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Research Article

HYDROGEOCHEMICAL STUDY OF GROUNDWATER FROM DEEPER AQUIFER OF WRE-2 WATERSHED OF CHANDRAPUR AND BALLARPUR TALUKA, CHANDRAPUR DISTRICT, MAHARASHTRA

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ABSTRACT

In the present study, evaluation of geochemistry of 33 water representative deeper aquifer groundwater samples from WRE2 watershed of Chandrapur and Ballarpur taluka of Chandrapur District Maharashtra is carried out. The groundwater from the deeper aquifer of watershed WRE2 area is alkaline in nature. The higher conductivity in the study area is due to high mineral concentration in groundwater. It indicates that the ion exchange and solublization processes have taken place within the aquifer. The interrelationship among Ca^{++} + Mg^{++} *vs* SO_4 + HCO_3 exhibits the calcium dissolution and silicate weathering for the source for Na^+ in study area. Besides, the interrelationship among HCO_3 and Cl *vs* Na also point out calcium dissolution and silicate weathering. Considering the TDS concentration the 27% groundwater samples from borewell from the study area is fresh water. The major plots of groundwater sample fall in C4-S2 and C3-S2 with minor plots in C3-S1 in US Salinity diagram (1954), which indicate groundwater is of medium to high salinity-medium sodium type and thus can be utilized for irrigation with little danger of exchangeable sodium.

Keywords: *Hydrogeochemistry, Deeper Aquifer Groundwater, Water Quality, WRE2 Watershed, Chandrapur District, Maharashtra*

INTRODUCTION

Groundwater is a most vital natural resources required for drinking and irrigation. The quality of groundwater is largely controlled by discharge-recharge pattern, nature of host and associated rocks as well as contaminated activities. Moreover, the nature and amount of dissolved species in natural water is strongly influenced by mineralogy and solubility of rock forming minerals (Raymahasay, 1996). The quality of groundwater is function of various parameters which determines its suitability for industrial use as well as irrigation practices and most importantly drinking purposes (WHO 1984; Trivedy and Goel 1986; ISI 1991; APHA 1998)

The requirement of water for all living beings is utmost important. The ultimate source of water is only one i.e. rainfall, there are two phases of water, namely surface water and groundwater. The groundwater occurrence and accessibility has been inconsistent all over the India. This may be ascribed to precipitation percentage, physiography and diverse hydrogeological conditions. Both, the unmanaged utilization as well as excessive groundwater exploitation are exclusively responsible for lowering of groundwater levels, de-saturation of aquifers. The groundwater from shallow aquifer occurs in dugwells and shallow tubewells whereas from deep aquifers it is obtained by means of deep borewells.

The availability of good quality of water in high quantity is linked with food security. However, there are number of places on the earth surface where quality of groundwater is deteriorated, either by nature or due to human interventions and groundwater resources are moreover not suitable for drinking purpose, The various studies on groundwater quality, geochemical characterization and its utility of various purposes have been carried out in different parts of India (Saxsena and Ahmed, 2001; Shivanna and Mahokar, 2003; Subba Rao, 2006; Raju, 2007; Gupta *et al.*, 2008; Subba and Surya, 2009; Bharadwaj *et al.*, 2010; Marghade *et al.*, 2010). The high content of arsenic (Pal and Mukharji, 2008) and fluoride (Madhnure and Malpe, 2007; Subba, 2009) have been reported from groundwaters from different parts of India. In the Central India, particularly in east parts of Maharashtra State the districts like Yavatmal and

Chandrapur have high concentrations of fluoride content (Murkute and Badhan, 2011, Murkute, 2014; Dharashivkar *et al.*, 2014). The present study is also an attempt to understand the hydrogeochemical characteristics of deeper aquifer of groundwater in WRE2 watershed of Chandrapur District (Maharashtra), India.

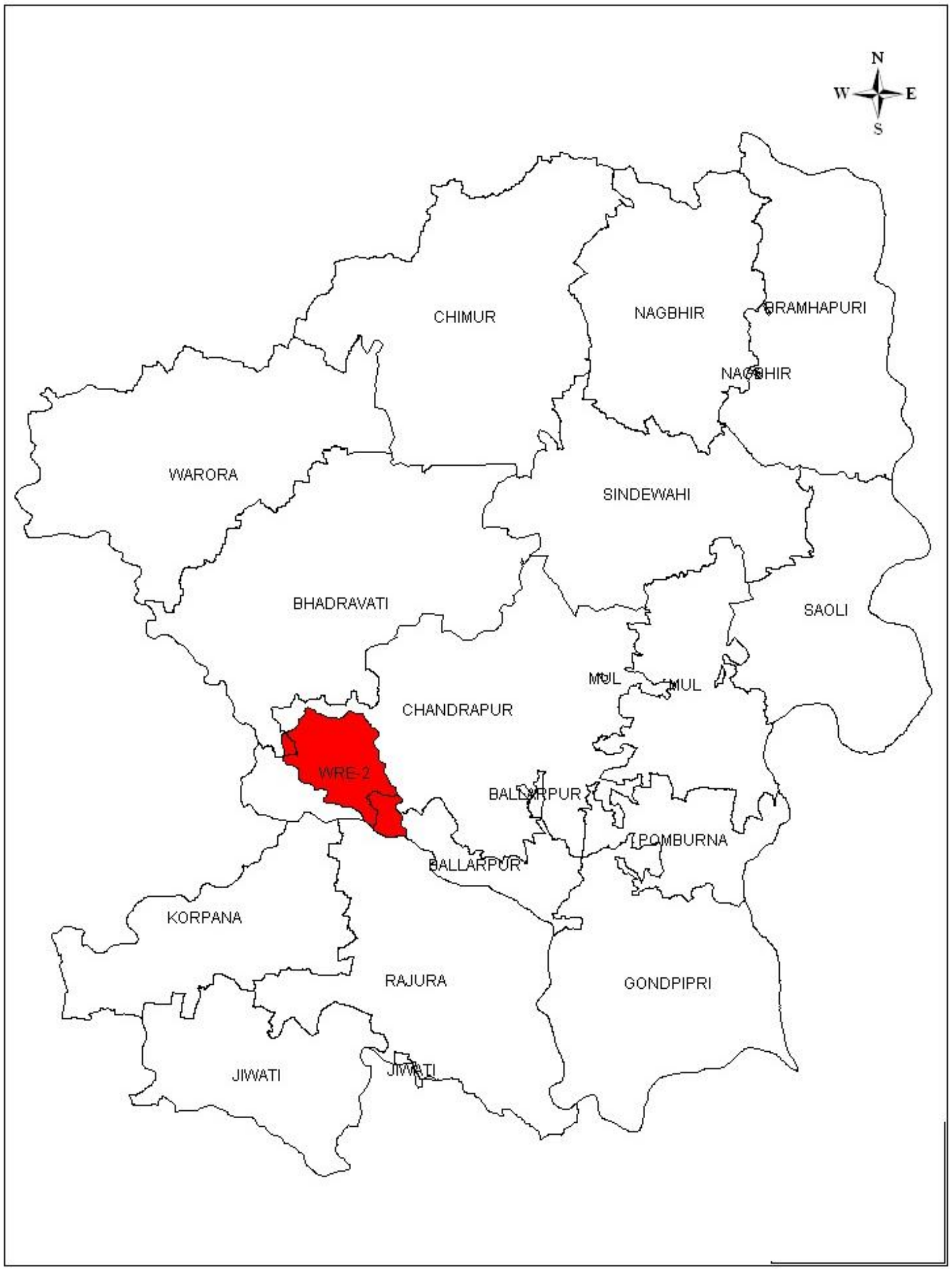
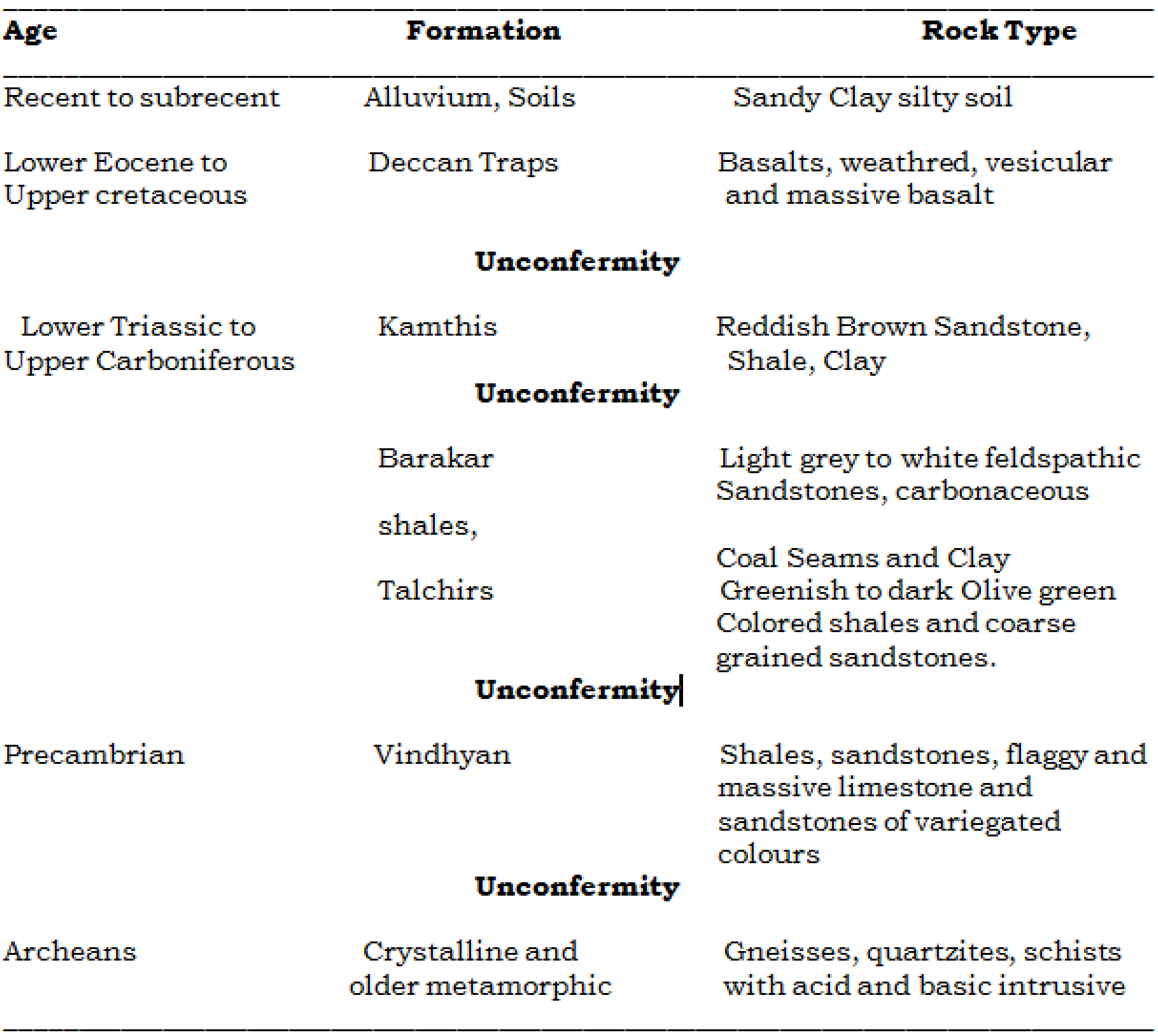


Figure 1: Location and Geological map of the study area

Geological Setting

The shale and sandstone of the Mesoproterozoic age belonging to Penganga Group form the basement along with the underlying by the Archaean metamorphics (Table 1). These rocks are unconformably overlain by the sediments of Gondwana Supergroup of Permo-carboniferous to Jurassic age. Geologically the area is dominated by Talchir shale and attained almost 80 to 100 m thickness, as noticed from borehole data (DGM, 2000). The Talchir Formation mainly comprises light green shale and sandstone. The Talchir Formation exhibits conformable relationship with the succeeding Barakar Formation. The rock types of Barakar formations are feldspathic sandstone and shale and are overlain by sandstones of Kamthi Formation. In turn, Deccan Trap basaltic flows cover the area and local alluvial patches can be noted from Wardha and Irai rivers which form the southern and eastern boundary of the watershed.

Table 1: Geological succession of the area is given below (DGM, 2000)



Age	Formation	Rock Type
Recent to subrecent	Alluvium, Soils	Sandy Clay silty soil
Lower Eocene to Upper cretaceous	Deccan Traps	Basalts, weathred, vesicular and massive basalt
	Unconfermity	
Lower Triassic to Upper Carboniferous	Kamthis	Reddish Brown Sandstone, Shale, Clay
	Unconfermity	
	Barakar	Light grey to white feldspathic Sandstones, carbonaceous
	shales,	
		Coal Seams and Clay
	Talchirs	Greenish to dark Olive green Colored shales and coarse grained sandstones.
	Unconfermity	
Precambrian	Vindhyan	Shales, sandstones, flaggy and massive limestone and sandstones of variegated colours
	Unconfermity	
Archeans	Crystalline and older metamorphic	Gneisses, quartzites, schists with acid and basic intrusive

Study Area

Location and Climate

The watershed WRE-2 covers 25 villages of Chandrapur and Ballarpur tahsil of Chandrapur district of Maharashtra, (Central India). The study area falls in latitude 19^{0}53'00" to 20^{0}01'35" N and longitude 79^{0}10'40" to 79^{0}17'35" E of Survey of India toposheet no. 56M/1, 56M/5, 55P/8 and 55P/4 covering 16231 ha area. Total annual groundwater recharge in study area is 769.85 ham with net annual groundwater availability as 731.36 ham and represents the 'Safe' watershed (GSDA, 2011). The study area is mainly covered by major part of Chandrapur MIDC that includes small scale to large scale industries comprising cement product plants, chemical plants, fly ash depot, soybean oil plant etc. The climate of the area is hot. The maximum temperature in summer reaches up to 47 ^{0}C and in winter about 28 ^{0}C. The average annual rainfall of the area is 1030 mm.

Figure 2: Showing watershed map of wre2 watershed with drainage pattern and village from water samples collected

Physiography and Drainage

The area exhibits moderately dissected topography with general slope towards southeast direction. The watershed is mainly drained by Erai and Wardha rivers and their tributaries. The streams of order I and III creates dendritic drainage pattern and higher order drainages run roughly parallel. The eastern boundary of watershed is marked by southerly flowing Erai River and southern boundary is marked by SW flowing Wardha River.

Hydrogeological Framework

In the area, the groundwater mainly occurs under phreatic conditions; however the deeper confined aquifers are also common. The dugwells penetrating Penganga limestones range in depth between 5 to 15 mbgl. The diameters of the dugwells range between 3 to 5 m. The deeper aquifers vary in depth from 25 to 60 mbgl upholding a discharge of 50 to 300 m^3/ day (GSDA, 2005, 2009).

From Talchir, Barakar and Kamthi formations, the groundwater mainly occurs under phreatic conditions; however the confined aquifers are also not uncommon. The borewells from the Gondwana sedimentary province vary in depth stuck between 60 m and uphold a discharge of 50 to 300 m^3/ day (GSDA, 2005). Murkute *et al.*, (2010) have established the relationship between aquifer parameters and the petrological characteristics of Kamthi Sandstone, exposed near Minjhari village, Chandrapur District. According to them the values of transmissivity and specific yield for the arenites range from 104.85 to 412.72 m^2/day and 20 to 29 % respectively. These high values of transmissivity and specific yield in arenites aquifer are accountable for higher percentage of detrital grains, lesser amount of matrix and the moderate sorting of the grains. The values of transmissivity and specific yield for the graywackes grade from 59.82 to 146.43 m^2/day and 11 to 16 % respectively. The lower percentage of detrital grains, higher amount of matrix and the poor or very poor sorting of the grains are responsible for low values of transmissivity and specific yield in graywacke aquifer.

The Basaltic lava flows are vesicular in nature and possess deep weathering as well as joints. The average depth of dugwells varies from 9 to 15 mbgl and the yield ranges from 75 to 100 m^3/ day. The borewells penetrating deeper aquifers have good yields ranging from 150 to 250 m^3/ day. The wells piercing deeper aquifers in alluvial areas have discharge in between 100 to 300 m^3/ day, though in a few cases higher yields are observed (GSDA, 2005; 2009).

MATERIALS AND METHODS

Table 2: Analytical methods followed in present study

Sr.No	Parameters	Characteristics	Unit
1	General	Tempreture	^{0}C
2		pH	---
3		Electrical conductity	µs/cm
4		Total dissolved solids	mg/L
5		Total hardness(as $CaCo_3$)	mg/L
6	Major Cations	Calcium (Ca^{2+})	mg/L
7		Magnesium(Mg^{2+})	mg/L
8		Sodium(Na^+)	mg/L
9		Potassium(K^+)	mg/L
10	Major anions	Bicarbonate(HCO^{3-})	mg/L
11		Nitrate(NO_3^-)	mg/L
12		Sulphate(SO_4^{2-})	mg/L
13		Chloride(Cl^-)	mg/L
14		Flouride(F^-)	mg/L
15	Irrigation Water use (by calculation)	Sodium Absorption Ratio(SAR)	meq/L
16		Percent Sodium(%Na)	%
17		Residual Sodium Carbonate(RSC)	meq/L
18		Mg Ratio(MR)	---
19		Corrosivity Ratio (CR)	---

Table 3: Analytical data of water samples collected from study area

Se. No.	Sample No.	Formation	Aquifer/ Lithology	Source	pH	EC µs/cm	TDS	TH	Ca++	Mg++	Na+	K+	NO3-	HCO3-	SO4--	Cl-	F-
1	WRE2-1	Talchir	Shale	Borewell	7.5	2080.00	1331.2	179.95	44.10	17.00	190.00	1.50	5.46	632.00	285.80	160.00	0.44
2	WRE2-3	Talchir	Shale	Borewell	7.2	2180.00	1395.2	500.08	132.30	41.30	210.00	49.00	160.87	500.00	276.00	179.90	0.54
3	WRE2-5	Talchir	Shale	Borewell	8.2	2120.00	1356.8	378.98	28.10	75.30	260.00	109.00	92.83	380.00	258.90	249.90	1.10
4	WRE2-8	Alluvium	Gravely sand	Borewell	8.0	1718.00	1099.5	339.67	60.10	46.20	222.00	20.00	145.61	280.00	124.60	194.90	1.24
5	WRE2-9	Talchir	Shale	Borewell	7.8	2250.00	1440	1196.8	80.20	243.00	372.00	9.00	88.70	580.00	160.00	359.90	1.08
6	WRE2-10	Talchir	Shale	Borewell	7.6	2760.00	1766.4	1197.5	132.30	211.40	350.00	10.00	90.25	500.00	224.70	329.90	0.40
7	WRE2-11	Talchir	Shale	Borewell	7.8	2050.00	1312	420.15	108.20	36.50	217.00	27.00	193.30	288.00	166.10	229.90	0.77
8	WRE2-12	Alluvium	Gravely sand	Borewell	7.6	2970.00	1900.8	439.9	120.20	34.00	330.00	14.50	681.95	480.00	269.90	409.90	0.83
9	WRE2-15	Alluvium	Gravely sand	Borewell	7.6	3140.00	2009.6	399.83	92.20	41.30	460.00	8.50	126.22	300.00	258.90	599.80	0.66
10	WRE2-17	Barakar	Fels pathic sst	Borewell	7.6	1071.00	685.44	480.24	128.30	38.90	82.00	7.00	51.19	230.00	289.50	84.00	0.49
11	WRE2-18	Talchir	Shale	Borewell	7.6	2390.00	1529.6	698.72	92.20	114.20	198.00	8.50	69.15	340.00	434.80	209.90	0.30
12	WRE2-20	Talchir	Shale	Borewell	7.9	1260.00	806.4	279.72	68.10	26.70	120.00	20.00	29.01	430.00	64.70	89.00	0.71
13	WRE2-23	Talchir	Shale	Borewell	7.9	1800.00	1152	559.46	116.20	65.60	240.00	5.50	116.04	330.00	114.80	304.90	0.57
14	WRE2-24	Alluvium	Gravely sand	Borewell	8.0	3130.00	2003.2	798.67	100.20	133.70	390.00	37.50	209.04	360.00	414.10	489.80	0.73
15	WRE2-26	Alluvium	Gravely sand	Borewell	7.8	5710.00	3654.4	1298.1	192.40	199.30	1280.00	42.00	131.94	360.00	978.30	1524.50	0.73
16	WRE2-28	Barakar	Fels pathic sst	Borewell	7.9	3780.00	2419.2	918.67	152.30	131.20	550.00	72.00	213.41	440.00	447.00	699.80	0.26
17	WRE2-29	Talchir	Shale	Borewell	7.8	5030.00	3219.2	1438.2	264.50	189.50	880.00	117.00	353.69	500.00	647.30	999.70	0.28
18	WRE2-30	Talchir	Shale	Borewell	8.0	3140.00	2009.6	638.63	72.10	111.80	490.80	60.50	224.54	360.00	263.80	599.80	0.50
19	WRE2-31	Talchir	Shale	Borewell	7.7	7160.00	4582.4	2240.2	601.20	179.80	1430.00	115.50	225.73	400.00	1027.20	1824.40	0.61
20	WRE2-32	Talchir	Shale	Borewell	8.2	2410.00	1542.4	839.59	188.40	89.90	260.00	16.00	17.88	520.00	505.70	189.90	0.97
21	WRE2-34	Talchir	Shale	Borewell	7.7	5910.00	3782.4	1299.3	280.60	145.80	2160.00	40.00	61.20	460.00	1023.50	2724.20	0.96
22	WRE2-36	Talchir	Shale	Borewell	8.6	947.00	606.08	139.54	24.00	19.40	292.50	18.00	5.40	212.00	57.40	230.00	0.54
23	WRE2-39	Talchir	Shale	Borewell	8.0	4400.00	2816	880.6	264.50	53.50	640.00	132.50	74.32	380.00	621.70	849.70	0.61
24	WRE2-40	Barakar	Fels pathic sst	Borewell	8.1	1476.00	944.64	479.67	120.20	43.70	200.00	21.50	19.08	300.00	73.30	135.00	0.30
25	WRE2-42	Alluvium	Gravely sand	Borewell	8.2	824.00	527.36	340.29	100.20	21.90	90.00	20.50	7.15	196.80	31.80	54.00	0.18
26	WRE2-44	Barakar	Fels pathic sst	Borewell	8.2	2500.00	1600	839.68	180.40	94.80	349.50	31.00	0.99	420.00	377.40	249.90	0.35
27	WRE2-45	Barakar	Fels pathic sst	Borewell	8.3	1240.00	793.6	1158	148.30	192.00	227.00	28.50	15.28	272.00	67.20	214.90	0.23

28	WRE2-47	Barakar	Felspathic sst	Borewell	7.8	2900.00	1856	941.47	328.70	29.20	398.00	103.00	12.27	540.00	247.90	369.90	0.28
29	WRE2-50	Barakar	Felspathic sst	Borewell	8.0	2350.00	1504	819.73	204.40	75.30	388.50	24.00	13.43	360.00	173.40	369.90	0.20
30	WRE2-52	Barakar	Felspathic sst	Borewell	8.1	1698.00	1086.7	479.69	100.20	55.90	300.00	24.00	6.91	270.00	171.00	239.90	0.40
31	WRE2-54	Talchir	Shale	Borewell	8.4	1460.00	934.4	239.81	44.10	31.60	110.00	24.00	5.56	300.00	276.00	89.00	0.44
32	WRE2-55	Talchir	Shale	Borewell	8.4	1230.00	787.2	219.79	56.10	19.40	88.00	24.00	4.93	288.00	235.70	69.00	0.65
33	WRE2-57	Talchir	Shale	Borewell	8.1	776.00	496.64	200.18	68.10	7.30	92.00	19.50	5.88	256.90	45.20	64.00	0.72

Cation Chemistry

Among the cations, Na^+ and Ca^{++} are the major constituents in the groundwater of the study area and ranges from 82 to 2160 mg/l and 24 to 601.20 mg/l respectively. The concentration of Mg^{++} from borewell samples ranges from 7.30 to 243 mg/l. The principal source of Mg^{++} in the natural waters is the magnesium bearing mineral present in the rocks. The domestic and industrial wastes also higher up the Mg^{++} concentration. Generally percentage of Mg^{++} content remains less than the Ca^{++} in groundwater samples. The K^+ contents in deeper aquifer range between 1.50 to 132.50 mg/l. The Na^+ and K^+ in groundwater samples from borewells related to weathered rock-forming minerals like sodium plagioclase, potash plagioclase and anthropogenic sources like domestic and animal waste (Marghade *et al.*, 2010). Handa (1975); Jacks *et al.*, (2005); Murkute (2014) have pointed out increased Na^+ content with decreasing Ca^{++} concentration in alkaline water conditions. However, in the present study negates such behaviour of these cations (Figure 1). Such behaviour of the Na^+ and Ca^{++} probably points out some another chemical mechanism which releases Na^+ in groundwater along with release of Ca^{++} and Mg^{++}.

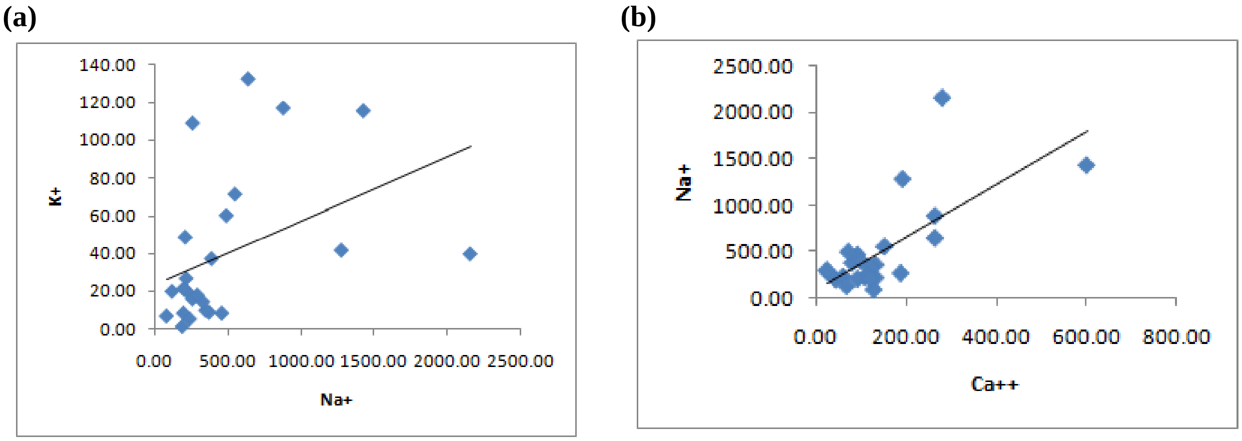


Figure 3: Interrelationship between cations a)Na^+ vs K^+ and b) Ca^{++} vs Na^+

Anion Chemistry

In groundwater samples from the study area HCO_3^- and SO_4^- are the leading ions. HCO_3^- content from the study area grades from 196.80 to 632 mg/l. The dissolution of CO_2 gas through anoxic biodegradation of organic matter derived from industrial and domestic waste in shallow aquifers is the source of HCO_3^- in groundwater (Canter, 1997; Jeong, 2001). Hitherto no health hazards due to HCO_3^- have been identified; however it should not exceed 300mg/l (WHO, 1997). However low values of HCO_3^- content is noted from the Alluvium and Barakar formation than the Talchir formation. The SO_4^- concentration grades from 31.80 to 1027.20 mg/l showing that 73 % of sample have SO_4^- concentration within potable limit (BIS, 1991). NO_3^- content varies between 0.99 to 681.95 mg/l indicating that 58.6% of groundwater samples have concentration of NO_3^- more than desirable limit (BIS, 1991). The Cl^- concentration in the water samples of the study area ranges between 54 to 2724.20 mg/l pointing that 45.5% of water samples have concentration above desirable limit (BIS, 1991). The higher value of Cl^- in the water is usually considered as pollution and indicative of groundwater contamination (Loizidou and Kapetanions, 1993). According to them the high Cl^- concentration in groundwater comes from weathering of minerals as well as from the percolation of domestic effluents and fertilizers. The F^- content in borewells of study area range between 0.18 to 1.24mg/l indicating that the groundwater from the study area have F^- concentration within permissible limit (BIS,1991).

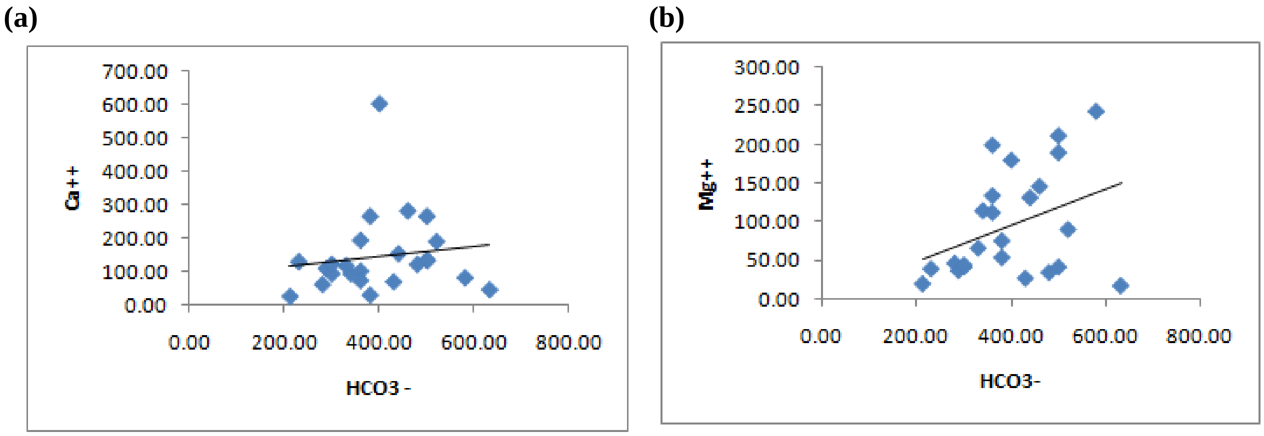


Figure 4: Relationship of cations and anions a) HCO_3^- vs Ca^{++} and b) HCO_3^- vs Mg^{++}

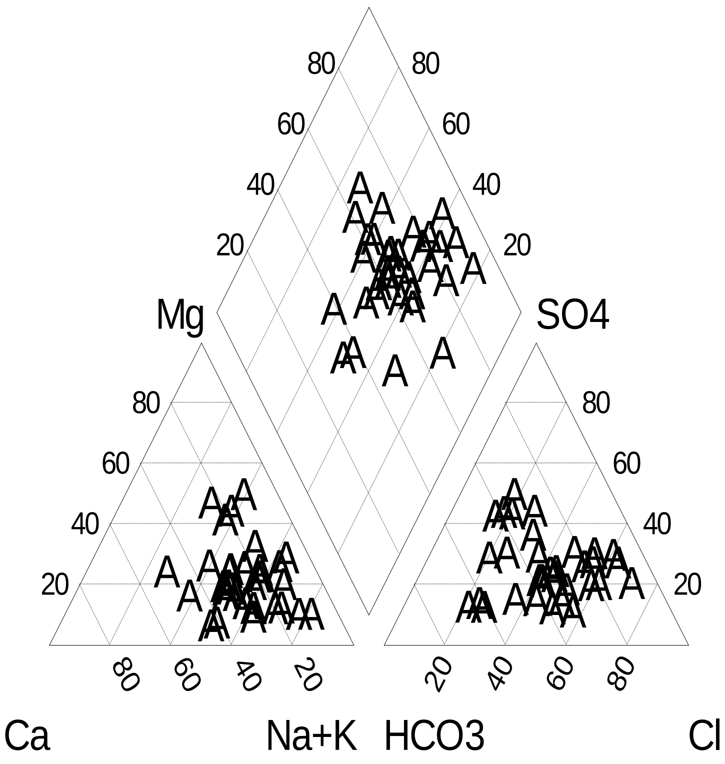


Figure 5: Piper triangular diagram of groundwater samples from study area

Rock-Water Interaction

The Ca^{++} and HCO_3^- as well as Mg^{++} and HCO_3^- show positive correlation between these ions because these cations have common tendency to combine with HCO_3^- as noted by Todd (1982). The interrelationship among $Ca^{++}+ Mg^{++}$ *vs* $SO_4 + HCO_3$ exhibits the calcium dissolution and silicate weathering for the source for Na^+ in study area (Figure 3). The interrelationship among HCO_3 and Cl *vs* Na also point out calcium dissolution and silicate weathering (Figure 4). The feldspars, calcite and clay minerals are the probable sources of Ca^{++} from sedimentary rocks (Hem, 1970; Todd, 1982; Murkute, 2014). The chief sources of Mg^{++} in natural water are the magnesium bearing minerals like pyroxenes, olivine and amphiboles (Singh *et al.*, 2010; Marghade *et al.*, 2010) while the feldspar and clay minerals are the probable sources for Na^+ and K^+. SO_4^- is generally derived from the oxidative weathering of sulphate bearing minerals like pyrite (FeS_2) which is very common secondary minerals in the Gondwana formations and associated sediments (Singh *et al.*, 2010). The F^- concentration in groundwater depends upon the degree of weathering and leaching of fluoride bearing minerals from the rocks and soils (Ramesam and Rajagopalan, 1985; Murkute and Badhan, 2011). Besides, the source of F^- is also expected to be the amphibolites and biotite (Madhnure and Malpe, 2007).

Table 4: Geochemical parameters of the study area in comparision to WHO(1997) and BIS(1991)

Major Ions	**Min**	**Max**	**Mean**	**WHO (1997)BIS**		**(1991)IS:10500**	
				Desirable	**Permissible**	**Desirable**	**Permissible**
pH	7.4	8.5	7.95	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
EC	565	1723	1144	750	1500		
TDS	362	1103	732.5	500	1500	500	2000
TH	289	1302	795.5	100	500	300	600
Ca++	62.4	431.3	246.85	75	200	75	200
Mg++	6.1	244.4	125.25	30	150	30	100
Na+	3.2	101.2	52.2	50	200	--	--
K+	2.1	61.3	31.7	100	200	--	--
NO3-	7.6	134.3	70.95	--	50	45	100
HCO3-	74	273	173.5	200	600	200	600
SO4--	5.6	356.7	181.15	200	600	200	400
Cl-	3.8	126.5	65.15	250	600	250	1000
F-	0.3	0.8	0.55	0.6-0.9	1.5	1	1.5

The geochemical evaluation of groundwater can be understood by plotting the concentration of major cations and anions in the piper diagram (Piper, 1953). In this diagram the relative abundance of cations *i.e.* Na+K, Ca and Mg in % meq/l is plotted on the cation triangle followed by the relative abundance of anions *i.e.* $Cl+NO_2=NO_3$, SO_4 and HCO_3+CO_3 in % meq/l is plotted on the anion triangle. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water (Hill, 1940; Piper, 1944). Thus, the piper diagram directly deciphers the groundwater quality, and as a result it is commonly used as an effective tool to specify different water-types. In general, piper diagram reveals six types with nine combinations, according to ionic placement in the diamond field. The Piper's trilinear diagram (Piper, 1953) prepared for the samples from the study area is presented in Figure 5. The plots of the chemical data on Piper's trilinear diagram show that non carbonate alkalis exceed 50% in the groundwater samples of the study area. In addition, some plots on Piper's trilinear diagram also suggest no one cation-anion pair exceeds 50%. In general, 26 water facies are noted from the study area, out of which Na-Ca-HCO3-Cl water-type is the dominant facies (34%).

Water Quality Assessment

Table 5: Irrigation quality test results of water samples from study area

Se. No.	Sample No.	Formation	SAR	% Na	RSC	MR
1	WRE2-1	Talchir	6.158	8.587	27.991	38.813
2	WRE2-3	Talchir	4.083	15.277	14.984	33.936
3	WRE2-5	Talchir	5.802	24.156	11.397	81.514
4	WRE2-8	Alluvium	5.235	12.670	7.192	55.849
5	WRE2-9	Talchir	4.671	16.751	4.996	83.294
6	WRE2-10	Talchir	4.395	15.873	0.992	72.447
7	WRE2-11	Talchir	4.603	13.163	5.986	35.695
8	WRE2-12	Alluvium	6.841	15.931	15.190	31.762
9	WRE2-15	Alluvium	10.001	20.780	6.991	42.433
10	WRE2-17	Barakar	1.627	4.907	1.884	33.285
11	WRE2-18	Talchir	3.255	9.565	2.993	67.085
12	WRE2-20	Talchir	3.119	9.733	15.895	39.216
13	WRE2-23	Talchir	4.411	11.086	5.292	48.159
14	WRE2-24	Alluvium	5.997	19.791	1.989	68.708
15	WRE2-26	Alluvium	15.439	56.978	-8.016	63.025
16	WRE2-28	Barakar	7.887	28.093	3.590	58.636
17	WRE2-29	Talchir	10.086	42.549	-3.816	54.106
18	WRE2-30	Talchir	8.439	25.683	5.195	71.844
19	WRE2-31	Talchir	13.137	64.890	-24.848	32.982
20	WRE2-32	Talchir	3.901	12.744	9.182	43.984
21	WRE2-34	Talchir	26.049	94.805	-3.025	46.092
22	WRE2-36	Talchir	10.762	15.604	9.402	57.084
23	WRE2-39	Talchir	9.379	34.775	1.373	24.972
24	WRE2-40	Barakar	3.970	11.616	5.393	37.432
25	WRE2-42	Alluvium	2.122	8.575	3.131	26.452
26	WRE2-44	Barakar	5.243	17.619	4.179	46.373
27	WRE2-45	Barakar	2.899	12.030	-9.344	68.055
28	WRE2-47	Barakar	5.642	24.104	8.161	12.754
29	WRE2-50	Barakar	5.899	18.709	1.584	37.741
30	WRE2-52	Barakar	5.954	15.687	3.890	47.863
31	WRE2-54	Talchir	3.087	10.800	11.526	54.110
32	WRE2-55	Talchir	2.581	10.769	11.063	36.267
33	WRE2-57	Talchir	2.828	9.864	8.938	14.994

The data obtained by geochemical analyses are evaluated in terms of suitability for drinking, irrigation, livestock and industrial uses.

Drinking and General Domestic Use

The prescribed limits of WHO (1997) and Indian drinking water standards (BIS, 1991) were used to assess the suitability for drinking and public health purposes (Table 4). The major objectionable physico-chemical parameters are TDS, total hardness (TH) and sulphate. Carrol (1962) has propounded the relationship of TDS and salinity as 0-1000 (mg/l), fresh water; 1000-10000 (mg/l), brakish water; 10000-100000 (mg/l), saline water and >100000 (mg/l) it is brine. According to his classification scheme the 27% groundwater samples from borewell from the study area is fresh water.

However, 77% of groundwater samples are brakish water and such high salinity in few samples is attributed to concentration of soluble salts within the geological formation (Todd, 1980). Based on TH, Sawyer and Mccarty (1967) have categorized the water as soft (< 75mg/l) moderately hard (75-150mg/l), hard (150-300 mg/l) and very hard water (> 300mg/l). The analyzed data indicate that only 18% groundwater samples have TH value lesser than 300 mg/l, which is the desirable limit as per BIS (1991), and remaining 82% are of very hard type.

The long term consumption of very hard water leads in increase incidences of urolithiasis, some types of cancer, permanent mortality, anecephaly and cardio-vascular disorders (Agrawal and Jagetia, 1997; Durvey *et al.*, 1991). 73% groundwater samples in the study area have the SO_4^- concentration less than 400 mg/l which is the permissible limit of BIS (1991). However, the water with 200-400 mg/l SO_4^- has a bitter taste and it may also cause corrosion of metals particularly in water with low alkalinity (Singh *et al.*, 2010).

Irrigation Use

In the present study, the suitability of groundwater has been checked for irrigation purpose using Sodium Absorption Ratio (SAR), Percent Sodium (%Na), Residual Sodium Carbonate (RSC), Mg Ratio (MR), Corrosivity Ratio (CR) (Table 5).

Sodium Absorption Ratio (SAR): The Sodium Absorption Ratio (SAR) is defined by the expression: SAR = $Na^+ / \sqrt{[(Ca^{++}+Mg^{++})/2]}$. Water with SAR value ≤10 is considered as of excellent quality, 10 to 18 is good, from 18 to 26 is fair and above 26 is said to be unsuitable for irrigation. The calculated SAR values in study area range from 1.627 to 26.049 meq/l. The major plots of groundwater sample fall in C4-S2 and C3-S2 with minor plots in C3-S1 in US Salinity diagram (1954), which indicate groundwater is of medium to high salinity-medium sodium type (Figure 6) and thus can be utilized for irrigation with little danger of exchangeable sodium.

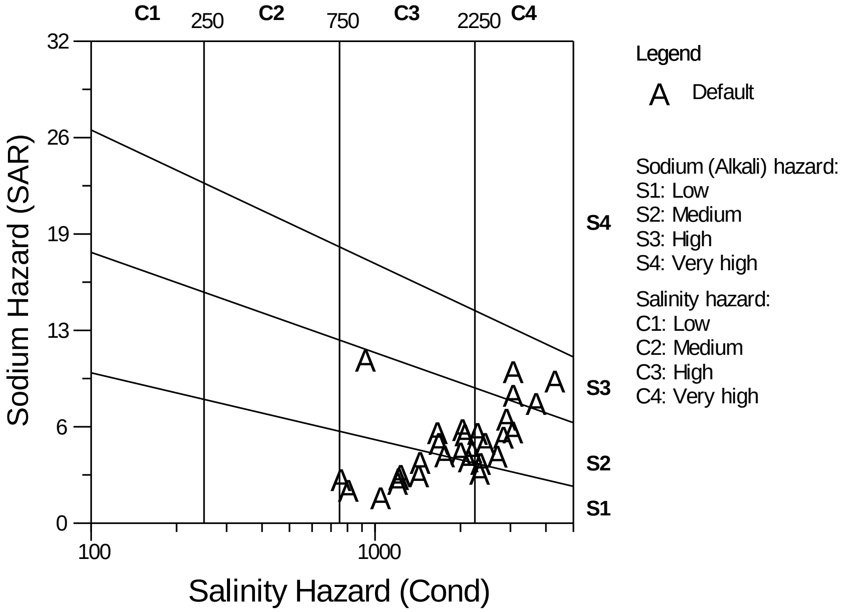


Figure 6: US salinity diagram of groundwater samples from study area

Percent Sodium (%Na): The % Na is widely used for evaluating the suitability of water quality for irrigation (Wilcox, 1995). It is defined by the expression: %Na= $Na^++K^+/(Ca^{++}+Mg^{++}+Na^++K^+)$ x 100. High % Na in irrigation water causes exchange of sodium in water, and exchange of calcium and magnesium contents in soil having poor internal drainage. The %Na in study area ranges from 4.907 to 94.805 meq/l. out of total samples 94% samples have the % Na < 60 represents safe water while 6% of samples have > 60 that is unsafe (Eaton, 1950) from study area for irrigation purpose.

Residual Sodium Carbonate (RSC): A high value (in meq/l) in water leads to an increase in the adsorption of sodium on soil (Eaton 1950). It is calculated by following as RSC = $(HCO_3^- + CO_3^-) - (Ca^{++} + Mg^{++})$. The RSC values < 1.25 meq/l are considered as suitable for the irrigation and in study area only 18% groundwater sample are suitable for irrigation.

Mg Ratio (MR): Magnesium ratio (MR) is calculated as MR = $(Mg^{++} \times 100)/(Ca^{++} + Mg^{++})$. The MR values >50 are unsuitable. Excess amount of magnesium can affect the quality of soil reduces the yield of crops. About 39 % samples from the study area are not suitable for irrigation while 61% samples are suitable for irrigation.

Corrosivity Ratio (CR): Corrosivity Ratio (in mg/l) is calculated by the following formula: CR= $[(Cl^-/35.5) + 2(SO_4^{--}/96)]/2(HCO_3^- + CO_3^{--}/100)$. The CR values ≤ 1 is considered as good and > 1 indicates corrosive nature of water, hence water should not be transported through the metal pipes (Ryner, 1994 and Raman, 1985). In the study area only the 6% samples have CR values ≤ 1 and remaining 94% of samples have CR value >1 which indicates that only 6% water in these areas is good for irrigation.

Conclusion

The groundwater from deeper aquifer of the watershed WRE2 area is alkaline in nature. The higher conductivity in the study area is due to high mineral concentration in groundwater. It indicates that the ion exchange and solublization processes have taken place within the aquifer. The Ca^{++} and HCO_3^- as well as Mg^{++} and HCO_3^- show positive correlation between these ions. The interrelationship among $Ca^{++} + Mg^{++}$ *vs* $SO_4 + HCO_3$ as well as HCO_3 and Cl *vs* Na exhibits the calcium dissolution and silicate weathering for the source for Na^+ in study area. The feldspars, calcite and clay minerals are the probable sources of Ca^{++} from sedimentary rocks. The chief sources of Mg^{++} in natural water are the magnesium bearing minerals like pyroxenes, olivine and amphiboles while the feldspar and clay minerals are the probable sources for Na^+ and K^+. SO_4^- is generally derived from the oxidative weathering of sulphate bearing minerals like pyrite (FeS_2) which is very common secondary minerals in the Gondwana formations and associated sediments. The F^- concentration in groundwater depends upon the degree of weathering and leaching of fluoride bearing minerals from the rocks and soils. The 27% groundwater samples from the study area are fresh water and can be suitable for drinking and domestic use. The major plots of groundwater sample in C4-S2 and C3-S2 with minor plots in C3-S1 class of US salinity diagram indicate groundwater is of medium to high salinity-medium sodium type and thus can be utilized for irrigation with little danger of exchangeable sodium.

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