31.7	49.3	10.4	11.6	0.4	2.0	56.3	36.1	9.5	6.2	18.3	19.3	1.3	0.6	60.0	14.9
37	31) Dhahigaon	76°51'28.71"	20°58'25.70"	740	2120	1.0	2.6	3.2	15.0	8.3	7.0	11.2	25.4	1.6	1.4	2.4	0.2	66.0	28.3	8.0	3.3	7.0	7.8	1.9	0.4	85.0	75.5
38	104) Hiwarkhed	76°51'29.44"	21°07'50.59"	590	1130	2.6	2.4	3.8	3.4	5.7	5.5	13.7	11.7	0.6	0.8	0.6	0.7	46.8	48.4	4.5	4.6	7.3	5.9	0.9	0.9	58.9	60.0
39	105) Danapur	76°47'15.99"	21°05'35.24"	490	2130	3.6	3.3	2.0	2.2	0.9	0.9	7.3	4.9	0.6	0.8	0.6	0.5	13.9	13.7	0.8	0.7	1.7	-0.6	0.2	0.2	39.7	35.7
40	106) Malegaon	76°47'32.91"	21°01'56.80"	470	2250	2.0	5.1	2.4	1.0	5.2	12.6	9.3	18.3	0.9	2.8	0.0	0.6	54.0	67.5	5.0	10.2	4.9	12.2	1.2	2.1	15.9	54.6
41	38) Kurum	77°34'32.40"	20°46'01.79"	570	1800	2.5	4.6	3.8	5.8	1.2	1.0	4.9	11.2	0.9	0.5	0.6	0.8	16.1	8.4	1.0	0.6	-1.4	0.8	0.2	0.1	55.4	60.8
42	39) Madhapuri	77°35'11.49"	20°47'49.91"	580	1620	2.2	2.4	3.8	6.4	6.1	0.9	9.8	9.8	1.3	1.1	2.1	0.5	50.2	9.0	5.0	0.6	3.8	1.0	1.0	0.1	72.7	62.7
43	41) Sonori Bapori	77°32'0.14"	20°49'39.31"	7340	460	28.5	2.4	6.1	1.2	33.9	33.9	25.9	39.5	54.0	6.8	3.1	2.3	49.2	90.3	11.5	35.7	-8.7	35.9	1.0	9.4	33.4	17.5
44	44) Aasara	77°30'05.98"	20°20'52.47"	3560	610	15.2	13.2	8.9	6.8	16.1	14.8	30.7	23.9	20.0	18.0	0.6	2.4	38.5	41.2	6.6	6.6	6.7	3.9	0.7	0.7	33.9	36.8
45	160) Chinchkhed	77°30'28.17"	20°45'2.38"	520	1900	2.3	2.4	6.9	6.4	1.5	1.3	7.3	9.8	1.0	0.8	2.5	0.4	14.1	12.5	1.0	0.8	-1.9	1.0	0.2	0.1	72.7	74.9
46	161) Murtizapur	77°22'4.97"	20°44'2.71"	3150	1520	12.4	11.5	4.8	6.2	8.7	8.5	4.9	4.9	23.2	22.4	2.1	2.3	33.5	32.3	4.2	4.0	-12.3	-12.8	0.5	0.5	35.3	27.9
47	58) Dapura	77°09'35.81"	20°49'33.20"	2830	4850	2.7	3.0	11.4	2.6	9.1	33.9	8.8	35.1	14.9	15.0	2.9	2.4	39.2	85.7	4.9	28.7	-5.3	29.5	0.6	6.1	45.7	80.7
48	60) Ghusar	77°03'11.19"	20°46'45.89"	5340	4850	4.0	12.5	6.6	4.3	34.8	34.8	11.2	2.4	40.4	38.4	2.9	2.9	76.3	67.1	21.4	17.0	0.7	-14.4	3.3	2.1	25.7	62.1
49	64) Walbhangar	76°59'59.91"	20°50'47.16"	700	760	10.0	6.3	2.0	11.3	10.9	13.0	14.2	9.8	12.0	24.8	2.7	2.1	47.4	42.5	6.3	6.2	2.2	-7.8	0.9	0.7	64.2	16.7
50	163) Palso Bade	77°13'47.40"	20°45'56.10"	3080	3400	0.8	11.9	4.0	9.4	30.0	26.1	29.3	53.7	13.6	9.7	2.9	2.6	84.5	54.0	27.4	11.3	24.5	32.4	6.3	1.2	44.0	83.3
51	164) Dahigaon	77°11'42.88"	20°45'46.08"	1880	1640	2.4	4.8	0.4	2.2	28.7	27.8	23.2	34.2	5.2	4.8	2.8	2.3	90.8	79.8	34.3	21.1	20.4	27.2	10.2	4.0	31.0	14.4
52	165) Ambicapur	77°8'49.123"	20°49'37.35"	1860	1150	2.4	1.7	15.1	1.5	32.2	28.3	39.3	31.7	7.2	8.0	1.9	2.6	64.7	89.5	15.4	31.2	21.8	28.4	1.8	8.6	46.9	86.1
53	166) Aapatapa	77°6'40.59"	20°48'17.39"	4600	3500	1.8	11.3	0.1	4.8	30.9	27.4	9.8	14.6	28.1	31.2	3.2	1.8	92.3	62.0	44.5	13.7	7.8	-1.5	16.0	1.7	29.8	6.4
54	167) Sangwi Mohad	76°59'29.13"	20°46'23.29"	1340	1250	1.4	15.1	7.5	3.3	31.3	27.0	36.6	39.0	3.0	6.2	3.3	2.7	77.0	58.9	21.0	12.6	27.7	20.7	3.5	1.5	17.9	84.2
55	75) Varwat Bakal	76°44'00.54"	21°02'15.06"	1190	900	8.0	5.5	0.4	3.4	10.0	12.2	12.2	21.0	6.0	4.7	1.9	1.4	54.2	57.9	6.9	8.2	3.8	12.2	1.2	1.4	38.1	4.8
56	78) Kurangaon	76°32'28.29"	20°59'15.02"	920	1260	2.6	2.4	17.4	1.2	11.3	12.6	25.9	16.1	2.0	4.1	2.0	0.8	36.1	77.7	5.1	13.3	5.9	12.5	0.6	3.5	33.4	87.0
57	85) Sawargawan	76°19'01.47"	20°50'02.15"	340	490	4.0	9.2	1.0	0.8	10.4	9.1	14.6	19.5	3.0	2.4	1.2	0.8	67.4	47.6	9.3	5.8	9.6	9.5	2.1	0.9	8.2	20.6
58	107) Mandwa	76°36'11.36"	20°46'51.41"	460	390	3.1	2.5	13.1	2.3	6.5	6.2	24.4	10.5	1.0	1.0	2.3	0.3	28.6	56.1	3.2	5.6	8.2	5.7	0.4	1.3	47.1	80.8
59	111) Nandura	76°27'35.38"	20°49'56.58"	2080	1730	4.0	15.2	3.9	1.2	11.3	15.2	7.3	27.8	12.2	11.5	3.0	2.2	58.7	48.1	8.0	7.5	-0.6	11.4	1.4	0.9	7.4	49.5
60	110) Jalamb	76°35'21.63"	20°48'55.55"	550	510	2.8	3.1	8.4	2.6	6.1	4.8	20.0	11.0	0.5	0.7	0.6	0.5	35.0	45.3	3.6	4.0	8.7	5.2	0.5	0.8	45.9	74.8
			Average	**1724**	**1402**	**4.6**	**6.0**	**4.7**	**4.6**	**14.2**	**16.2**	**16.4**	**21.0**	**8.6**	**7.8**	**1.6**	**1.5**	**52.2**	**50.5**	**10.0**	**10.9**	**7.1**	**10.4**	**2.0**	**2.1**	**46.4**	**49.7**
			Minimum	**340**	**150**	**0.8**	**1.0**	**0.1**	**0.8**	**0.9**	**0.9**	**2.4**	**2.4**	**0.5**	**0.5**	**0.0**	**0.1**	**13.9**	**8.4**	**0.8**	**0.6**	**-12.3**	**-14.4**	**0.2**	**0.1**	**5.4**	**4.8**
			Maximum	**7340**	**4850**	**28.5**	**22.4**	**27.0**	**18.0**	**44.3**	**113.5**	**51.2**	**53.7**	**54.0**	**54.0**	**4.8**	**4.4**	**92.3**	**94.5**	**44.5**	**88.6**	**39.1**	**35.9**	**16.0**	**17.3**	**85.0**	**93.6**

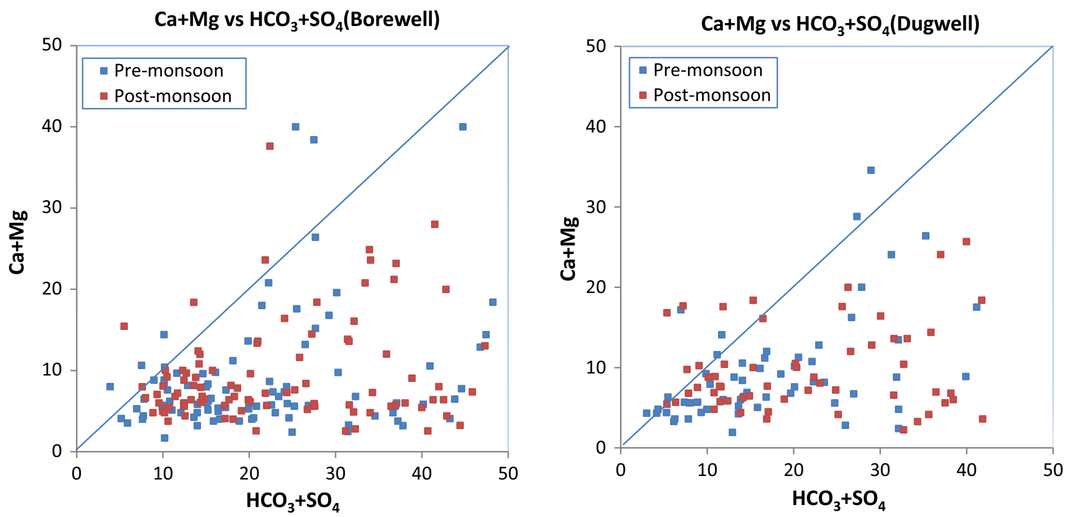

Figure 2. (Ca+Mg) *vs.* (SO_4+HCO_3) scatter diagram showing carbonate dissolution and silicate weathering.

Ca+Mg *vs.* HCO_3+SO_4 shows that majority of the samples collected during both pre- and post-monsoon periods from both shallow and deep aquifers lie below the equiline indicating more concentration of sulphate + bicarbonate than calcium + magnesium (figure 2). It is a common phenomena of sandy aquifers due to predominance of silicate minerals weathering there, in which, the increase of HCO_3 concentration is balanced by Na, as the silicate weathering is the prime mechanism to release the Na and HCO_3 ions (Subba Rao and Surya Rao 2010; Srinivasamoorthy *et al.* 2011). Excess concentration of HCO_3+SO_4 may occur due to the dissolution of silicate minerals present in sandstone and silt (Datta and Tyagi 1996; Elena *et al.* 2010; Isa *et al.* 2012; Srinivasamoorthy *et al.* 2014; Nageswara Rao *et al.* 2017; Jain and Vaid 2018). The HCO_3 may get derived from the dissolution of silicate minerals including orthoclase, plagioclase, hornblende, diopside, hypersthene, olivine and biotite of country rocks of the area by the carbonic acid (Srinivasamoorthy *et al.* 2011; Isa *et al.* 2012; Fadili *et al.* 2015; Nageswara Rao *et al.* 2017). Low concentration of points above the equiline exhibits minor phenomena of carbonate weathering (Datta and Tyagi 1996; Dehnavi *et al.* 2011). High concentrations of calcium and magnesium have also been detected in the groundwater of certain areas of the basin suggesting the phenomena of carbonate weathering. In such areas, Ca and Mg ions dominates over both bicarbonate and sulphate revealing release of carbonate minerals due to dissolution of calcretes from the host rock, e.g., present basin (Srivastava and Parimal 2014), Ganga basin (Saha *et al.* 2010), and Godavari basin (Nageswara Rao *et al.* 2017). High concentrations of calcium and magnesium ions in groundwater may result due to leaching processes of limestone, dolomite, gypsum and anhydrites (Katz *et al.* 1997; Srinivas *et al.* 2013; Nageswara Rao *et al.* 2017). During infiltration or, along the flow, the groundwater may dissolve $CaCO_3$ and $CaMg(CO_3)_2$ present in the rocks that increases the concentration of calcium ions in the same (Saha *et al.* 2008, 2010; Dehnavi *et al.* 2011; Sarkar and Shekhar 2015).

Medium to high quantities of both Na and Cl are also recorded in the groundwater, hence, the Na/Cl plot is also used to identify ion exchange processes. The scatter diagram of Na and Cl shows that majority of the samples during pre- and post-monsoon periods for both the aquifers fall below the equiline (figure 3). In ion exchange processes, Na/Cl ratio >1 indicates the role of silicate weathering as source of sodium and ratio <1 indicates excess chloride due to carbonate weathering, whereas, being equal to 1 indicates that dissolution of halite could be responsible for sodium ions (Meybeck 1987; Dongmei *et al.* 2009; Isa *et al.* 2012; Belgacem *et al.* 2013; Mondal *et al.* 2016). In the study area, sodium is noticed to be high during pre- and post-monsoon periods in both aquifers which may be due to the weathering of sodium bearing minerals like plagioclase and hornblende in the sediments (Meybeck 1987; Satyanarayana *et al.* 2016; Hussein 2017; Subba Rao 2018). The probable source of the high concentration of sodium may occur due to the addition of dissolved hydrated salts from the host strata (Srivastava *et al.* 2009).

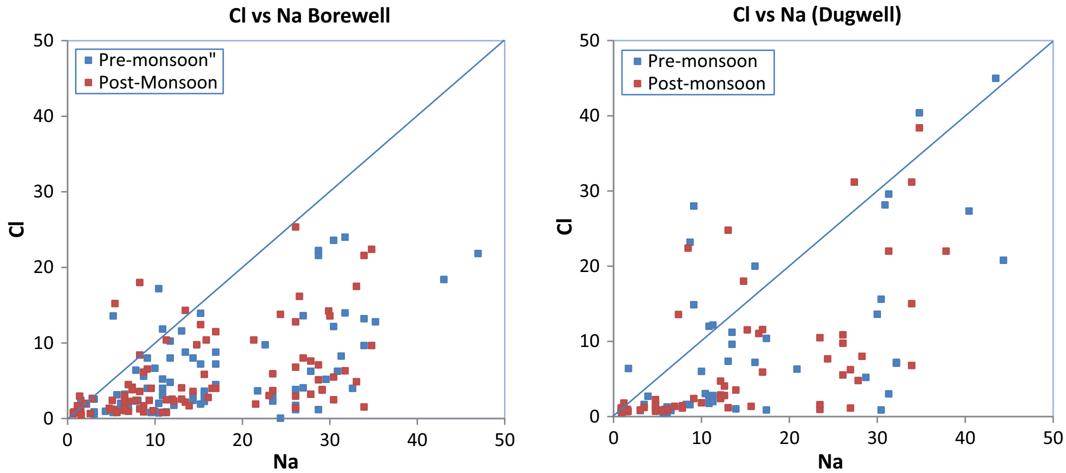

Figure 3. Na *vs.* Cl scatter diagram showing high concentration of Cl as compared to Na indicating silicate weathering.

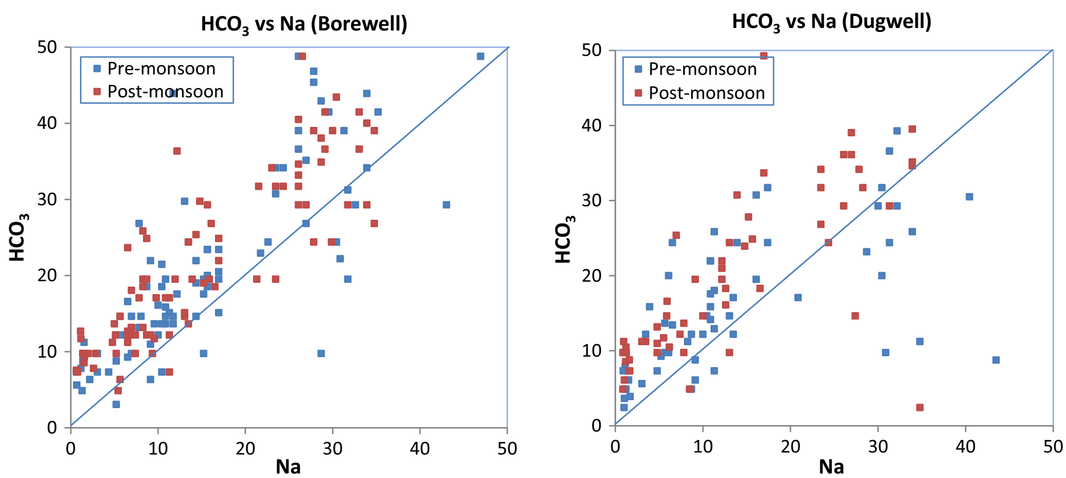

Figure 4. Na *vs.* HCO_3 scatter diagram showing high concentration of HCO_3 as compared to Na indicating silicate weathering.

Chloride is abundant in certain parts of area during pre- and post-monsoon periods. This may be either due to the dissolution of minor chloride bearing minerals or excessive use of chloride rich fertilizers (Todd 1980; Meybeck 1987; Li *et al.* 2016; Subba Rao 2018).

The plot of Na *vs.* HCO_3 shows that most of the groundwater samples are located above the equiline (figure 4). Bicarbonate is one of the most dominant ions among anion in the study area. According to Lakshmanan *et al.* (2003), ion exchange process tends to shift the points above the equiline due to silicate weathering. It may happen due to the increased concentration of HCO_3 indicating prevalence of silicate weathering (Dongmei *et al.* 2009). It is due to reduction of the sodium concentration in the groundwater because of ion exchange process (Isa *et al.* 2012; Srinivasamoorthy *et al.* 2014; Nageswara Rao *et al.* 2017).

The ratio of $Ca/Ca+SO_4$ is a criteria to evaluate the probable source of calcium in the groundwater. The ratio >0.5 indicates removal of calcium by ion exchange or calcite precipitation while <0.5 depicts calcium source rather than gypsum-carbonate or silicates (Rumy *et al.* 2009; Srinivasamoorthy *et al.* 2014; Fadili *et al.* 2015). In the study area, majority of groundwater samples exhibit >0.5 ratio during pre- and post-monsoon periods in both the aquifers, which indicates excessive sodium in water. However, a few samples, having <0.5 ratio indicates the calcium source rather than gypsum-carbonate or silicates. High calcium concentration may occur due to the presence of plagioclase feldspar in the sediment originating from surrounding igneous rocks and also from contamination by agricultural effluent (Al-Shaibani 2008; Srinivasamoorthy *et al.* 2011; Srinivas *et al.* 2013; Srivastava and Parimal 2014; Vasu *et al.* 2017).

Table 2. *Classification of groundwater samples on the basis of salinity and alkali hazards (Richard 1954).*

	Alkali hazard								Salinity hazard							
Water class	Excellent		Good		Fair/ medium		Poor/bad		Excellent		Good		Fair/ medium		Poor/bad	
SAR and EC	Up to 10		10–18		18–26		>26		Up to 250		250–750		750–2250		>2250	
Monsoon period	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Bore well (98 samples)	48	53	24	16	16	16	10	13	0	2	19	28	51	45	28	23
Dug well (60 samples)	41	37	9	14	6	5	4	4	0	1	15	23	30	35	15	3

In the present basin area, most of the subsurface sediments are sourced from areno-argillaceous Gondwana successions and basalt of the Deccan Trap. These sediments were deposited by Purna river system, forming thick alluvial deposit of Quaternary age. These deposits are also marked by interbeddings of laterally extended bands/beds of impervious clay in the vertical profile at various stratigraphic levels, making the alluvial deposit of heterogeneous nature (CGWB 1998; Siddiqui 2004). This heterogeneous nature of the alluvium has a control on physical and chemical compositions over the water retained in the same. Hence, quality analysis of the same for irrigation purpose has been made separately, which is based on various established parameter.

5.2 *Irrigation water quality*

The irrigation quality of groundwater is computed by various methods to evaluate its suitability. In the present attempt, the same has been interpreted with the help of SAR, EC, Na%, RSC, Kelley ratio and magnesium ratio.

5.2.1 *Sodium absorption ratio (SAR)*

Sodium is an important constituent for determining the quality of irrigation water. The excessive sodium content in the water reduces its permeability (Kelley 1946; Manjusree *et al.* 2009; Todd 2009; Nagaraju *et al.* 2014; Hussein 2017). It replaces adsorbed calcium and magnesium that have an adverse effect on the growth of plants as it directly affects the soil structure resulting in its compact and impervious nature (Srinivasamoorthy *et al.* 2009; Subba Rao and Surya Rao 2010; Chidambaram *et al.* 2011; Srivastava and Parimal 2014). Sodium hazards, expressed as SAR (sodium absorption ratio) is expressed as follows:

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

where, all ionic concentrations are expressed in meq/l.

The SAR value <18 indicates good quality water for irrigation; 18–26 fair medium to marginally suitable and >26 is unsuitable (Richards 1954). Table 2 shows that out of 98 samples each collected from deep aquifer during pre- and post-monsoon periods, 72 and 79 samples, respectively, fall under excellent to good category hence, suitable for irrigation. Similar results have been obtained for 50 samples in pre- and 51 in post-monsoon periods out of 60 samples collected from shallow aquifer. Rest of the samples, in both the aquifers during pre- and post-monsoon seasons exhibit marginally suitable to unsuitable category having SAR value more than 18. The sampling was restricted to central parts of the basin along both the sides of the Purna river channel, which is characterized by fine grained alluvial deposit having low permeability (Kale 2009; Srivastava and Kale 2018). Contour diagrams of SAR values for both the seasons show that ground water in both shallow and deep aquifers are suitable for most of the basin area, except a small patch in the center adjacent to the Purna river course (figure 6).

5.2.2 *Salinity hazard (EC)*

Electrical conductivity (EC) is the measure of capacity of a substance to conduct the electric current which depends upon temperature, concentration and types of ions present in the water (Todd 1980; Nag and Suchetana 2016). Water with high EC reduces the osmotic activity of plants and thus, interferes with the absorption of water and nutrients from the soil (Srinivas *et al.* 2013; Mondal *et al.* 2016). It also affects the salt intake capacity of the plants through the roots (Belgacem *et al.* 2013; Nagaraju *et al.* 2014). Based on EC values, Richards (1954) classified the groundwater for irrigation into four classes, i.e., excellent, good, fair to medium and bad. In the study area, most of the samples during both pre- and post-monsoon periods from deep and shallow aquifers fall under fair to medium category and are unsuitable for irrigation. However, the water of excellent to good categories in the range of <750 μS/cm exists during pre- (19 samples) and post-monsoon periods (30 samples) in deep aquifer whereas 15 and 24 samples in shallow aquifer during the same periods. The trend of EC for shallow aquifer in the basin area shows occurrence of excellent to good quality water in the northern, eastern and western parts, whereas, deep aquifer exhibits comparatively less area of the same water, restricted to northern part. Fair to medium and bad quality water occurs in central part of the basin is also interpreted by SAR contour map (figure 6).

5.2.3 *USSL Wilcox diagram*

The Wilcox diagram (1948) is used to describe the irrigation quality of groundwater of the basin area under investigation. The suitability of irrigation by groundwater can be understood by plotting the concentrations of SAR or alkali hazards and specific conductance EC or salinity hazards in the USSL diagram (Richards 1954). The diagram provides 16 classes depending upon the proportion of EC and SAR. The diagram classifies the water into C1, C2, C3 and C4 types on the basis of salinity hazard; and, S1, S2, S3 and S4 types on sodium hazard. The details of the same are as follows:

(a) On the basis of salinity hazard: C1 – low salinity water, can be used for irrigation with most crops on most soils, C2 – medium salinity water, can be used if a moderate amount of leaching occurs, C3 – medium to high salinity water, satisfactory for plants having moderate salt tolerance, can be used on soils of moderate permeability with leaching and, C4 – high salinity water, cannot be used on soils.

(b) On the basis of sodium hazard: S1 – low sodium water, can be used for irrigation on almost all soils with little danger for the development of harmful levels of exchangeable sodium, S2 – medium sodium water, can be used in fine-textured soils of high cation exchange capacity, especially under low leaching conditions, S3 – high sodium water, generally unsatisfactory for irrigation and, S4 – very high sodium water, unsatisfactory for irrigation purposes.

The USSL diagram (Wilcox diagram) (figure 5a and b and table 3) reveals that majority of the samples fall in the categories of C2S1 and C3S1 suggesting medium to high salinity and low SAR and C3S2, i.e., medium to high salinity and medium SAR in both the aquifers. It has also been noticed that a few samples falling in the categories of C3S4 and C4S4 during both pre- and post-monsoon periods are attributed with high salinity and medium to high sodium, therefore, unsuitable for irrigation. The samples falling in these categories are restricted in the central part of the basin having high values of SAR and EC. The quantitative analysis of samples in both deep and shallow aquifers indicates that most of the samples from shallow aquifer fall in C2S1 and C3S1 fields during both pre- and post-monsoon periods (table 3). The water of these fields exhibits medium to high salinity and low sodium, hence, suitable for irrigation to all types of soils.

5.2.4 *Percent sodium (Na%)*

The groundwater suitability for various purposes also depends on the chemical constituents present in it due to their release from host aquifer or from other sources. The exchange process of sodium in water for Ca and Mg in soil reduces the permeability and eventually results in soil with poor internal draining (Wilcox 1955; Srinivasamoorthy *et al.* 2009; Goyal *et al.* 2010; Tiri *et al.* 2011; Srivastava and Parimal 2012, 2014). It is significant in determining the quality of irrigation water which is usually denoted as percent sodium and can be determined using the following formula (Doneen 1962):

$$\mathrm{Na\%} = \frac{(\mathrm{Na^+})100}{(\mathrm{Ca^{2+}} + \mathrm{Mg^{2+}} + \mathrm{Na^+} + \mathrm{K^+})},$$

where, the quantity of Ca^{2+}, Mg^{2+}, Na^+ and K^+ are expressed in meq/l.

The classification of groundwater samples with respect to sodium percent is shown in table 4. It has been observed that most of the samples from deep aquifer have Na percentage more than 80 in both the seasons, hence, unsuitable for irrigation. Some of the samples from deep aquifer, showing

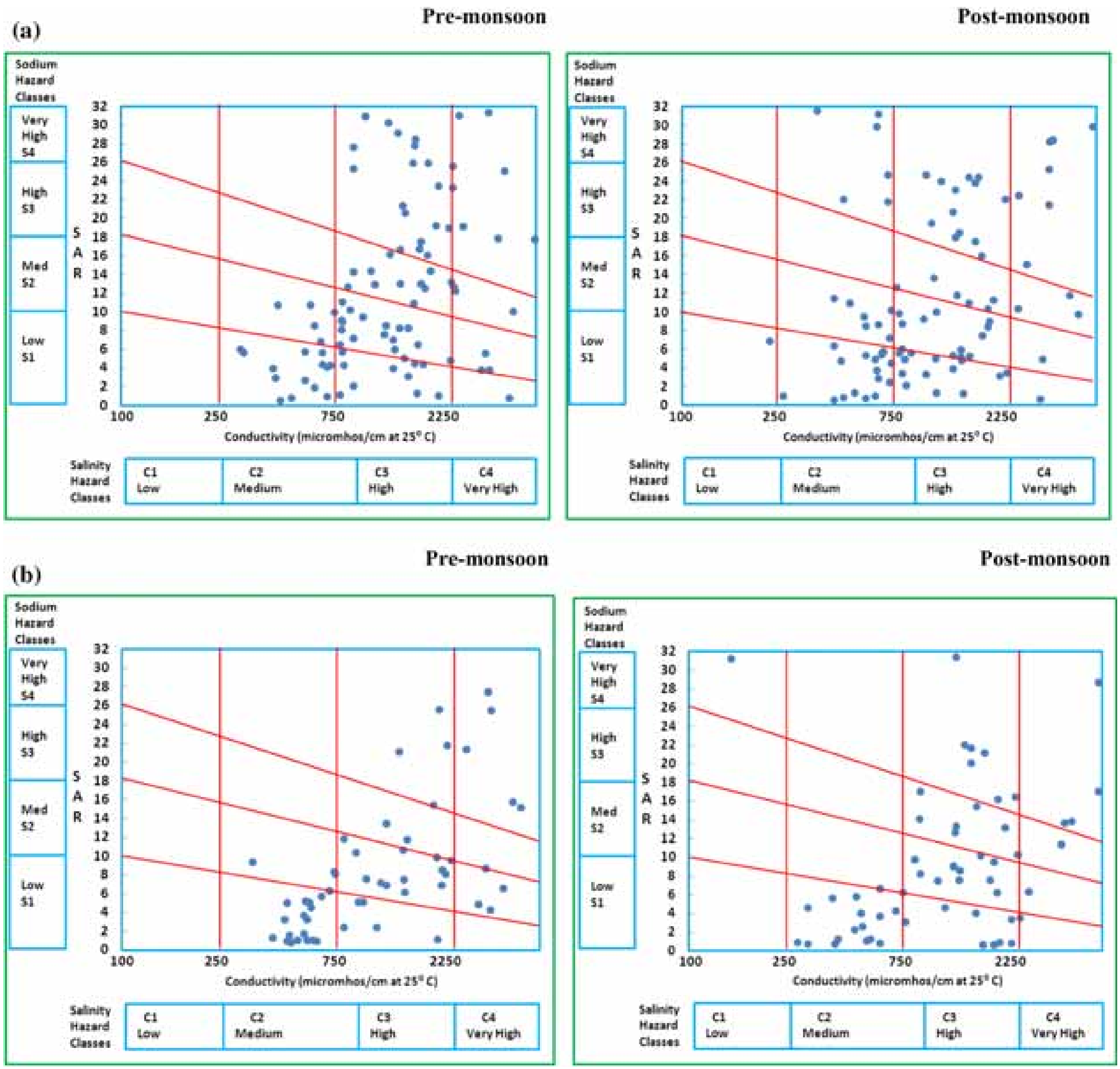

Figure 5. Classification of groundwater samples (USSLS 1954) collected from (**a**) bore well and (**b**) dug well during pre- and post-monsoon periods of the year 2009.

excellent to good water quality are located in northern part of the basin lying in both alluvial and basaltic regions. In shallow aquifer, most of the samples fall in permissible to doubtful category, hence, unsuitable for irrigation. Comparing the number of samples analyzed separately from both deep and shallow aquifers, it is evident that majority of the samples in the former are under doubtful to unsuitable category during both the seasons as compared to the shallow aquifer. It shows that deep water aquifer is more saline than the shallow aquifer. Todd (1980) proposed a limit of 60% as the maximum permissible limit of sodium percentage in groundwater. A comparative data of bore well and dug well reveals that the water from deep aquifer is more deteriorated as having high number of samples in doubtful to unsuitable categories than the shallow aquifer.

5.2.5 *Residual sodium carbonate (RSC)*

Residual sodium carbonate (RSC) is the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium and considered as an important parameter to measure the suitability of groundwater for irrigation (USSL 1954). The RSC values >2.50 indicate unsuitability for irrigation; the value from 1.25 to 2.50 are marginally suitable and <1.25 is suitable (Eaton

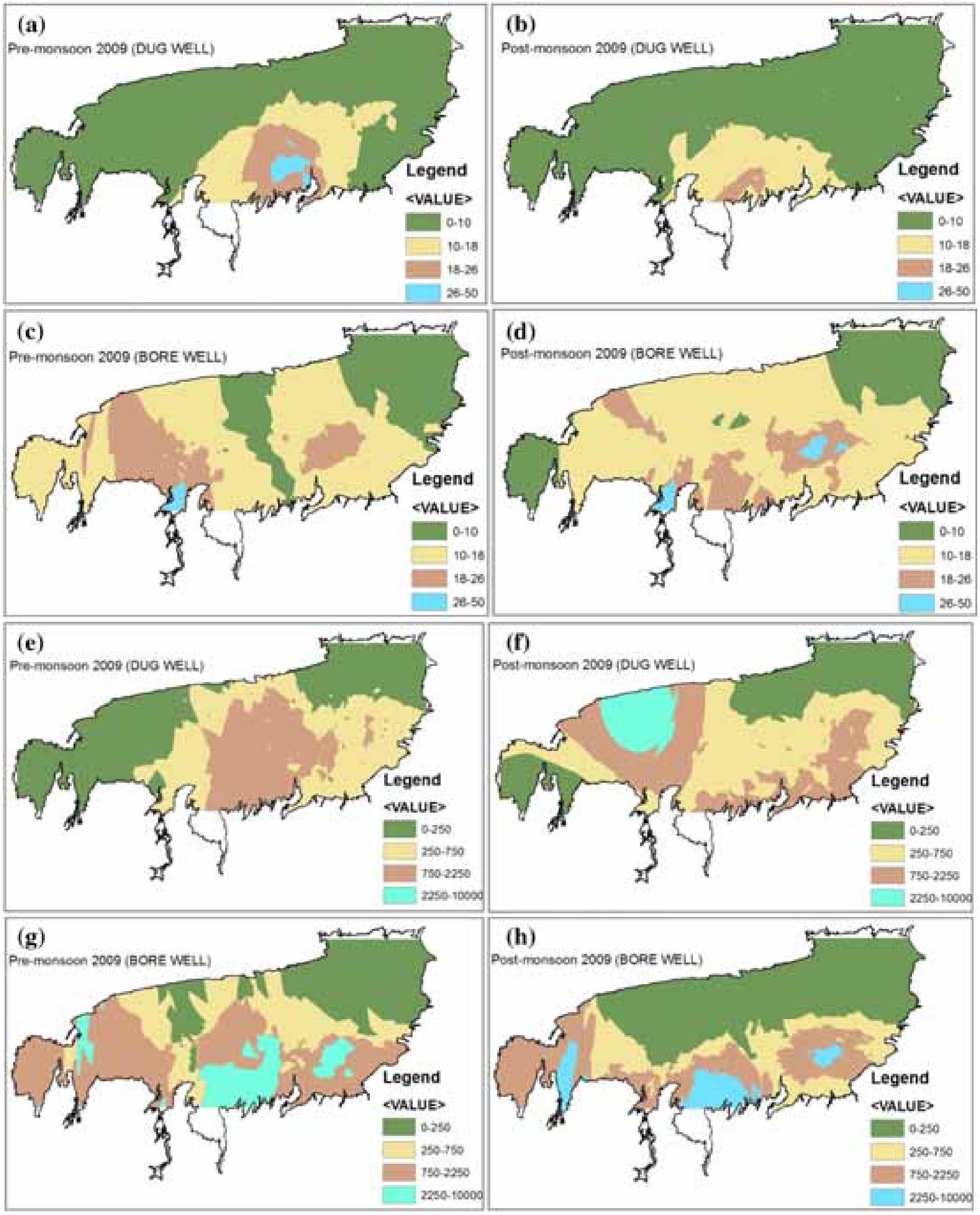

Figure 6. Contour maps showing spatial distribution of (**a–d**) sodium absorption ratio (SAR) and, (**e–h**) electrical conductivity (EC) and comparison of the same for pre- and post-monsoon periods of the year 2009.

1950; Raghunath 1987). RSC is calculated using the following equation:

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

where, all ionic concentrations are expressed in meq/l.

It has been observed that most of the groundwater samples, from both the aquifers, exceed the value of 2.50 during both pre- and post-monsoon periods that represent their unsuitability for irrigation (Eaton 1950) (table 4). Rest of the samples, particularly adjacent to the basaltic boundary in the north show values <1.25, hence, safe for irrigation (Eaton 1950) (table 4). In the waters having high concentration of bicarbonate, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated (Goyal *et al.* 2010).

In general, the groundwater from shallow aquifer is comparatively more suitable for irrigation than

Table 3. *Classification of groundwater samples on the basis of USSL diagram.*

Well type	Monsoon period	Water class											
		C1S1	C2S1	C3S1	C4S1	C2S2	C3S2	C4S2	C3S3	C4S3	C2S4	C3S4	C4S4
Bore well	Pre-	0	15	12	3	5	13	2	9	4	1	17	17
(98 samples)	Post-	1	16	18	1	7	7	1	6	4	4	13	20
Dug well	Pre-	0	18	10	0	3	8	3	3	2	0	3	10
(60 samples)	Post-	0	16	9	1	0	12	1	5	3	0	9	4

Table 4. *Classifications of groundwater samples from the study area based on sodium percent (Na%), residual sodium carbonate (RSC), Kelley ratio (KR) and magnesium ratio (MR).*

Parameters	Range	Classification	Number of samples			
			Bore wells		Dug wells	
			Pre-	Post-	Pre-	Post-
Sodium percent (Na%)	<20	Excellent	6	1	6	11
	20–40	Good	10	11	12	8
	40–60	Permissible	22	27	22	18
	60–80	Doubtful	38	29	15	18
	80 <	Unsuitable	25	23	5	5
	>1.25	Safe	15	12	14	14
	1.25–2.50	Marginally suitable	3	3	1	2
	>2.50	Unsuitable	80	83	45	44
Kelley ratio (KR)	>1	Suitable	27	27	22	27
	<1	Excess level	71	71	38	33
Magnesium ratio (MR)	>50%	Excellent	58	60	27	33
	<50%	Harmful for soil	40	38	33	27

deep aquifer as evident by higher percentage of samples falling in the suitable category from the shallow aquifer. The percentage of samples in unsuitable category is high in deep aquifer, indicating unsuitable nature for irrigation purpose.

5.2.6 *Kelley ratio (KR)*

Kelley ratio (KR) is also a measure of the sodium hazard on water quality for irrigation usage (Kelley 1940). He suggested that, the ratio >1 indicates excessive sodium in the water which is unsuitable for irrigation, whereas, <1 is suitable for irrigation. It is calculated by the following formula:

$$\text{Kelley ratio (KR)} = \text{Na}^{+}/\left(\text{Ca}^{2+} + \text{Mg}^{2+}\right),$$

where, all ionic concentrations are expressed in meq/L.

The values of Kelley ratio in the present study conclude that majority of groundwater samples exhibit more than one value during pre- and post-monsoon periods in both the aquifers. It indicates excessive sodium in water which is not suitable for irrigation (table 4). However, few samples, having less than one value indicates the good quality of water in shallow aquifer for irrigation.

5.2.7 *Magnesium ratio (MR)*

Magnesium is an important constituent for determining Kelley ratio and magnesium ratio and affects the water and soil quality depending on its concentration and association with other constituents. Mg and Ca ions are essential for plant growth and may also get associated with soil aggregation and friability (Khodapanah *et al.* 2009). In irrigation water, if the sodium is high, its ions tend to replace the magnesium as the clay particles absorb sodium and release magnesium and calcium (Srinivas *et al.* 2013). Magnesium hazard is categorized in <50 values to ensure safe and suitable quality of water, whereas >50 values are unsuitable for irrigation. High amount of magnesium in groundwater also have a negative effect on soil structure and permeability (Vasu *et al.* 2017). In the study area, <50 value has been observed for 58 samples in pre- and 60 samples in post-monsoon periods for deep aquifer and 27 and 33 samples, respectively, for shallow aquifer in the same region (table 4). Rest of the samples during pre- and post-monsoon periods for both the aquifers exhibits >50 value for magnesium concentration, therefore, unsuitable for irrigation use (Belgacem *et al.* 2013). The main source of magnesium in groundwater is considered due to its influx by dissolution of dolomite ($CaMg(CO_3)_2$) present in host rock (Raghunath 1987; Magesh *et al.* 2013; Nagaraju *et al.* 2014; Hussein 2017).

6. Conclusion

Both shallow and deep aquifers of Purna alluvial basin, Maharashtra have been studied for their weathering indices and suitability of water for irrigation purposes. The work is based on detailed hydrogeochemistry of total 158 groundwater samples, i.e., 98 from bore wells and 60 from dug wells, collected in both pre- and post-monsoon periods during the year 2009. The important conclusions drawn from the studies are as follows:

- The plots of Ca+Mg *vs.* HCO_3+SO_4 and Na *vs.* Cl scatter diagrams show that most of the sample points falls below the equiline, whereas Na *vs.* HCO_3 scatter diagram exhibits points above the equiline, hence, indicating together the prevalence of silicate weathering in the area.
- Bicarbonate is the dominant anion in the basin area. The scatter diagram of Ca+Mg *vs.* HCO_3+SO_4 shows that most of the samples from both shallow and deep aquifers fall below the equiline indicating high concentration of bicarbonate. Its high concentration in the groundwater is due to weathering of silicate minerals present in sandy-silty sediments of the basin area. The HCO_3 also gets derived from the dissolution of silicate minerals including feldspar, diopside, hypersthene, biotite of country rocks of the area by the carbonic acid.
- Irrigation water quality of the groundwater was determined by various parameters, i.e., %Na, SAR, EC, RSC, Kelley ratio and magnesium ratio. Spatial distributions of SAR and EC show that the groundwater in most of the area is suitable for irrigation except the central part of the basin adjacent to east–west course of Purna river.
- USSC diagram shows that most of the samples fall in C2S1 and C3S1 categories, hence, can be used for irrigation on almost all soils, however, some samples falling in C3S2 and C3S4 categories in the central part representing high SAR and EC indicate their unsuitability for irrigation.
- The groundwater in northern part of the basin represented mostly by basaltic region is comparatively good for irrigation as compared to the central part which is dominantly covered with the fine grain argillaceous sediments.

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