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Evaluation of Groundwater Quality and Its Suitability for Drinking and Agriculture Use: A Case Study of 06 Quality Affected Watersheds in Kolhapur District, Maharashtra, India

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Abstract

Groundwater is an important component of water resources for human survival and economic development in any regions of the world. Human activities and environmental change have imposed considerable impacts on groundwater quality. Thus the present studies were carried out for physico-chemical quality of groundwater with reference to their suitability for drinking and irrigation use. For this purpose 6 watersheds has been chosen (viz. KR 55, KR 63, KR 64, KR 66, KR 71 and KR 77) from Shirol, Gadhinglaj, Bhudargad and Radhanagari Talukas located in Kolhapur district, Maharashtra (India). Forty eight groundwater samples were collected and analysed their physico-chemical characteristics such as pH, EC, TDS, alkalinity, total hardness, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} , SO_4^{2-}, HCO_3^{-}, CO_3^{2-}, NO_3^{-}, F^{-} and Fe^{2+} to understand the sources of contaminant. The quality of the groundwater from the study area is mainly dominated by calcium bicarbonate type. The other dominant parameters is chloride in the groundwater from the study area due to disproportionate use of inorganic fertilizers, landfill leachate, septic tank effluents, animal feeds, industrial effluents and irrigation drainage. In general, hardness, calcium, magnesium and potassium in the groundwater samples from the study area is exceed the permissible limit prescribed by bureau of Indian standards. Based on the irrigation parameters (Sodium Adsorption Ratio and Residual soluble carbonate), the groundwater quality is assessed and the overall irrigation qualities of wells are demarcated as suitable for irrigation except few locations.

Keywords: Groundwater; geochemistry; watersheds; drinking water; irrigation hazards

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1. INTRODUCTION

A comprehensive investigation of the groundwater regime in any area or region should include a study of the hydrogeochemistry. Assessment and hydrogeochemical characterization of groundwater quality have been burning issue for the past decades as the awareness of groundwater quality protection arises. Problems to the nature because of heavy usage of fertilizers in the agricultural area for high growth lead becoming the groundwater and surface water sources as contaminated. There is a probability of altered groundwater quality in the abstraction structures like dug wells and bore wells. These further necessitate a systematic water quality monitoring and recognize the major pollutants in the studied areas. In recent years water contamination has been recognized as one of the major issues in world. The quality of groundwater is declining due to heavy industrialization and agricultural activities. According to World Health Organization (WHO, 1993) about 30 percent diseases are due to poor quality of drinking water.

The chemical alteration of meteoric water depends upon mineral species, duration of solid water interaction, dissolution of mineral species and anthropogenic sources (Fathy and Traugott, 2012). It is known fact that infiltration of effluents is responsible for the contamination of aquifers in different parts of India (Shivkumar et al., 1997; Mondal et al., 2005; Singh et al., 2011; Pujari et al., 2007; Naik et al., 2007; Khairy and Janardhana, 2013; Golekar et al., 2017; Golekar et al., 2014; Golekar et al., 2013a, b; Baride et al., 2014 and Mahadev et al., 2010). Therefore, it is necessary to study the quality of groundwater in terms of regular chemical parameters. Keeping in view the importance of water quality for drinking and agriculture use, the present study was designed. For water quality monitoring representative 48 stations has been selected in 06 different watershed areas (viz. KR 55, KR 63, KR 64, KR 66, KR 71 and KR 77) from Shirol, Gadhinglaj, Bhudargad and Radhanagari Talukas located in Kolhapur district, Maharashtra (India). Watershed wise distribution of water quality monitoring stations is shown in Table 1. Location map of the study area has depicted in Figure 1. Watershed wise distribution of water quality monitoring stations has shown in Figure 2, 3 and 4.

Table 1: Location details of groundwater quality monitoring stations in the study area

Well ID	WS No	Village	Latitude	Longitude	Altitude a MSL
1	KR 55	Kondigre	74° 30'	16° 44'	564 m
2	KR 55	Kondigre	74° 31'	16° 44'	581 m
3	KR 55	Jambhali	74° 34'	16° 43'	544 m
4	KR 55	Yedrav	74° 32'	16° 43'	548 m
5	KR 55	Yedrav	74° 32'	16° 43'	543 m
6	KR 55	Yedrav	74° 30'	16° 43'	560 m
7	KR 55	Haroli	74° 31'	16° 42'	557 m
8	KR 55	Nandani	74° 32'	16° 41'	544 m
9	KR 55	Nandani	74° 31'	16° 41'	539 m
10	KR 55	Nandani	74° 30'	16° 41'	550 m
11	KR 63	Shiradwad	74° 32'	16° 38'	563 m
12	KR 63	Shivnakwadi	74° 30'	16° 38'	583 m
13	KR 63	Lat	74° 29'	16° 39'	536 m
14	KR 63	Latwadi	74° 31'	16° 39'	550 m
15	KR 63	Herwad	74° 33'	16° 39'	544 m
16	KR 63	Kurundwad	74° 35'	16° 40'	540 m
17	KR 64	Ganeshwadi	74° 39'	16° 41'	549 m
18	KR 64	Malwadi	74° 38'	16° 40'	556 m
19	KR 64	Kavatheguland	74° 39'	16° 42'	549 m
20	KR 64	Gurwad	74° 37'	16° 42'	541 m
21	KR 64	Khidrapur	74° 35'	16° 35'	547 m
22	KR 64	Rajapur	74° 36'	16° 36'	551 m
23	KR 64	Takali	74° 37'	16° 38'	549 m

24	KR 64	Akiwat	74° 37'	16° 37'	543 m
25	KR 64	Danwad	74° 40'	16° 37'	551 m
26	KR 64	Danwad	74° 33'	16° 36'	544 m
27	KR 64	Ghosarwad	74° 35'	16° 36'	551 m
28	KR 64	Dattawad	74° 32'	16° 37'	545 m
29	KR 64	Takaliwadi	74° 34'	16° 36'	545 m
30	KR 66	Jalakewadi	74° 01'	16° 15'	687 m
31	KR 66	Adsulwadi	74° 01'	16° 17'	667 m
32	KR 66	Chaphodi	74° 01'	16° 18'	670 m
33	KR 66	Aini	74° 03'	16° 20'	679 m
34	KR 66	Auchitwadi	74° 02'	16° 21'	616 m
35	KR 66	Ategaon	74° 02'	16° 23'	549 m
36	KR 71	Anturli	74° 01'	16° 10'	590 m
37	KR 71	Tambale	74° 03'	16° 11'	595 m
38	KR 71	Kondoshi	74° 04'	16° 12'	583 m
39	KR 71	Kudtarwadi	74° 04'	16° 13'	587 m
40	KR 71	Nitwade	74° 06'	16° 15'	558 m
41	KR 71	Donwade	74° 06'	16° 17'	558 m
42	KR 77	Hasurwadi	74° 22'	16° 08'	717 m
43	KR 77	Naukud	74° 25'	16° 08'	682 m
44	KR 77	Narewadi	74° 24'	16° 09'	660 m
45	KR 77	Nandanwad	74° 26'	16° 09'	660 m
46	KR 77	Basarge Bk.	74° 27'	16° 11'	670 m
47	KR 77	Idargucchi	74° 29'	16° 11'	633 m
48	KR 77	Nangnur	74° 29'	16° 12'	626 m

WS stands for watershed code, m - meter, a MSL - above mean sea level

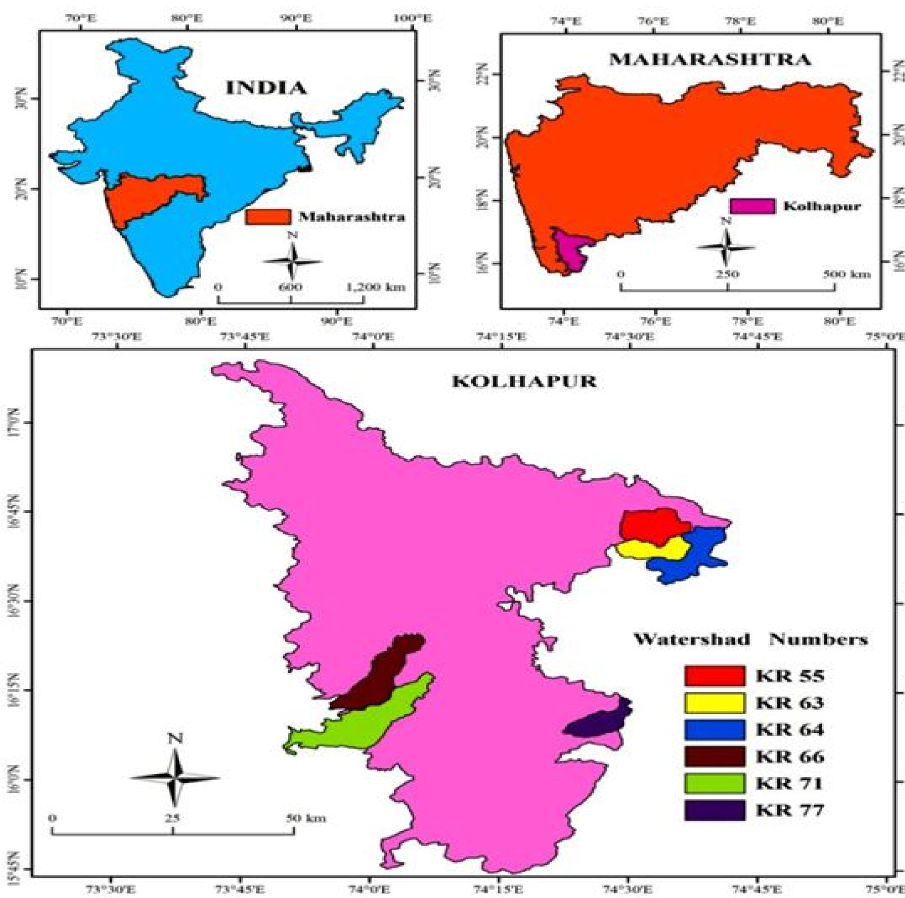

Fig. 1: Location Map of the study area

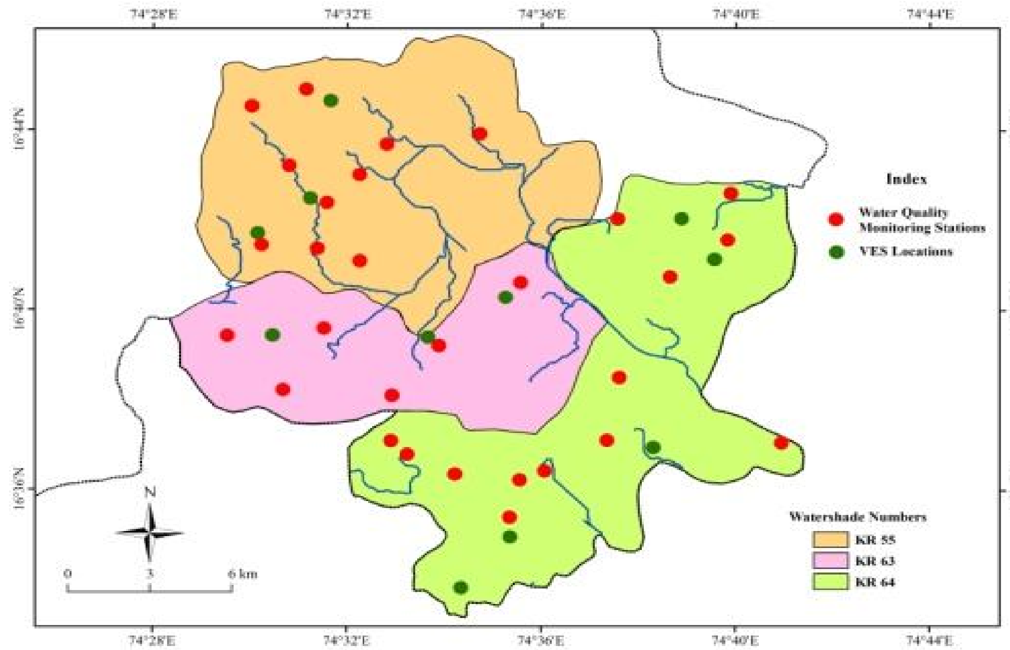

Fig. 2: Water Quality Monitoring stations in KR 55, KR 63 and KR 64 watershed

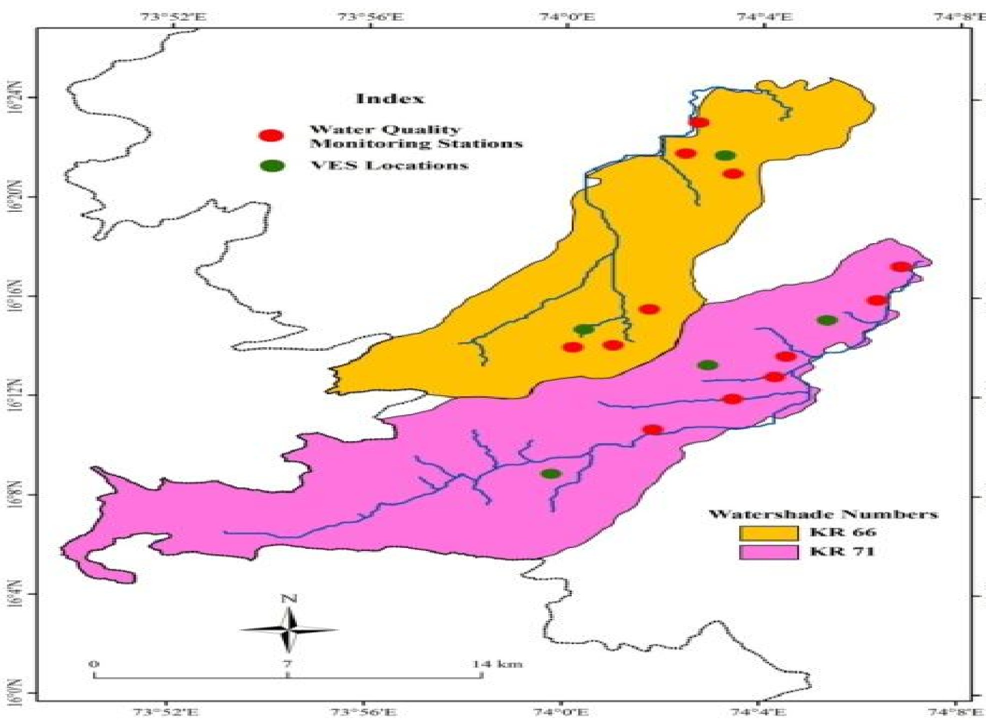

Fig. 3: Water Quality Monitoring stations in KR 66 and KR 71 watershed

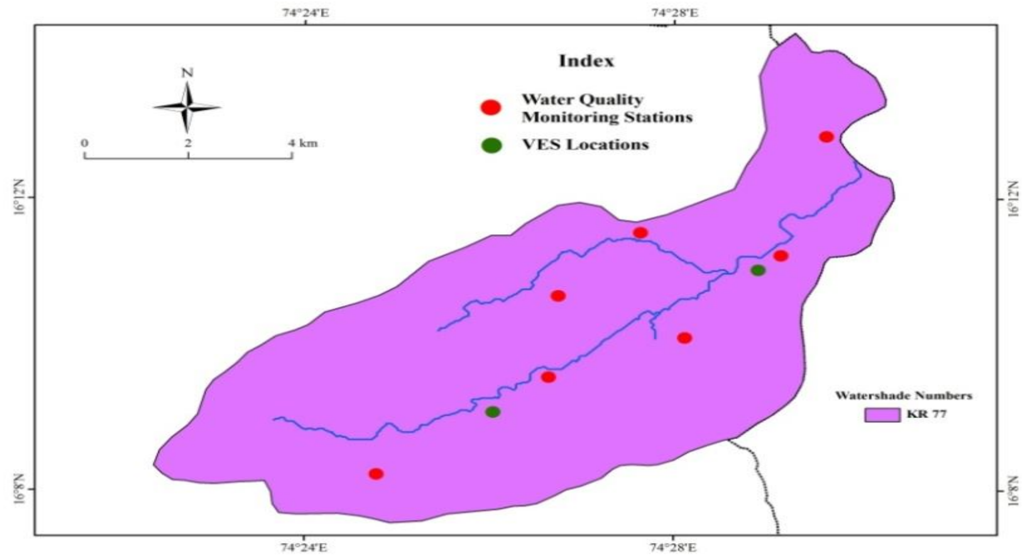

Fig. 4: Water Quality Monitoring stations in KR 77 watershed

1.1 Climate of the study area

There is a rapid increase temperature in March, reaching the maximum in April. April is the hottest month of the year, with mean maximum temperature of 37°C. Daily maximum temperatures exceeding 38°C are fairly frequent in April. The minimum temperature is occurs in the month of December it ranged from 14.5°C to 16°C. The average annual rainfall varies widely in the district from 500 mm in the North-East to 6350 mm in the west, this rainfall primarily from south-west monsoon.

1.2 Geology of the study area

In general, major portion of the Kolhapur district covers the 'Deccan trap' (Cretaceous to Eocene age); only in the southern extremities the rocks of the Dharwar (Archean age) and Lower Kaladgi series are exposed (Proterozoic Age). The stratigraphic succession of the Kolhapur district has depicted in Table 2.

Table 2: Stratigraphic succession of the Kolhapur District

Litho Unit	Age	Litho Unit
Deccan Trap	Cretaceous to Lower Eocene	Basalts
Kaladagis	Proterozoic	Shale and Sandstone
Dharwar	Achaean	Phyllite, Amphibolite , Granite and Gneiss

2. METHODOLOGY

The physico-chemical characteristics of collected groundwater samples were determined according to the standards procedure (APHA 1998). During every monitoring cycle, the groundwater samples were collected as per the standard sampling procedures. The groundwater samples for chemical analysis were collected in one litre polythene bottles. The bottles were washed for two to three times with the water to be sampled before collection. The water samples were collected during summer season (pre monsoon) and late rainy season (post monsoon) i.e. in the months of May (2009 and 2010) and October (2009 and 2010), respectively.

Electrical conductance, total dissolved solids and pH were analysed with the help of digital water analysis kit. Volumetric method was employed for the analysis of calcium, total hardness, total alkalinity and chloride from groundwater samples (APHA, 1998). Alkalinity was determined by simple acid base titration method (APHA, 1998). In this method, hydroxyl ions present in the sample as a result of dissociation or hydrolysis is determined by titration with strong acid like HCl using phenolphthalein and methyl orange as indicators used for determination of phenolphthalein alkalinity and total alkalinity, respectively. Total hardness and Ca^{2+} determined by standard EDTA (0.01 M) titrimetric method, $AgNO_3$ was used to estimate Cl^- and magnesium determined by difference in total hardness and calcium by calculation method. Sulphate was analyzed by spectrophotometer using ammonium molybdate and barium chloride solution (at 420 µm). Nitrate was analyzed by spectrophotometer using brucine sulphate solution (at 540 µm). Iron was analyzed by spectrophotometer using hydroxylamine hydrochloride, 1-10 phenanthroline and sodium acetate solution (at 508 µm). Interpretations of the water quality data were taking average concentration of two pre-monsoon seasons (2009-2010) and two post-monsoon seasons (2009-2010).

3. RESULT AND DISCUSSION

The groundwater quality results are presented in Table 3 (a, b) and 4 (a, b) for pre monsoon and post monsoon, respectively.

Table 3 a: Physico-chemical parameters of groundwater samples from the study area (Average Pre-monsoon)

Well ID	pH	EC	TDS	Hardness	Alkalinity	Ca^{2+}	Mg^{2+}	Na^+	K^+
1	7.50	1308	837.5	512	262	92.8	68.0	74.0	4.9
2	7.40	1671	1070	496	444	138.4	36.5	120.0	44.0
3	7.65	1720	1101	590	342	188.8	28.7	144.5	40.8
4	7.80	1125	720	568	202	116.8	67.1	53.5	1.4
5	7.55	1576	1008	576	190	147.2	50.5	57.5	10.4
6	8.05	1498	959	532	310	105.6	65.1	86.5	29.5
7	8.35	2414	1545	464	402	92.8	56.4	133.5	385.2
8	8.15	2093	1339	604	294	164.0	47.1	187.5	33.1
9	9.15	1570	1005	352	296	65.6	45.7	170.5	63.0
10	7.65	1676	1073	338	336	88.0	28.7	159.5	43.8
11	7.90	1234	789.5	544	136	162.4	33.5	56.0	1.2
12	8.05	1851	1185	614	306	166.4	48.1	101.0	16.0
13	7.55	1366	874	440	312	76.8	60.3	75.0	8.0
14	7.75	1604	1026	440	220	117.6	35.5	137.5	2.8
15	7.90	2400	1536	456	396	116.8	39.9	292.0	0.2
16	8.60	920	588.5	316	100	48.8	47.1	50.6	2.1
17	8.25	1809	1158	628	208	172.8	47.6	119.0	22.2
18	7.75	1331	852	430	272	106.4	39.9	139.0	4.4
19	7.55	1315	841.5	438	396	95.2	48.6	126.5	5.0
20	7.80	1403	897.5	456	382	122.4	36.5	133.0	3.1
21	8.55	1129	722	266	290	71.2	21.4	57.5	70.1
22	7.75	1214	776.5	500	272	84.0	70.5	73.5	3.8
23	7.20	2350	1504	920	272	212.0	94.8	129.0	37.8
24	7.60	1415	905	496	202	124.0	45.2	106.0	35.8
25	7.55	783.5	501.5	300	180	71.2	29.6	56.5	0.3
26	8.35	1496	957.5	338	242	33.6	61.7	163.0	2.5
27	7.65	1873	1199	314	224	59.2	40.3	184.5	0.6
28	8.55	2510	1606	1008	200	233.6	103.0	159.0	14.3
29	7.30	1687	1080	466	552	119.2	40.8	120.0	89.0
30	8.00	603.5	386	174	200	23.2	28.2	39.5	1.7
31	8.20	638	408	276	252	96.0	8.7	47.0	7.3
32	7.95	868	555.5	290	238	94.4	13.1	71.0	2.9

33	7.60	1518	971.5	536	318	124.0	54.9	90.0	28.7
34	7.65	589.5	377	220	264	63.2	15.1	29.2	26.3
35	7.40	455	291	171	196	68.0	0.2	28.5	7.0
36	8.20	535.5	343	150	126	41.6	11.2	59.5	4.2
37	7.45	781.5	500	326	264	87.2	26.2	59.5	5.0
38	7.60	310.5	199	144	130	36.8	12.6	8.0	0.6
39	7.40	107.5	68.5	22	36	6.4	1.5	19.5	0.4
40	7.60	939.5	601.5	402	252	100.8	36.5	45.5	1.3
41	7.30	307	196.5	108	84	32.8	6.3	15.5	9.0
42	7.65	942.5	603	310	286	61.6	37.9	60.5	1.0
43	7.55	892	571	308	302	78.4	27.2	60.5	25.4
44	7.95	1312	839.5	496	290	112.0	52.5	73.5	9.1
45	8.35	1428	914	280	370	46.4	39.9	107.5	110.5
46	7.70	1999	1280	480	536	99.2	56.4	212.0	80.0
47	7.75	774.5	495.5	340	242	84.0	31.6	48.5	0.4
48	7.80	1479	946.5	584	368	171.2	37.9	85.0	7.6
Minimum	7.20	107.5	68.5	22	36	6.4	0.2	8.0	0.2
Maximum	9.15	2510.0	1606.0	1008	552	233.6	103.0	292.0	385.2
Average	7.83	1308.7	837.5	417	271	100.4	40.3	96.4	27.1

All parameters are expressed in mg/L except EC in $\mu S\ cm^{-1}$ and pH

Table 3 b: Physico-chemical and irrigation parameters of groundwater samples from the study area (Average Pre-monsoon)

Well ID	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	F^-	NO_3^-	Fe^{2+}	SAR	RSC
1	234.0	97.0	0	280.6	0.25	8.30	0.35	2.02	-5.62
2	206.0	130.5	0	541.7	0.13	21.80	0.05	3.33	-1.03
3	297.0	249.5	0	402.6	0.5	21.50	0.15	3.68	-5.19
4	182.0	162.5	0	229.0	0.55	5.15	0.10	1.39	-7.58
5	243.0	202.5	0	212.3	0.45	12.80	0.20	1.48	-8.02
6	257.0	116.0	0	319.6	0.4	8.40	0.10	2.32	-5.38
7	416.0	229.0	0	397.7	0.4	5.75	0.20	3.83	-2.74
8	345.0	229.5	0	358.7	0.25	24.00	0.40	4.71	-6.18
9	260.0	189.5	0	312.3	0.9	7.00	0.20	5.62	-1.90
10	217.0	183.5	0	409.9	0.75	7.50	0.06	5.36	-0.03
11	240.0	106.5	0	126.9	0.4	10.15	0.10	1.48	-8.79
12	282.0	245.0	0	290.4	0.35	6.30	0.20	2.52	-7.50
13	121.0	103.0	0	341.6	0.5	5.25	0.30	2.21	-3.18
14	309.0	221.5	0	224.5	0.15	4.90	0.30	4.05	-5.11
15	362.0	281.5	0	463.6	0.5	5.35	0.25	8.45	-1.51
16	144.0	153.5	0	95.5	0.45	6.80	0.30	1.76	-4.74
17	287.0	190.5	0	244.0	0.75	38.35	0.06	2.93	-8.54
18	167.0	264.0	0	292.8	0.55	4.50	1.30	4.14	-3.79
19	164.0	201.0	0	483.1	0.45	4.60	0.12	3.74	-0.82
20	181.0	157.5	0	466.0	0.35	14.50	0.21	3.85	-1.47
21	123.0	22.0	0	261.1	0.275	8.85	0.25	2.18	-1.03
22	183.0	82.5	0	283.0	0.4	11.25	0.15	2.03	-5.34
23	450.0	337.5	0	307.4	0.65	9.20	0.15	2.63	-13.33
24	198.0	230.5	0	222.0	0.45	11.00	0.20	2.94	-6.26
25	114.0	45.5	0	177.4	0.3	12.50	0.15	2.02	-3.08
26	201.0	196.0	0	236.7	0.75	8.90	0.10	5.48	-2.86
27	177.0	309.1	0	273.3	0.45	6.79	0.15	6.44	-1.79
28	605.0	312.0	0	200.1	0.35	13.75	0.10	3.10	-16.85
29	226.0	109.5	0	672.2	0.22	15.50	0.09	3.44	1.71

30	62.0	14.9	0	197.6	0.3	2.35	0.15	1.85	-0.23
31	83.0	21.5	0	288.6	0.15	1.55	0.15	1.75	-0.79
32	108.0	110.5	0	271.9	0.23	5.25	0.15	2.58	-1.34
33	252.0	132.5	0	357.0	0.2	20.00	0.10	2.40	-4.85
34	47.6	33.6	0	262.4	0.2	1.75	0.15	1.21	-0.09
35	47.0	31.3	0	195.6	0.2	1.95	0.90	1.35	-0.21
36	75.0	44.5	0	119.2	0.45	2.50	0.15	3.00	-1.04
37	106.0	55.0	0	296.1	0.15	3.50	0.20	2.04	-1.66
38	24.0	8.5	0	129.3	0.25	2.75	0.10	0.41	-0.76
39	8.0	15.5	0	35.8	1.7	1.05	0.10	2.57	0.15
40	128.0	48.5	0	287.9	0.65	13.65	0.15	1.40	-3.31
41	34.0	12.0	0	83.8	0.3	5.00	0.10	0.92	-0.78
42	115.0	29.0	0	324.5	0.3	0.50	0.10	2.12	-0.87
43	119.0	31.7	0	333.4	0.15	4.50	0.25	2.13	-0.69
44	194.0	66.0	0	331.6	0.2	10.70	0.15	2.04	-4.47
45	225.0	64.5	0	363.6	0.35	4.70	0.10	3.97	0.37
46	348.0	39.0	0	575.8	0.2	1.30	0.10	5.98	-0.14
47	120.0	49.5	0	274.9	0.5	3.75	0.15	1.63	-2.28
48	194.0	64.5	0	424.6	0.2	8.00	0.15	2.17	-4.71
Minimum	8.0	8.5	0	35.8	0.13	0.50	0.05	1.20	0.25
Maximum	605.0	337.5	0	672.2	1.70	38.35	1.30	5.68	-9.11
Average	197.5	129.8	0	297.5	0.41	8.65	0.20	2.92	-3.45

All parameters are expressed in mg/L except SAR and RSC

Table 4 a: Physico-chemical parameters of groundwater samples from the study area (Average Post-monsoon)

Well ID	pH	EC	TDS	Hard-ness	Alkali-nity	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
1	7.90	1440	921	624	392	141.6	65.6	91.5	4.0
2	7.85	1390	910	402	318	88.0	44.2	190.0	0.6
3	7.45	1637.5	1048	644	214	172.0	52.0	82.0	0.6
4	7.80	1113	712	530	166	126.4	52.0	43.5	1.0
5	7.85	1466	938.5	436	332	137.6	22.4	60.0	1.1
6	7.70	2585	1654.5	756	496	232.0	42.8	219.0	85.5
7	7.60	1291.5	826.5	346	142	79.2	36.0	131.5	1.5
8	7.90	1870	1197	526	274	116.8	56.9	211.5	85.0
9	7.70	3565	2281.5	1034	420	139.2	166.7	220.0	28.0
10	7.75	2115	1353.5	622	364	156.0	56.4	171.0	27.1
11	7.65	1653	1058	782	292	238.4	45.2	130.0	1.0
12	7.65	2663	1702.5	870	360	270.4	47.1	230.0	1.1
13	7.85	1479.5	946.5	534	340	116.8	58.8	134.5	2.5
14	7.90	1542.5	984.5	346	204	104.0	20.9	139.0	3.0
15	8.10	1520	972.5	302	322	53.6	40.8	249.5	1.1
16	7.95	949	607	302	282	90.4	18.5	53.0	6.5
17	7.95	1200	768	410	276	108.0	34.0	95.0	3.6
18	7.85	1605	1027	464	300	137.6	29.2	97.5	0.4
19	8.30	1328	850	348	128	65.6	44.7	112.0	5.0
20	8.05	1455	931.5	510	478	172.8	19.0	74.0	75.2
21	7.65	1651.5	1057	656	456	141.6	73.4	110.0	1.6
22	7.75	1553.5	994.5	630	386	158.4	56.9	80.5	0.9
23	7.95	897.5	574.5	460	310	125.6	35.5	76.0	1.1
24	7.50	2795	1789	1164	350	295.2	103.5	230.0	3.0
25	7.90	1052	673	478	292	116.8	45.2	74.0	0.7
26	7.55	2375	1584	836	400	233.6	61.2	187.5	84.6
27	7.95	2665	1705.5	890	354	206.4	90.9	280.5	2.8

28	8.00	1626	1040.5	452	186	104.0	46.7	153.5	1.3
29	8.60	1962	1255.5	498	542	72.0	77.3	187.5	59.6
30	8.35	536	343	218	264	50.4	22.4	62.5	4.6
31	8.05	165	105.5	78	88	24.0	4.4	10.0	0.5
32	7.75	394.5	252.5	200	210	52.0	17.0	26.5	0.2
33	7.55	509.5	326	86	114	18.4	9.7	21.0	5.5
34	8.25	421.5	270	134	126	33.6	12.2	28.0	2.6
35	8.45	450.5	314.5	170	146	37.6	18.5	21.0	0.6
36	7.95	618.5	396	178	155	48.8	13.6	48.0	7.7
37	7.95	677	433	186	144	32.8	25.3	64.0	8.5
38	7.95	328	210	132	114	32.8	12.2	19.0	0.3
39	7.80	232	148.5	160	208	47.2	10.2	21.5	0.8
40	8.30	747	478	304	180	79.2	25.8	31.5	4.4
41	7.60	195	125	56	54	12.0	6.3	21.5	2.8
42	7.90	725	464	290	245	92.0	14.6	63.0	1.6
43	8.05	1421	909.5	328	304	64.8	40.3	102.0	155.0
44	7.65	1696	1085.5	712	193.5	160.8	75.3	55.5	17.5
45	7.75	2960	1894.5	834	336	139.2	118.1	250.0	240.0
46	8.20	1993	1275.5	328	422.5	52.8	47.6	240.5	116.5
47	7.80	1139.5	729	444	222.5	110.4	40.8	100.5	0.6
48	7.25	2416.5	1546.5	1134	199	399.2	33.1	86.5	2.0
Minimum	7.25	165.00	105.50	56.00	54.00	12.00	4.37	10.00	0.15
Maximum	8.60	3565.00	2281.50	1164.00	542.00	399.20	166.70	280.50	240.00
Average	7.88	1418.15	909.79	475.50	272.95	118.50	43.56	112.22	22.09

All parameters are expressed in mg/L except EC in μS cm^{-1} and pH

Table 4 b: Physico-chemical parameters of groundwater samples from the study area (Average Post-monsoon)

Well ID	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	F^-	NO_3^-	Fe^{2+}	SAR	RSC
1	221.0	112.5	0.0	478.2	0.5	14.8	0.30	2.26	-4.62
2	186.0	145.0	0.0	388.0	0.1	9.2	0.15	5.86	-1.67
3	262.0	154.0	0.0	261.1	0.8	8.0	0.25	2.00	-8.58
4	203.0	117.5	0.0	188.7	0.9	8.5	0.55	1.17	-7.49
5	280.0	108.0	0.0	405.0	0.4	6.9	0.30	1.78	-2.07
6	397.0	160.0	0.0	605.1	0.5	10.2	0.20	4.92	-5.19
7	285.0	84.0	0.0	173.2	0.5	6.7	0.25	4.37	-4.07
8	391.0	150.5	0.0	334.3	0.6	4.1	0.80	5.70	-5.02
9	605.0	303.0	0.0	512.4	0.6	12.2	0.25	4.23	-12.22
10	332.0	300.0	0.0	444.1	0.4	9.7	1.35	4.24	-5.14
11	246.0	150.0	0.0	356.2	0.3	13.4	0.15	2.87	-9.78
12	321.0	265.0	0.0	439.2	0.8	26.5	0.30	4.82	-10.18
13	195.0	105.0	0.0	414.8	0.7	11.8	0.15	3.60	-3.86
14	150.0	272.5	0.0	248.9	0.6	9.7	0.20	4.62	-2.83
15	162.0	208.5	0.0	392.8	0.7	7.9	0.70	8.88	0.41
16	79.0	70.0	0.0	344.0	0.7	11.6	0.20	1.88	-0.39
17	146.0	182.5	0.0	336.7	0.9	7.6	0.70	2.90	-2.67
18	137.0	182.0	0.0	366.0	0.4	19.0	0.25	2.80	-3.27
19	254.0	62.0	0.0	156.2	0.4	9.5	0.10	3.71	-4.38
20	170.0	25.0	0.0	583.2	0.4	13.7	0.15	2.02	-0.63
21	276.0	72.5	0.0	556.3	0.5	5.7	0.40	2.65	-3.98
22	201.0	98.5	0.0	470.9	0.7	7.0	0.20	1.98	-4.86
23	165.0	54.0	0.0	378.2	0.6	7.5	0.15	2.19	-2.99
24	524.0	435.0	0.0	427.0	0.1	12.7	0.25	4.17	-16.25

25	154.0	71.5	0.0	356.2	0.5	18.8	0.60	2.09	-3.70
26	329.0	390.0	0.0	488.0	1.2	8.3	0.25	4.01	-8.70
27	444.0	418.5	0.0	431.9	0.5	13.5	0.15	5.81	-10.69
28	223.0	282.5	0.0	226.9	0.9	20.8	0.15	4.46	-5.30
29	417.0	34.5	0.0	660.8	0.3	5.7	0.30	5.20	0.90
30	37.5	27.0	0.0	258.2	0.4	5.5	0.20	2.62	-0.12
31	7.0	4.0	0.0	87.0	0.6	0.8	0.15	0.70	-0.13
32	25.0	13.0	0.0	208.2	0.6	3.5	0.25	1.16	-0.58
33	13.0	19.0	0.0	113.0	0.4	0.8	2.10	1.40	0.14
34	40.0	10.5	0.0	120.7	0.6	3.5	0.25	1.49	-0.70
35	37.0	21.0	0.0	142.2	0.5	6.4	0.20	1.00	-1.06
36	73.0	26.5	0.0	152.5	0.6	4.0	0.35	2.22	-1.06
37	63.5	33.0	0.0	161.3	0.7	3.7	0.45	2.90	-1.07
38	30.0	7.5	0.0	111.1	0.2	3.0	0.20	1.02	-0.81
39	27.0	29.5	0.0	206.9	0.4	0.5	1.05	1.05	0.19
40	88.0	24.0	0.0	205.7	0.2	16.1	0.30	1.12	-2.70
41	23.0	44.0	0.0	53.8	0.3	0.3	0.55	1.78	-0.24
42	92.0	31.5	0.0	281.3	0.3	1.0	1.00	2.29	-1.18
43	221.0	80.0	0.0	363.6	0.4	20.5	0.25	3.48	-0.59
44	304.0	61.0	0.0	236.1	0.4	62.0	0.10	1.29	-10.34
45	567.0	186.5	0.0	409.9	0.5	63.5	0.15	5.35	-9.92
46	394.0	54.5	0.0	515.5	0.7	1.4	0.21	8.21	1.91
47	230.0	80.0	0.0	271.5	0.6	16.7	0.20	2.95	-4.42
48	511.0	179.5	0.0	242.8	0.5	56.0	0.25	1.59	-18.69
Minimum	7.0	4.0	0.0	53.8	0.1	0.3	0.10	0.70	-18.69
Maximum	605.0	435.0	0.0	660.8	1.2	63.5	2.10	8.88	1.91
Average	219.5	123.9	0.0	324.3	0.5	12.3	0.37	3.14	-4.18

All parameters are expressed in mg/L except SAR and RSC

3.1 Drinking quality of groundwater

Hydrogen ion concentration (pH)

The pH concentrations above 8.5 indicates that water has high sodium carbonate content while low pH concentrations i.e. 4.00 indicate the presence of free acids in water. Roy (1955) suggested that the high pH and alkalinity are associated with high photosynthetic activity. The lowest concentrations are obtained during summer season and higher during post-monsoon season. It is observed that pH concentration in groundwater from the study area ranged from 7.2 to 9.15 and 7.25 to 8.6 for pre monsoon and post monsoon season, respectively. The groundwater is more alkaline during late rainy season and almost neutral during summer. The alkaline nature of pH indicates dissolution of leached materials during late rainy season. The alkaline pH concentrations were mainly obtained in the samples from agricultural areas of watershed KR 55, KR 63 and KR 64 i.e. in Shirol Tahsil.

Electrical conductivity

Electrical conductivity depends on water's capacity to convey an electric current, which is used for indicating the total concentration of ionized constituents present in natural water (Hem, 1991). Electrical conductivity is a good measurement of salinity hazard to crops as it reflects the total dissolved solids in groundwater. It is observed that the electrical conductivity concentrations in the area under study ranged from 107.5 to 2510 µS/cm for pre monsoon season whereas for post monsoon season it is 165 to 3565 µS/cm. Electrical conductivity concentrations are high in groundwater from KR 55, KR 63 and KR 64 watershed area and are lower in KR 66 and KR 71 watershed.

Total dissolved solids (TDS)

Chemical and biological reactions taking place between groundwater and rocks cause dissolution of various elements in water, which increases the total dissolved solids. TDS in water also originates from natural sources, sewage, agricultural runoff, urban runoff and industrial wastewater (WHO, 1996). On the basis of TDS content in groundwater have been classify according to David and DeWeist (1966) and it is presented in Table 5. Desirable limit of TDS is 500 mg/L and maximum permissible limit is 1000 mg/L as per (David and DeWeist 1966)). The TDS concentrations of the groundwater samples from the study ranged from 68.5 to 1606 mg/L and 105.5 to 2281.5 mg/L for pre monsoon season and post monsoon season, respectively. Overall TDS concentrations are seen to increase during post monsoon season than pre monsoon season. The maximum concentrations recorded in the samples from agricultural areas.

Table 5: David and DeWeist (1966) classification of groundwater based on TDS

TDS (Mg/L)	Classification	Number of samples	
		Pre monsoon 2009-10	Post Monsoon 2009-10
< 500	Desirable for drinking	08	12
500-1000	Permissible for drinking	26	21
1000-3000	Useful for irrigation	14	15
> 3000	Unfit for drinking and irrigation	Nil	Nil

Total hardness

Calcium and magnesium ions derived from rocks in varying proportions are responsible for the hardness of water. Generally, the hardness of water is defined as its capacity to precipitate soap. Soap is soluble in pure or soft water, but when the calcium and magnesium salts are present in water, it forms hard soluble precipitates. Compounds like bicarbonates, carbonates and sulphates in association with calcium and magnesium account for the hardness of water. Apart from these compounds, chlorides and nitrates also contribute to hardness of groundwater. When the hardness is numerically greater than sum of the carbonate and bicarbonate alkalinity, the amount of hardness equivalent to alkalinity is called carbonate hardness, and the amount of hardness in excess of this is called non-carbonate hardness. Temporary hardness of the water is caused due to presence of cation salts like carbonate while permanent hardness is due to the presence of sulphates and chlorides. Classification groundwater from the study area based on total hardness concentrations are presented in Table 6.

Table 6: Classification of groundwater from the study area (Durfor and Becker's 1964)

Sr. no.	Classification of groundwater	Hardness (mg/L)	No. of samples	
			Pre monsoon 2009-10	Post monsoon 2009-10
1	Soft	0 – 60	01	01
2	Moderately hard	60- 120	Nil	02
3	Hard	121 – 180	05	05
4	Very hard	>180	40	42

The total hardness in groundwater from the study area shows ranged from 22 to 1008 mg/L and 56 to 1154 mg/L for pre monsoon season and post monsoon season, respectively. The total hardness of groundwater in the study area is mainly due to calcium, magnesium and carbonate, however in agricultural areas, it may be due to sulphate and chloride ion combination. It is observed that hardness increases from higher reaches of the watershed to lower parts of the watershed. The higher hardness concentrations are found in KR 55, KR 63 and KR 64 watershed.

Total alkalinity

The amount of carbonate and hydrogen carbonate ions of water to neutralise acids and this ability of water to neutralise acids is known as alkalinity. Normally the ion which reacts with acids contributes the alkalinity. Anions of weak, completely dissociated acids of carbonic nature gives rise to alkalinity. Weak acids like silicic, phosphoric and boric acids, hydroxides and organic acids also may often contribute to the alkalinity in the groundwater. The alkalinity of water is usually due to the presence of bicarbonate, carbonate and hydroxide compounds of calcium, magnesium and other elements. In natural waters, alkalinity is usually due to calcium carbonate. Total alkalinity is a measure of the capacity of water to neutralize a strong acid to a specific pH (Hem, 1991). Groundwater samples from the study area showed that total alkalinity concentration ranged from 36 to 552 mg/L during pre monsoon season and 54 to 542 mg/L during post monsoon season. The groundwater samples from the study area showed overall increase in total alkalinity in agricultural areas as compared to non agricultural area.

Calcium (Ca^{2+})

Calcium is widely distributed in the earth's crust and is present in nearly all waters. The main sources of calcium are the carbonates, silicates, sulphates, fluorides and phosphates. The groundwater samples from the study area shows that calcium concentration ranged from 6.4 to 233.6 mg/L and 12 to 399.2 mg/L for pre monsoon and post monsoon season, respectively. The desirable limit of calcium for drinking water is 75 mg/L (BIS 2003). The calcium concentration shows those of 32 groundwater samples of post monsoon and 33 groundwater samples of pre monsoon beyond the permissible limit. Calcium concentration during pre monsoon season is higher than post monsoon season. Geologically study area covers Deccan Trap basalt. In basalt, it is predominantly held in plagioclase feldspar, a solid solution series with anorthite ($Ca\ Al_2\ Si_2O_8$) and albite ($NaAlSi_3O_8$) as an end member. The important calcium bearing pyroxene mineral i.e. augite, is also one of the constituents of basalt releasing calcium in groundwater from the study area. The zeolites occurring in the Deccan Traps as secondary minerals and montmorillonite clays holding calcium as an absorbed ion on the mineral surface in soils and rocks may also contribute to calcium in groundwater from the study area.

Magnesium (Mg^{2+})

The desirable limit of magnesium for drinking water is 30 mg/L (BIS 2003). It is observed that magnesium content ranged from 0.2 to 103 mg/L and 4.37 to 166.7 mg/L for pre monsoon and post monsoon seasons, respectively. Magnesium content is high in the irrigated areas i.e. in watershed KR 55, KR 63 and KR 64, indicates leaching of basaltic rocks make magnesium rich groundwater. The basalts contributing pyroxene minerals, due to weathering of basalts release the magnesium ions in the groundwater.

Sodium (Na^{+})

Sodium content in the groundwater samples from the study area ranged from 8 to 292 mg/L and 10 to 280.5 mg/L for pre monsoon and post monsoon seasons respectively. Groundwater samples from agricultural areas i.e. KR 55, KR 63 and KR 64 shows higher concentration as compared to samples from watershed KR 66 and KR 71. In Deccan Trap basalts, the sodium is found in the plagioclase feldspars and zeolites minerals. The sodium in groundwater from the area under study is caused by leaching of sodium element during the weathering of basalt.

Potassium (K^{+})

Potassium which is slightly less abundant than sodium is similar in behaviour to sodium. Its concentration in natural waters compared to sodium is very low. Potassium content in the groundwater samples from the study area ranged from 0.15 to 240 mg/L and 0.2 to 385.1 mg/L for pre monsoon and post monsoon seasons respectively. Potassium concentration seems to exceed the desirable limit of 10 mg/L (BIS, 2003; Ravikumar and Venkatesharaju, 2010). It is observed that maximum concentration of potassium is in agricultural areas which may be due to potassium fertilizers used for agriculture which in turn increases the concentration of potassium in groundwater significantly.

Chloride (Cl^-)

Chloride content in rocks is generally low. During weathering processes, Cl^- released from the rocks goes into solution as Cl^- ions through recharging waters into the groundwater. The concentration of chloride in groundwater does not ordinarily exceed 5 mg/L. Chlorides in groundwater is contributed from both the natural and anthropogenic sources like use of inorganic fertilizers, landfill leachate, septic tank effluents, animal feeds, industrial effluents and irrigation drainage (WHO, 1996). The average abundance of Cl^- in the basaltic rocks is about 200 mg/Kg (Konrad and Dennis, 1994). Chlorides could be due to natural source of irrigation and anthropogenic activities. The chlorides concentration in the groundwater from the study area is ranged from 7 to 705 mg/L during pre monsoon season and 8 to 605 mg/L during post monsoon season. The desirable limit of Cl^- for drinking purpose is 250 mg/L (BIS, 2003). The maximum concentrations are observed during post monsoon season and minimum during pre monsoon season. The chloride concentration in groundwater never shows much variation in the study area.

Sulphate (SO_4^{2-})

The source of sulphates in groundwater can be attributed to minerals like calcium sulphates, sewage, industrial wastes and fertilizers. The groundwater samples from the study area shows concentration of sulphates ranged from 8.5 to 337.5 mg/L and 4 to 435 mg/L for pre monsoon and post monsoon, respectively. The desirable limit of sulphate for drinking water is up to 200 mg/L if beyond this causes gastro. The sulphate concentration showed 09 groundwater samples of post monsoon and 13 groundwater samples of pre monsoon beyond the permissible limit. The higher sulphate concentrations are found in KR 55, KR 63 and KR 64 watershed. Presence of sulphate is due to dissolution of material from natural source or may be derived from pesticide and fertilizers (WHO, 2006).

Nitrates (NO_3^-)

Higher concentration of nitrate in groundwater may be due to extreme use of nitrogenous fertilizers, human waste, animal wastes and manure (Janardhana et al., 2009). The nitrate concentration in groundwater samples from the study area shows maximum concentration is 63.5 mg/L and 38.35 mg/L during post monsoon and pre monsoon seasons, respectively. The desirable limit of NO_3^- for drinking purpose is 45 mg/L (BIS, 2003), it is seen that only 03 groundwater samples (ID 44, 45 and 48) from KR 77 watershed exceeds the permissible limit.

Fluorides (F^-)

Higher doses of fluoride (greater than 1.5 mg/L) it leads to dental fluorosis or excessive concentration (greater than 3.0 mg/L) F^- may lead to skeletal Fluorosis. The concentrations of F^- ion in the study area ranged from 0.13 to 1.7 mg/L and 0.05 to 1.2 mg/L for pre monsoon and post monsoon season, respectively. The permissible limit of fluoride for drinking use is 1.5 mg/L (BIS, 2003). It is observed only 1 sample from watershed KR 77 shows greater than 1.5 mg/L. Earlier studies (Sloof et al., 1989) have reported that the fluorides in surface and the groundwater are due to leaching of phosphatic fertilizers. This suggests that F^- occurrence in groundwater from the study area caused by excessive use of phosphatic fertilizer.

Iron ($Fe2^+$)

The iron content in the study area ranged from 0.05 to1.3 mg/L and 0.1 to 2.1 mg/L for pre monsoon and post monsoon season, respectively. The desirable limit of iron for drinking use is 0.3 mg/L (BIS 2003). Beyond this limit taste appearance are affected, has adverse effect on domestic uses and water supply structures, and promotes iron bacteria. Higher Fe^{2+} content was noticed in 14 and 04 water samples for post and pre monsoon, respectively. Malwadi (pre monsoon), Nandani, Aini and Kudtarwadi (post monsoon) showed above the permissible limit (1.0 mg/L). The concentration of iron in post monsoon season is higher than the pre monsoon may be due leaching of lateritic rocks during the weathering mostly in rainy season.

3.2 Water Quality for Irrigation Purpose

Sodium Adsorption Ratio (SAR)

The relative activity of sodium ion in the exchange reaction with soil is expressed in terms of Sodium Absorption Ratio (Srivastava and Parimal, 2012). It determines the suitability of irrigation water, because the same is considered as a measure of alkali or sodium hazard for crops. High SAR concentrations indicate the risk of displacement of alkaline earths (Suyashkumar, 2008). It also adversely affects the soil structure. Adverse effect caused by high concentration of sodium on soil is known as sodium hazard. The SAR for groundwater from the study area was calculated by using following equation (Richard, 1954).

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

Where all ionic concentration expressed in meq/L

The groundwater from the study area has been classified based on SAR (Table 7). SAR value of groundwater from the study area it shows that 46 out of 48 samples fall under the excellent category. Only two samples showed that increasing problem of sodium hazards.

Table 7: Classification of groundwater sample based on SAR (Raghunath, 1987)

SAR Ratio	Water quality	Avg. Pre monsoon 2009-10	Avg. Post monsoon 2009-10
0-06	Excellent	46	46
06-09	Increasing Problem	02 (Well ID WQ15 and 27)	02 (Well ID WQ15 and 46)
>10	Severe Problem	Nil	Nil

Residual Sodium Carbonate (RSC)

Residual sodium carbonate (RSC) is an index used to determine the HCO_3^- hazard (McLean et al., 2000). High bicarbonate concentration in groundwater can arrest plant growth and lead to calcite precipitation, decreased soil permeability, lowered infiltration capacity and an increase in erosion (McLean et al., 2000).

The value of RSC is calculated as per Eaton (1950),

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

Where all ionic concentration expressed in meq/l

The groundwater having excess of CO_3^{2-} and HCO_3^- concentration over the Ca^{2+} and Mg^{2+} in excess of limits have unfavourable effects on agriculture (Eaton, 1950). According to Lloyd and Heathcote (1985) groundwater from the study area has been classified based on RSC (Table 8). RSC value of groundwater from the study area shows that 47 samples out of 48 fall under the suitable category for both seasons. Only 01 water sample indicating marginal water and none of the sample belongs to the unsuitable category in terms of RSC.

Table 8: Classification of water sample based on RSC

RSC Ratio	Water quality	Pre monsoon 2009-10	Post monsoon 2009-10
< 1.25	Suitable	47	47
1.25 to 2.5	Marginal	01 (Well ID WQ 29)	1 (Well ID WQ 46)
>2.5	Not suitable	0	0

4. CONCLUSION

According to the drinking water quality standards, the groundwater from the study area is not suitable for drinking with reference to the concentrations of total dissolved solids, total hardness, Ca^{2+} and Mg^{2+} in many locations; based on the irrigation parameters (Sodium Adsorption Ratio and Residual soluble carbonate), most of the groundwater samples fall into the classification of suitable irrigation. The weathering of host rocks primarily controls the natural chemistry of waters in the study area. The nitrate concentration is very low in host rock of the studied area, the excessive nitrate may be comes from anthropogenic activities.

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