Journal of Geosciences and Geomatics, 2014, Vol. 2, No. 5A, 22-28
Available online at http://pubs.sciepub.com/jgg/2/5A/5

DOI:10.12691/jgg-2-5A-5

Hydro-chemical Analysis and Evaluation of Groundwater Quality of Hial Area, Bolangir District, Odisha, India

S.R. Barick, B.K. Ratha*

P.G. Department of Geology, Utkal University, Bhubaneswar, Odisha, India
*Corresponding author: rathabk62@gmail.com

Received November 01, 2014; Revised November 10, 2014; Accepted November 20, 2014

Abstract Ground water is a scarce resource in most part of Odisha as 80 percent of its area is underlain by hard rocks. As the study area is drought prone most people depend on ground water for drinking and agriculture. Hence, constant monitoring and assessment of water resource is necessary. With this purpose the present study area Hial, a part of Bolangir district of Odisha, India is chosen. Water samples were collected from the study area for quality evaluation during pre monsoon period of 2010. They were analyzed for physical parameters such as pH, EC, TDS and chemical parameters such as Ca, Mg, Na, K, Cl, HCO_3, CO_3, SO_4, F. Suitability of groundwater for purposes such as drinking, irrigation and industrial was evaluated following various classification schemes and water quality standards. The water quality study reveals that pH of the water varies from 7.23-8.35, EC ranges from 69.3-1345 µmho/cm, TDS values range from 238 to 777.3 mg/l, total alkalinity values range from 84-420 mg/l, total hardness values range from 88 to 452 mg/l. Analytical study of water samples reveals that calcium varies from 8 to 174.4 mg/l, magnesium varies from 2.9 to 78.1 mg/l, sodium varies from 9.4 to 176.5 mg/l, potassium varies from 0.1 to 12.5 mg/l, chloride values range from 8.5 to 195.68 mg/l, carbonate values range from 0 to 33.6 mg/l, bicarbonate values range from 82.96 to 512.4 mg/l, sulphate values range from 0 to 76 mg/l, fluoride values range from 0.25 to 2.8 mg/l in water of the area. Piper Trilinear plot shows most ground water samples as Mg-HCO^3 and Ca-HCO^3 type. From Richard’s salinity diagram it is observed that most of the samples are plotted in C3-S1 field indicating low Sodium Adsorption Ratio and high salinity hazard. The water chemistry of the area is controlled by lithology of the area.

Keywords: *groundwater, Bolangir, Odisha, India*

Cite This Article: S.R. Barick, and B.K. Ratha, “Hydro-chemical Analysis and Evaluation of Groundwater Quality of Hial Area, Bolangir District, Odisha, India.” *Journal of Geosciences and Geomatics*, vol. 2, no. 5A (2014): 22-28. doi: 10.12691/jgg-2-5A-5.

1. Introduction

Water is most important natural resource for man. The different forms of water are surface water and ground water. Out of this total water, 97.2% is saline confined to the ocean, leaving only 2.8% as fresh of which about 2.2% is available as surface water and 0.6% as ground water. Ground water is one of the earth’s most widely distributed resources and is increasingly catering to the need of the domestic, industrial and agricultural sectors. Ground water is located in the pore space of soil and rock. The value of ground water as a resource lies in the fact that it is dependable even during the period of scarcity and drought, widely distributed and can be put into use with ease and speed. Surface water and groundwater are closely interconnected. The occurrence and availability of groundwater is governed by the interactions of numerous environmental factors especially climate, topography, vegetation, soil and geology of an area. However, considering its use for drinking purpose, agriculture and industry its quality assessment is essential. With this purpose the present study was carried out in Hial area of Bolangir district of Odisha.

2. Location and Hydrogeological Setting

The study area exists between 82° 47’ 30” to 82° 56’ longitude and 20° 24’ to 20° 30” latitude in the Toposheet No. 64L/15 and belong to Bolangir district of Odisha. The area is underlain by hard rocks, which are khondalites, granite gneisses, calc-sillicate rocks, anorthosites and quartzites. They all belong to Eastern Ghats Super Group. Granite gneisses are major rocks of the area followed by khondalites. Calc-sillicate rocks form low hills and occur associated with khondalites. The hydrogeological framework of the area is mainly controlled by geological set up, rainfall distribution and degree of primary and secondary porosity in the geological formations. Since major part of the area is underlain by hard rock of diverse lithological composition and structure, the water bearing properties of the formations also vary to a great extent. Lithological character and tectonic deformation present in rocks play a great role in their water bearing and water yielding properties. The hard rock recharge ground water from precipitation or seepage from surface water bodies which percolate into the weathered zone. Here the groundwater occurs in unconfined condition where as in the fractured bed rocks lying below the weathered zone it occurs under semi confined to confined condition. Water occurs 5 to 10 meters below the ground level in most part of the area. Most people of the area depend on agriculture for their livelihood. As surface water source is limited people use ground water both for drinking and agriculture. (Sarkar and Naik, 2011)

3. Materials And Methods

Thirty water samples were collected from tube wells of the area (Figure 1) during pre monsoon period of November, 2010. Air tight rectified polythene bottles were used to collect the samples. Sample bottles were thoroughly washed with ground water collected at the spot. Bottles were completely filled with water without air gaps and were sealed. The pH and electrical conductance were measured on the spot by using pH meter and conductivity meter respectively. Ca and Mg were determined by titration method using standard EDTA. Chloride was determined by silver nitrate solution. Phenolphthalein Alkalinity and total Alkalinity is determined by titrating the samples against HCl solution using phenolphthalein indicator and methyle orange indicator. Carbonate and bicarbonate in the samples were determined from alkalinity. Sulphate was determined gravimetrically by precipitating $BaSO_4$ from $BaCl_2$. Na and K were determined by flame photometer. Total hardness of the water was determined by complexometric titration with EDTA. EDTA acts as a complexing reagent, which forms soluble complexes with metal ions like Ca^{++} and Mg^{++}. Since Ca/Mg – EDTA complexes are stable at pH 8-10, the pH of the solution during the titration was maintained at 10 by adding a suitable buffer such as NH_4OH solution using Eriochrome black T, as indicator. Fluoride was determined by ion selective electrode method.

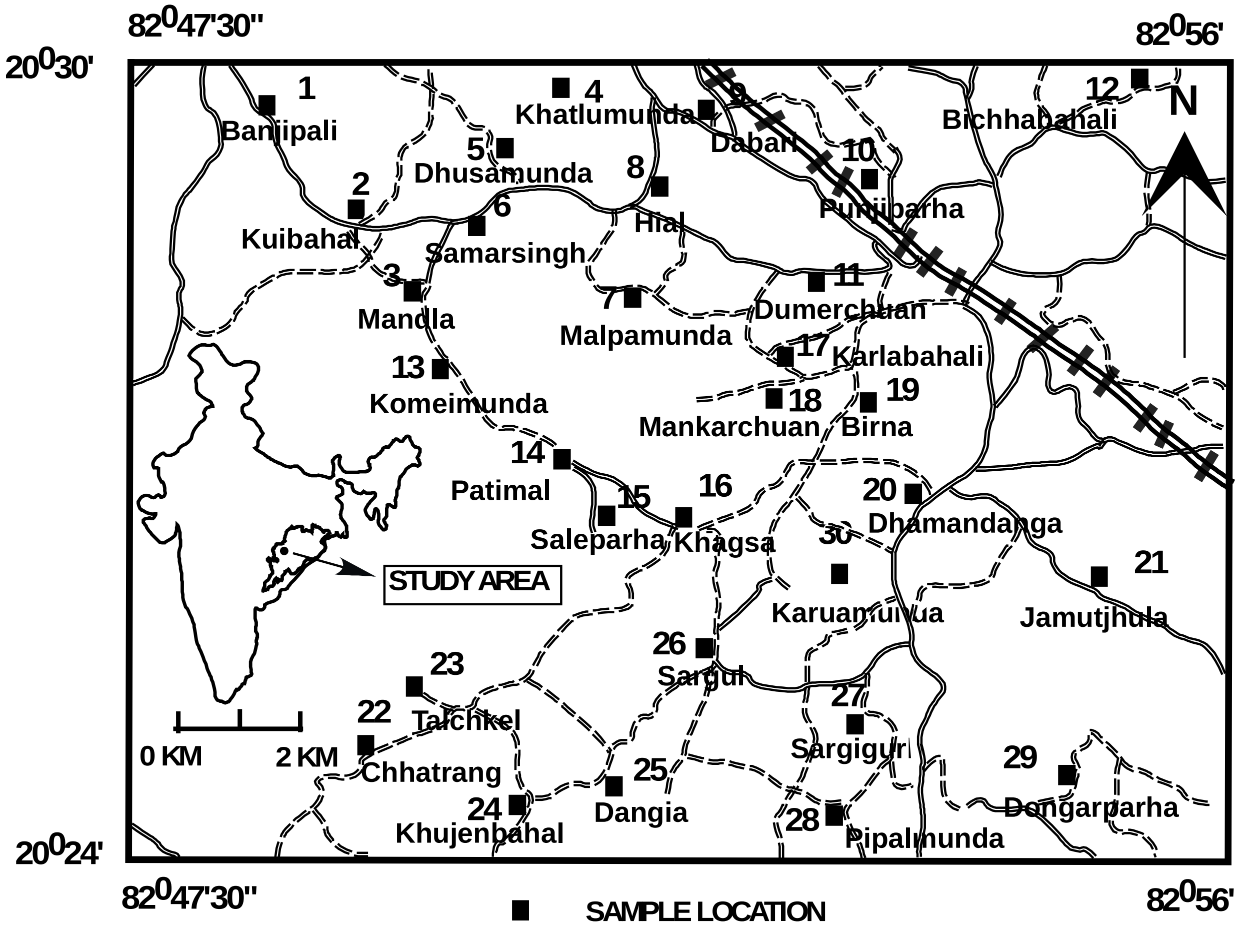

Figure 1.

4. Result and Discussion

The water quality study reveals that pH of the water varies from 7.23-8.35, EC ranges from 69.3-1345 µmho/cm, total dissolved solids(TDS) values range from 238 to 777.3 mg/l, total alkalinity(TA) values range from 84-420 mg/l, total hardness(TH) values range from 88 to 452 mg/l. Analytical study of water samples reveals that calcium varies from 8 to 174.4 mg/l, magnesium varies from 2.9 to 78.1 mg/l, sodium varies from 9.4 to 176.5 mg/l, potassium varies from 0.1 to 12.5 mg/l, chloride values range from 8.5 to 195.68 mg/l, carbonate values range from 0 to 33.6 mg/l, bicarbonate values range from 82.96 to 512.4 mg/l, sulphate values range from 0 to 76 mg/l, fluoride values range from 0.25 to 2.8 mg/l in water of the area. Analytical data of water samples are given in Table 1 and other parameters such as Sodium Adsorption Ratio(SAR), Sodium Percentages(SP), Kelly's Ratio(KR), Magnesium Adsorption Ratio(MAR), Soluble Sodium Percentage(SSP), Permeability Index(PI), Potential Soil Salinity(PS) as derived from water analytical data are given in Table 2.

Table 1. Analytical data of water samples

Sl. No	Place	pH	EC, µmhos/cm	TA as $CaCO_3$ mg/L	TH CaCO3 mg/L	Ca, mg/L	Mg, mg/L	Na, mg/L	K, mg/L	Cl, mg/L	SO_4, mg/L	CO_3, mg/L	HCO_3, mg/L	F, mg/L
1	Banjipali	7.8	962	184	364	97.6	29.8	61.1	1	144.63	42	0	224.46	0.5
2	Kuibahal	7.86	699	252	256	62.4	24.4	69.6	1.6	23.736	20	0	307.44	0.5
3	Mandla	8.32	828	208	216	9.6	46.848	28.4	1.9	93.588	0	14.4	224.48	0.5
4	Khatlumunda	8.34	873	400	332	22.4	67.344	65	7.4	79.408	5	4.8	478.24	2
5	Dhusamunda	7.96	806	392	204	33.6	29.28	110.3	1	14.18	30	0	478.24	2.1
6	Samarsingh	7.85	833	412	308	64	36.112	70	0.6	56.72	0	0	502.64	2.1
7	Malpamunda	8.34	1243	236	348	11.2	78.08	167	10	196.68	29	28.8	229.36	2.6
8	Hial	8.34	69.3	212	104	8	20.496	156.5	2	53.884	76	33.6	190.32	2.8
9	Dabari	7.48	960	348	388	76.8	47.824	39.7	0.5	45.376	10	0	424.56	1.8
10	Punjiparha	7.83	1098	392	164	36.8	17.568	168	2.5	73.736	0	0	478.24	0.5
11	Dumerchuan	7.68	817	420	388	35.2	73.2	33.1	1.1	8.58	5	0	512.4	2
12	Bichhabahali	8.35	504	232	272	48	37.088	9.4	0.8	25.524	10	14.4	253.76	0.25
13	Komeimunda	8.34	1345	332	388	32	75.152	32.4	2.4	170.16	5	33.6	336.72	1.25
14	Patimal	8.34	873	400	332	22.4	67.344	65	7.4	79.408	5	4.8	478.24	1.25
15	Saleparha	7.95	830	184	212	33.6	31.232	57.1	1.1	76.572	5	0	224.48	1.25
16	Khagsa	7.99	1210	284	248	40	36.112	100	6	119.11	10	0	346.48	0.5
17	Karlabahali	8.32	830	332	328	9.6	74.176	74.8	1.1	76.572	28	.33.6	336.72	2.2
18	Mankarchuan	7.86	1108	280	88	9.6	15.616	176.5	2.5	73.736	15	0	341.6	1.8
19	Birna	7.94	708	228	224	49.6	22.4	45	0.9	17.016	30	0	278.16	2
20	Dhamandanga	7.65	561	220	204	76.8	2.928	33.1	1.3	25.524	0	0	268.4	2.6
21	Jamutjhula	7.86	603	164	248	60.8	23.424	11.5	0.8	62.392	10	0	200.06	0.5
22	Chhatrang	8.34	270	84	108	19.2	14.64	87	0.8	14.18	10	9.6	82.96	0.25
23	Talchkel	8.33	486	228	172	27.2	25.376	67	8.8	22.688	0	9.6	258.64	0.45
24	Khujenbahal	8.19	1216	292	316	72	33.184	86	3	45.376	60	0	356.24	0.25
25	Dangia	7.91	1065	216	268	70.4	22.448	78	12.5	144.64	5	0	263.52	0.25
26	Sargul	7.99	1210	284	248	40	36.112	100	6	119.11	10	0	346.48	0.5
27	Sargigurh	7.6	609	284	272	80	17.568	14.5	0.6	11.344	5	0	346.48	0.5
28	Pipalmunda	7.23	1203	268	452	174.4	3.904	26.5	0.8	104.93	45	0	326.96	0.25
29	Dongarparha	7.96	592	192	256	51.2	31.232	29.8	1.1	59.556	10	0	234.24	0.25
30	Karuamunda	7.81	551	248	228	75.2	9.76	19.5	0.1	8.508	0	0	302.56	2.1

Table 2. Derived parameters of water samples

1	Banjipali	Ca-Cl	1.39	33.5	0	26.84	0.36	5.01	45.88
2	Kuibahal	Ca-HCO3	1.89	39.2	0	37.48	0.59	1.31	64.72
3	Mandla	Mg-HCO3	0.84	88.9	0	22.89	0.29	2.64	56.61
4	Khatlumunda	Mg-HCO3	1.55	83.2	1.29	31.19	0.42	2.56	59.33
5	Dhusamunda	Na-HCO3	3.36	59	3.61	54.13	1.17	1.198	5.49
6	Samarsingh	Ca-HCO3	1.73	48.2	1.86	33.15	0.49	1.60	64.245
7	Malpamunda	Na-Cl	3.89	92	0	51.82	1.04	6.30	64.56
8	Hial	Na-HCO3	6.67	80.9	1.6	76.66	3.26	2.78	96.37
9	Dabari	Mg-HCO3	0.876	50.7	0	18.32	0.22	1.74	45.98
10	Punjiparha	Na-HCO3	5.7	44	4.34	69.15	2.22	2.08	95.38
11	Dumerchuan	Mg-HCO3	0.73	77.4	0.28	15.87	0.19	0.56	47.05
12	Bichhabahali	Mg-HCO3	0.25	56	0	7.30	0.08	1.17	41.79
13	Komeimunda	Mg-HCO3	0.72	79.5	0	15.89	0.18	5.12	40.91
14	Patimal	Mg-HCO3	1.55	83.2	1.29	31.19	0.42	2.56	59.33
15	Saleparha	Mg-HCO3	1.7	60.5	0	37.11	0.58	2.48	65.35
16	Khagsa	Na-HCO3	2.76	59.8	0.62	47.52	0.88	3.81	72.25
17	Karlabahali	Mg-HCO3	1.79	92.7	0	33.26	0.49	2.92	56.97
18	Mankarchuan	Na-HCO3	8.17	72.8	3.69	81.40	4.34	2.64	106.32
19	Birna	Ca-HCO3	1.31	44.8	0	30.63	0.44	0.73	63.49
20	Dhamandanga	Ca-HCO3	1.01	5.91	0.13	26.57	0.35	0.72	64.19
21	Jamutjhula	Ca-HCO3	0.32	38.8	0	9.49	0.10	2.22	42.33
22	Chhatrang	Na-HCO3	3.64	55.7	0	63.78	1.75	0.86	83.30
23	Talchkel	Na-HCO3	2.22	60.6	0.96	47.61	0.84	0.64	78.13
24	Khujenbahal	Na-HCO3	2.1	43.2	0	37.65	0.59	2.40	61.20
25	Dangia	Ca-HCO3	2.07	34.5	0	40.90	0.63	4.40	62.50
26	Sargul	Na-HCO3	2.76	59.8	0.62	47.54	0.88	3.81	72.25
27	Sargigurh	Ca-HCO3	0.38	26.6	0	10.61	0.12	0.64	49.65
28	Pipalmunda	Ca-HCO3	0.54	3.56	0	11.48	0.13	3.93	34.07
29	Dongarparha	Mg-HCO3	0.81	50.1	0	20.56	0.25	2.13	50.69
30	Karuamunda	Ca-HCO3	0.56	17.6	0.26	15.62	0.18	0.24	56.90

5. Mechanism Controlling Ground Water Quality

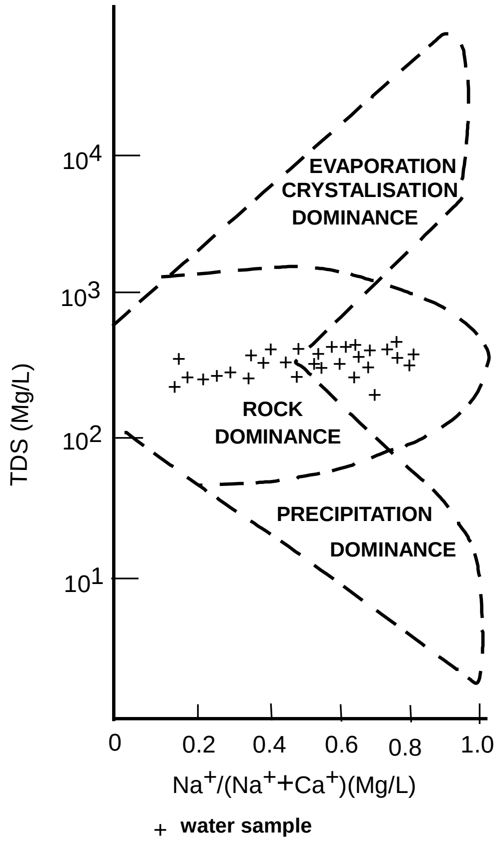

Figure 2. Gibbs diagram for Cations

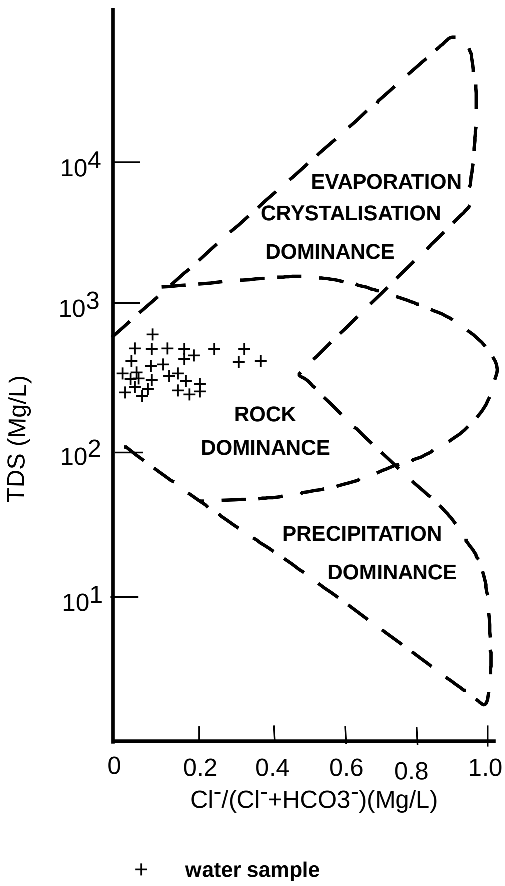

Figure 3. Gibbs diagrams for Anions

According to the source of contributing ions in ground water the Gibbs diagram (Gibbs, 1970) has three distinct fields: precipitation dominance, rock dominance and evaporation dominance. The Gibbs ratio Na / (Na+Ca) for cations and Cl / (Cl+HCO_3) for anions of water samples are plotted separately against the respective TDS. Both type show rock dominance in controlling the quality of ground water (Figure 2 & Figure 3). Gibbs diagram suggests that chemical interaction between rock forming minerals of aquifer and the groundwater is the main mechanism in contributing ions to the ground water. Hence, Fluoride may have been leached out from rocks contaminating ground water. Calc-sillicate rocks associated with khondalites may have contributed the calcium and magnesium ions in abundance to the ground water.

6. Hydrochemistry of Ground water

Piper (1944, 1953) introduced a Trilinear diagram used to evaluate the geochemical evolution of groundwater and relationship between rock type and water composition. Analysis of piper's trilinear plot show that most of ground water samples are of Mg-HCO^3 and Ca-HCO^3 type (Figure 4). The facies mapping approach (Back, 1961) is adopted in the present study to determine the hydrochemical facies of groundwater. The hydrochemical variation and distribution of facies of groundwater throughout the study area shows that 83 percent samples fall in the magnesium-calcium facies. Out of 30 samples 90 percent of samples fall in bicarbonate-chloride field.

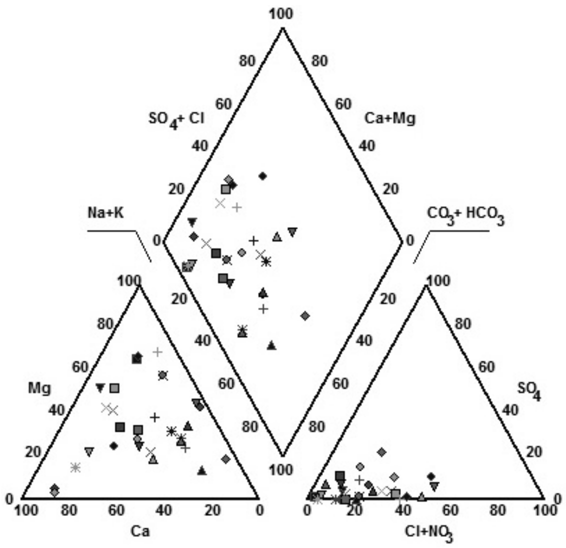

Figure 4. Piper Trilinear diagram of Cations and Anions of the study area

6.1. Ground Water Quality

Ground water quality is evaluated to know the suitability of groundwater for drinking, gricultural and industrial uses.

6.2. Drinking Water Quality

The drinking water quality of the area can be evaluated by comparing with Indian Standard Specification for drinking water (BIS-1991). 63 percent of samples exceeds the Highest Desirable Limit(HDL) for TDS, 36 percent samples exceeds the HDL for total hardness, 83 percent samples exceeds the HDL for total alkalinity, 46 percent exceeds the HDL for fluoride. 50 percent samples are not suitable for drinking (Table 3).

Table 3. Drinking water quality parameter

Quality parameter	BIS-1991		Number of samples exceeding HDL	% of samples Exceeding HDL
	Highest Desirable Limit (HDL)	Maximum Permissible Limit(MPL)		
pH	6.5-8.5	No relaxation	Nil	
TDS	500	2000	19	63
TH	300	600	11	36
TA	200	600	25	83
Ca^{+2}	75	200	5	16
Mg^{+2}	30	100	14	46
Cl^{-}	250	1000	Nil	
$SO4^{-2}$	200	400	Nil	
F^{-}	1	1.5	14	46

All values are in Mg/L except pH.

6.3. Agricultural Quality

The following are important characteristic properties of groundwater to determine its suitability for irrigation in the present study:

- **Based on Sodium Adsorption Ratio (SAR):**

Sodium Adsorption Ratio is one of the criteria to study the suitability of water for irrigation. SAR has direct relation to the adsorption of sodium by soil and hence needs to be assessed.

SAR is calculated as per the following formula:

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

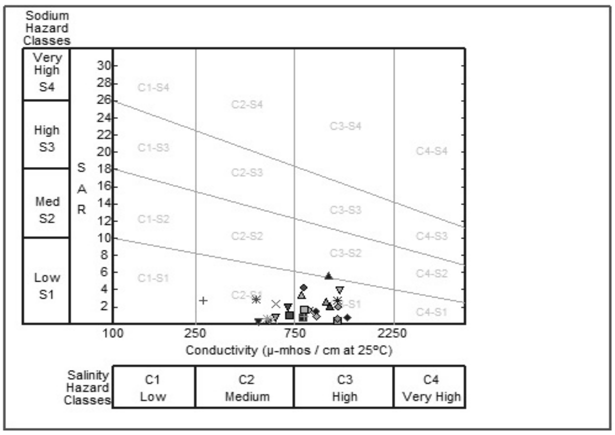

Figure 5. US salinity diagram of the water samples

Here, the concentration is expressed in meq/litre. On the basis of SAR value, the suitability of groundwater for irrigation purposes is determined. The SAR values of the groundwater for the study area varies from 0.248 (Bichhabahali) to 8.17 (Mankarchuan).The United States Salinity Laboratory (USSL) (Richards, 1954) has constructed a diagram for classification of irrigation water describing 16 classes with reference to SAR as an index for Sodium hazards(S) and EC as an index of salinity hazards (C).Sodium and salinity hazards are two important parameters, which can indicate the suitability of water for irrigation uses. USSL diagram for water samples of the area reveal that 13 no. of samples fall in C2-S1 field. 17 samples fall in C3-S1 field. From Richard's salinity diagram it is observed that most of the samples are plotted in C3-S1 field indicating low Sodium Adsorption Ratio and high salinity hazard. Plottings of different water samples are given in Figure 5.

- **Based on Sodium Percentages (% Na):**

Wilcox (1955) defined the sodium percentages as;

$$\%\mathrm{Na} = \frac{\mathrm{Na}+\mathrm{K}}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}+\mathrm{K}} \times 100$$

Here all the values are in meq/l. The different water classes for irrigation on the basis of % Na value are given in Table 4.

Table 4. Classification of water based on % Sodium

CLASSIFICATION OF WATER BASED ON % SODIUM			
% Na	**Water Class**	**No of Samples**	**% of Samples**
Up to 20	Excellent	8	27
20 - 40	Good	12	40
40 - 60	Permissible	6	20
60 - 80	Doubtful	3	10
> 80	Unsuitable	1	3

The % Na value of the water for the study area varies from 7.29 (Bichhabahali) to 81.4 (Mankarchuan). Out of the 30 samples, 12 samples are excellent to good class for irrigation and 17 samples are good class for irrigation. One sample of Punjiparha is found as not suitable for irrigation. All samples are shown in Figure 6.

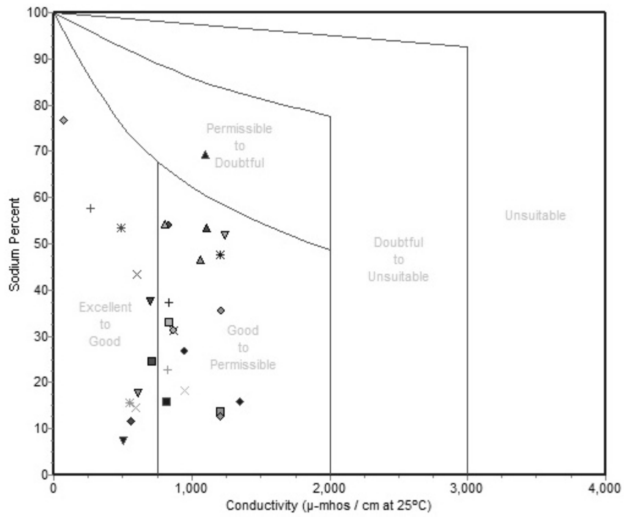

Figure 6. Wilcox diagram of the water samples

- **Based on Kelly's Ratio (KR):**

Kelly defined the Kelly's Ratio as

$$\mathrm{KR} = \frac{\mathrm{Na}}{\mathrm{Ca}+\mathrm{Mg}}$$

Here all the values are in meq/l (Kelly, 1957, 1963). The water quality is good for irrigation, when Kelly's Ratio is less than 1. The KR values of the water samples of the study area indicate that all samples are good for irrigation except five samples. Mankarchuan sample has highest value of Kelly's Ratio i.e. 4.34 indicating its unsuitability for irrigation.

- **Based on Magnesium Adsorption Ratio (MAR):**

Magnesium Adsorption Ratio is defined as-

$$MAR = \frac{Mg \times 100}{Ca + Mg}$$

The highest MAR value of the water samples of the study area varies from 3.56 to 92.7. Highest value is recorded at Karlabahali.

- **Based on Permeability Index (PI):**

Permeability Index is calculated by using the following formula;

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100$$

Here all the values are in meq/l.

The PI values of the study area varies from 34.07 to 106.32. One samples (PI > 80) fall in class III of Doneen's chart (Doneen, 1962) indicating its unsuitability for irrigational purpose for the soil. Four samples fall in Class-II field. 25 samples fall in Class-I field (Figure 7).

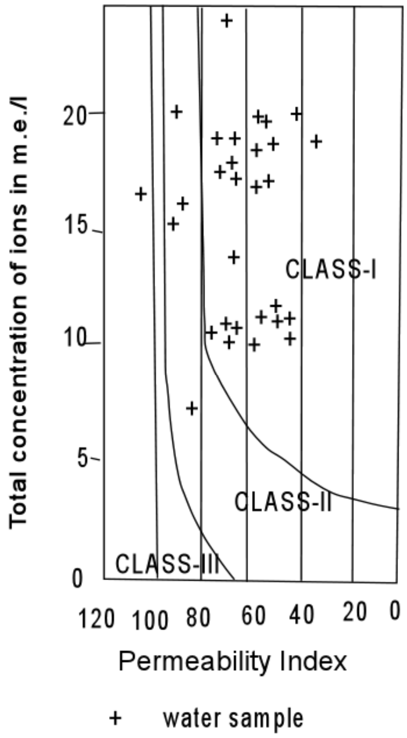

Figure 7. Permeability Index diagram for water samples of the area

- **Based on Potential Soil Salinity (PS):**

Potential Soil Salinity is calculated by using the following formula;

$$PS = Cl + \sqrt{SO_4}$$

Here all the values are in meq/l.

The PS values of the study area varies from 0.24 to 6.29. Out of 30 samples 20 samples are excellent to good, 3 samples are good to injurious (Table 5).

Table 5. Classification based on Potential Soil Salinity

CLASSIFICATION BASED ON POTENTIAL SOIL SALINITY		
Class	**Potential Soil Salinity in epm**	**No. of Samples**
Excellent to Good	<5	20
Good to Injurious	5-10	3
Injurious to Unsatisfactory	>10	0
Total		**30**

- **Based on Residual Sodium Carbonate (RSC):**

The relative abundance of sodium with respect to excess of carbonate and bicarbonate over alkaline earth affects the suitability of water for irrigation purpose. Residual Sodium Carbonate id determined by applying the following formula;

$$\mathbf{RSC} = (\mathbf{CO_3} + \mathbf{HCO_3}) - (\mathbf{Ca} + \mathbf{Mg})$$

Here all the values are in meq/l.

The RSC values vary from 0 to 4.34.

With respect to RSC values, the groundwater can be classified into following categories.

Table 6. Classification 0f groundwater based on RSC

CLASSIFICATION 0F GROUNDWATER BASED ON RSC			
RSC	**Category**	**No. of Samples**	**% of Samples**
< 1.25	Good/Safe	24	80
1.25 - 2.5	Medium/Marginal	3	10
> 2.5	Bad/Unsuitable	3	10

All the RSC values of the water samples of the study area are less than 1 and are classified under good and safe category and are good for irrigational purposes.

7. Conclusion

The ground water of the area occurs under confined to unconfined aquifer condition in weathered and fractured granite gneisses and khondalites. SAR, %Na, PI values suggest suitability of most water samples for irrigation purposes. From Richard's salinity diagram it is observed that most of the water samples are plotted in C2-S1 and C2-S3 field indicating low sodium and medium to high salinity hazard. The water chemistry of the area is controlled by lithology of the area. Fluoride contamination is common in most of the samples. Hence, defluoridation technique should be adopted before using the water for drinking purposes.

References

[1] Back, W. (1961) Techniques for mapping of hydrochemical facies.USGS Prof. Paper 424-D, pp. 380-382.
[2] Domenico, P.A. and Schwartz, F.W. (1990) Physical and chemical Hydrogeology. John Wiley and sons. New York. pp. 410-420.
[3] Doneen, L.D. (1962). The influence of crop and soil on percolating water. Proc. 1961. Biennial conference on Groundwater Recharge, pp. 156-163.
[4] Gibbs, R.J. (1970) Mechanism controlling world water chemistry. Science, v170, pp. 1088-1090.
[5] BIS (1991). Indian standard drinking water specification, Bureau of Indian standard.
[6] Kelly, W.P. (1957) Adsorbed Sodium, cation exchange capacity and percentage sodium adsorption in alkali soils, sci., vol. 84, pp. 473-477.
[7] Kelly, W.P. (1963) Use of saline irrigation water, soil science, 95 (4), pp. 355-391.
[8] Piper, A.M. (1944**)** A graphic procedure in the geochemical interpretation of water analysis. Am. Geophysics. Union Trans, 25: pp. 914-923.
[9] Piper, A.M. (1953) A graphic procedure in geochemical interpretation of water analysis, U.S. geol. Surv. Groundwater note 12, 63.
[10] Richards, L.A. (1954). Diagnosis and improvement of saline and alkali soils, U.S. Dept. Agri. Hand book, No. 60, pp. 160.

[11] U.S salinity laboratory (1954) Diagnosis and Improvement of Saline and Alkali soils, U.S Dept. Agriculture Handbook, pp. 60.
[12] Sarkar, S.N. & Saha, A.K. (1977). The present status of the Precambrian stratigraphy, tectonics, and geochronology of Singhbhum – Keonjhar-Myurbhanj region, Eastern India, Ind. Jour. Earth Sc. S. Roy Vol. pp. 37-65.
[13] Sarkar, S & Naik, K.C. (2011):Role of ground water in sustainability and development of a drought prone area-a case study from Bolangir district, DRS spl. Publ. in Geology, Utkal University, pp. 84-91.
[14] Saha, A.K. (1994) Crustal evolution of Singhbhum-North-Odisha, Eastern India. Geol Soc. Ind Mem 27, pp. 341.