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Groundwater Quality Assessment for Drinking and Industrial Purpose of Rourkela, Sundergarh District, Odisha, India

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Abstract: A study on geochemical characterization of groundwater and its suitability for drinking and industrial purpose was carried out in and around Rourkela, an industrial city of Odisha. Altogether 36 groundwater samples were collected during May 2011 and analyzed for the water quality parameters such as pH, electrical conductivity, total dissolved solids, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride etc. Suitability of the groundwater for drinking and industrial purpose is evaluated following various classification schemes and water quality standards. Piper's Trilinear diagram reveals that water of the study area belongs to the Ca-Mg-HCO_3 facies. Calcium and magnesium are major cations and bicarbonate is the major anion in the study area. The prolific presence of Ca, Mg and bicarbonate ions demonstrates that the total hydro-geochemistry is dominated by alkaline earths and weak acids. The chemical composition of ground water is controlled by sediment-water interaction. Various classifications show that present status of ground water is better for drinking purpose. Corrosivity ratio is analysed and Gibb's diagram is plotted to estimate the quality of water for industrial use and rock water interaction.

Key words: Groundwater quality, hydro-geochemistry, corrosivity ratio, Gibb's ratio, Rourkela.

Introduction

The study area is located at 22° 12′ North Latitude and 84° 54′ East Longitude in the district of Sundergarh (Figure 1) at an elevation of 219 m above mean sea level (msl). The current population of Rourkela is approximately 4.2 lakhs. The city is spread over an area of 264.7 square km. Rourkela is situated in the very heart of iron ore, dolomite and coal belts. It is the important industrial centre in the mineral-rich state of Odisha. One of the largest steel plants of the Steel Authority of India Limited (Rourkela Steel Plant—RSP) is located here. The important litho units of the area are arenaceous, calcareous, carbonaceous and argillaceous rocks of well known Gangpur Group. The calcareous horizons contain rich deposits of limestone and dolomite, while argillaceous horizons show metamorphism up to staurolite grade (Mahalik and Nanda, 2006). The perennial river Koel and Sankh meet at Vedvyas on the outskirts of Rourkela. After this point of confluence at Vedvyas, the river is known as Brahmani. Rourkela region comes under tropical monsoon climate with average annual rainfall ranges between 160 and 200 cm. The geological set up controls the occurrence and movement of groundwater in the area. In this area the depth of dug wells range from 3 to 15 m below ground level (bgl). In continuation to our earlier attempts of studying physico-chemical parameters of different

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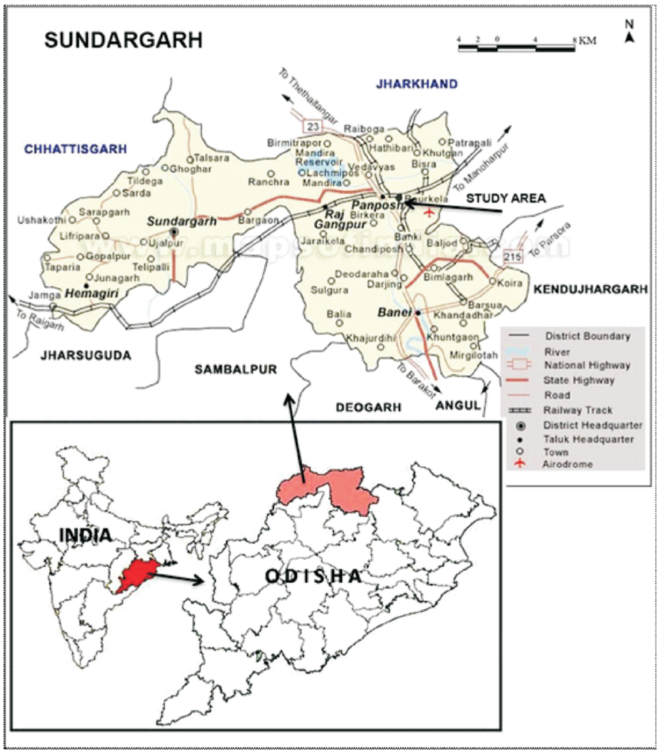


Figure 1: Location map of the study area (Rourkela).

parts of Odisha (Das et al., 2013a, 2013b, 2012), in the present study, various chemical parameters of ground water in and around Rourkela were analyzed to find out its suitability for drinking and industrial purpose. Usually, ground water contains small amount of soluble salts dissolved in it; but the nature of these salts depend upon the sources for recharge of the ground water and the strata through which it flows. The soluble salts, when present in excess amount happen to be harmful. Thus, a better understanding of the chemistry of groundwater is essential to properly evaluate groundwater suitability for drinking and industrial purposes.

Methodology

In total, 36 water samples were collected during May 2011 from different locations of Rourkela. Out of that 12 samples were from dug wells and 24 were from tube wells. The samples were analysed for pH, electrical conductivity (EC), total dissolved solids (TDS), major cations and anions by adopting standard analytical procedures (Trivedi and Goel, 1984; Saxena, 1995; Gupta, 2004; Jaiswal, 2004; Gray, 2005; APHA, 2005). Electrical conductivity (EC) and pH were measured using digital meters immediately after sampling. Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, Cl^- and TDS were analysed by volumetric titrations. Flame photometer was used to measure Na^+ and K^+ ions. SO_4^{2-} and F^- were determined by spectrophotometric techniques.

Results and Discussions

Groundwater Chemistry

The hydro-chemical parameters are analyzed to assess the suitability of ground water of the study area for drinking and industrial purpose. The analytical results and computed values of water samples of the study area are given in Table 1. The groundwater quality data interpretation for drinking has been carried out as per guidelines given by Ayers (1977) and Christiansen et al. (1977). The suitability of water for industrial purpose depends upon TDS (salinity) and the Corrosivity Ratio.

Understanding the quality of ground water with its temporal and seasonal variation is important because it determines the suitability for drinking, domestic and industrial purposes. The pH of water is an indicator of its quality and geochemical equilibrium for solubility calculation (Hem, 1985). pH of the samples ranged from 6.18 to 7.86 (with an average less than 7) indicating acidic nature (Table 1). The EC values ranged from 164 to 1990 mhos/cm^2. Higher values are generally noticed in Sector 2 and Sector 3 of the city. TDS values ranged from 101 mg/l to 1334 mg/l, while total alkalinity values ranged from 35 mg/l to 350 mg/l. The chemical parameters of different groundwater samples are given in Table 1. The concentrations of chloride and fluoride ranged from 3.17 mg/l to 262.33 mg/l and from 0 mg/l to 0.975 mg/l, while that of sulphate and bicarbonate concentrations ranged from 0 mg/l to 109.52 mg/l and from 42.7 mg/l to 427 mg/l respectively. The calcium and magnesium content of the water samples ranged from 8 mg/l to 154 mg/l and from 3.64 mg/l to 47.385 mg/l, whereas sodium and potassium concentrations ranged from 5.3 mg/l to 175 mg/l and from 0.96 mg/l to 78 mg/l respectively. Table 1 explicitly demonstrates that most of the subsurface water of the study area is suitable for drinking and industrial use with little exceptions.

Drinking Water Suitability

To assess the suitability of groundwater for drinking purpose, the concentrations were compared with the WHO standards (2004) and BIS 10500 standard ISI (1995) for drinking water, which shows that most of the surface and subsurface water of the study area are suitable for drinking and domestic use with few exceptions, as most of the parameters are within the permissible limits (Table 2).

Table 1: Physico-chemical parameters and their analytical values of ground water of Rourkela

Location	*Well type*	*pH*	*EC µmho/cm*	*TDS mg/l*	*Alkalinity*	*TH mg/l*	CO_3^{2-} *mg/l*	HCO_3^- *mg/l*	Cl^- *mg/l*	F^- *mg/l*	SO_4^{2-} *mg/l*	Ca^{2+} *mg/l*	Mg^{2+} *mg/l*	Na^+ *mg/l*	K^+ *mg/l*	*Gibb's cation*	*Gibb's anion*	*CR*
Koel Nagar	TW	6.42	355	241	40	50	0.00	48.80	39.63	0.00	0.00	14.00	3.65	43.90	27.00	0.84	0.45	1.14
Koel Nagar	DW	6.51	363	232	49	125	0.00	159.40	25.71	0.00	4.12	18.00	10.30	36.10	21.05	0.76	0.14	0.25
Panposh	TW	6.59	388	329	145	150	0.00	176.90	31.90	0.00	15.06	52.00	4.86	23.60	15.70	0.43	0.15	0.34
Panposh	DW	6.63	396	253	136	152	0.00	193.90	29.92	0.00	22.50	48.00	11.10	24.00	18.00	0.47	0.13	0.34
Basanti Colony	TW	6.57	274	236	115	120	0.00	140.30	17.72	0.00	7.70	34.00	8.51	8.50	11.70	0.37	0.11	0.24
Basanti Colony	DW	6.51	284	181	108	127	0.00	273.50	37.45	0.00	12.40	42.00	11.25	19.30	14.90	0.45	0.12	0.24
Jhil Pani	TW	6.86	331	294	140	140	0.00	170.80	28.36	0.00	13.02	38.00	10.94	20.70	7.80	0.43	0.14	0.31
Jhil Pani	DW	6.90	324	207	152	133	0.00	275.60	36.82	0.00	11.12	46.00	20.40	32.40	21.60	0.54	0.12	0.23
Bandha Munda	TW	6.45	490	378	160	190	0.00	195.20	46.08	0.00	23.52	54.00	13.37	24.30	10.20	0.39	0.19	0.46
Bandha Munda	DW	6.54	495	316	171	142	0.00	247.50	29.62	0.00	27.50	78.00	28.40	34.60	6.70	0.35	0.11	0.28
Sector-1	TW	6.18	583	403	120	195	0.00	146.40	81.53	0.00	17.65	62.00	9.72	37.90	16.30	0.47	0.36	0.91
Sector-1	TW	6.87	590	372	134	137	0.00	108.60	30.40	0.00	21.06	60.00	16.91	19.70	4.04	0.28	0.22	0.60
Sector-2	TW	6.85	1990	1334	350	580	0.00	427.00	262.33	0.98	109.52	154.00	47.39	175.00	36.10	0.58	0.38	1.13
Sector-3	TW	6.92	1885	1206	267	325	0.00	155.50	34.60	0.00	77.50	32.00	16.60	10.30	3.32	0.30	0.18	0.83
Sector-4	TW	6.20	514	336	90	155	0.00	109.80	56.72	0.00	24.21	46.00	9.72	20.20	15.10	0.43	0.34	0.96
Sector-4	DW	6.32	532	340	85	154	0.00	116.70	40.61	0.00	31.50	54.00	18.37	39.00	11.90	0.49	0.26	0.77
Sector-5	TW	6.94	346	305	155	140	0.00	189.10	28.36	0.00	0.00	44.00	7.29	18.00	8.10	0.37	0.13	0.21
Sector-6	TW	7.00	621	492	225	290	0.00	274.50	56.72	0.00	15.02	64.00	31.59	16.60	16.00	0.34	0.17	0.35
Sector-6	DW	7.05	628	401	240	178	0.00	261.30	23.59	0.00	16.72	98.00	18.40	47.00	4.30	0.34	0.08	0.19
Sector-7	TW	6.59	334	271	151	125	0.00	143.30	22.90	0.00	0.27	45.00	17.61	39.00	0.96	0.47	0.14	0.23
Sector-8	TW	7.30	436	332	155	156	0.00	142.50	56.72	0.00	38.60	44.00	36.23	28.80	23.30	0.54	0.28	0.84
Sector-9	TW	6.54	356	226	177	110	0.00	202.60	22.70	0.14	27.30	62.00	16.39	27.00	9.20	0.37	0.10	0.30
Sector-10	TW	6.82	398	254	232	183	0.00	211.60	145.70	0.07	33.50	29.00	15.51	23.20	25.40	0.63	0.41	1.13
Sector-12	DW	7.15	712	583	109	134	0.00	100.00	37.51	0.23	19.80	38.00	21.83	34.50	21.00	0.59	0.27	0.73
Civil Township	TW	7.08	950	724	275	320	0.00	335.50	63.81	0.30	51.56	100.00	17.01	51.60	78.00	0.56	0.16	0.43
Civil Township	DW	7.12	892	570	214	192	0.00	204.70	138.70	0.94	52.70	37.00	8.76	19.90	3.70	0.39	0.40	1.22
Civil Township	DW	7.20	963	616	233	190	0.00	209.00	179.50	0.66	15.61	51.00	13.53	32.07	4.06	0.41	0.46	1.29
Vedvyas	TW	7.86	387	319	185	185	0.00	225.70	14.18	0.04	0.00	26.00	29.16	5.30	11.30	0.39	0.06	0.09
Vedvyas	DW	7.77	390	249	178	197	0.00	261.70	69.89	0.56	5.09	129.00	16.02	14.30	8.10	0.15	0.21	0.40
Bishra Chhak	TW	6.49	499	343	140	120	0.00	170.80	42.54	0.00	0.00	36.00	7.29	46.30	16.70	0.64	0.20	0.35
Bishra Chhak	DW	6.61	502	323	149	140	0.00	194.30	36.60	0.21	13.70	76.00	9.97	10.00	9.61	0.21	0.16	0.34
Fertiliser	TW	6.39	457	314	135	175	0.00	164.70	3.17	0.00	18.41	50.00	12.15	33.40	18.20	0.51	0.02	0.14
Chhend Colony	TW	6.62	587	476	190	250	0.00	231.80	56.72	0.00	47.98	60.00	24.30	22.80	9.30	0.35	0.20	0.56
Chhend Colony	TW	6.78	288	184	206	116	0.00	167.10	20.70	0.00	7.52	51.00	10.05	46.00	12.60	0.53	0.11	0.22
Sector-19	TW	6.26	164	115	35	35.	0.00	42.70	28.36	0.00	0.00	8.00	3.65	14.00	6.60	0.72	0.40	0.94
Sector-19	DW	6.35	158	101	47	152	0.00	103.60	32.21	0.00	5.20	19.00	9.97	41.50	3.10	0.70	0.24	0.49

Table 2: Comparison of water quality of the study area with WHO and BIS 10500 standards

Parameter	*Ranges*	*WHO (2004)*	*BIS 10500 (ISI, 1995)*	
			Highest desirable	*Maximum desirable*
pH	6.18 -7.86	6.5-8.5	6.5	8.5
EC	164 - 1990	400-2000	-	-
TDS	101 - 1334	500-1000	500	2000
Calcium	8 - 154	100-200	75	200
Magnesium	3.64 - 47.385	30-50	30	100
Sodium	5.3 - 175	20-1756	-	-
Potasium	0.96 - 78	10-12	-	-
Bicarbonate	42.7 - 427	-	200	600
Sulphate	0 - 109.52	25-250	200	400
Chloride	3.17 - 262.33	25-600	250	1000
Fluoride	0 - 0.975	-	1.0	1.5
Alkalinity	35 - 350	-	200	600
Total Hardness	35 - 580	-	300	600

Total Dissolved Solids

The TDS value is an imperative and convenient method for comparing salinity of ground water. The U.S. Geological survey (Winslow and Kister, 1955) has classified the water based on TDS value (Table 3). Groundwater samples in the study area have TDS varying from 101 mg/l to 1334 mg/l. Based on TDS classification, 39% of water samples are excellent and 50% samples are classified under good class for drinking purpose.

Piper Trilinear Diagram

The groundwater samples are plotted in the Piper (1944) Trilinear Diagram (Figure 2). The plot shows that most of the groundwater samples fall in the field of mixed Ca–Mg-HCO_3 type of water. The groundwater samples fall in the fields 4 and 5 (Figure 2), which suggest that alkaline earth exceeds strong acids. Calcium and magnesium are the major cations in the study area forming 75-90% of the cations. Bicarbonate is the major anion in the study area.

Table 3: Suitability of ground water for drinking based on TDS classification

TDS (mg/l)	*Water class*	*Number of water samples (out of 36)*
<300	Excellent	14 (39%)
300-600	Good	18 (50%)
600-900	Fair	2 (5.5%)
900-1200	Poor	0 (0%)
>1200	Unacceptable	2 (5.5%)

Electrical Conductivity (EC)

Electrical conductivity is the measure of capacity of a substance or solution to conduct electric current. It is an excellent indicator of TDS which is a measure of salinity that affects the taste of potable water (WHO, 2004). The variation in electrical conductivity is based on sedimentary structure and composition of rock. Chemically pure water does not conduct electricity. Any rise in the electrical conductivity of water indicates pollution. It is a good and rapid measure of the total dissolved solids. The higher values are obviously due to the contamination of ground water by ions like

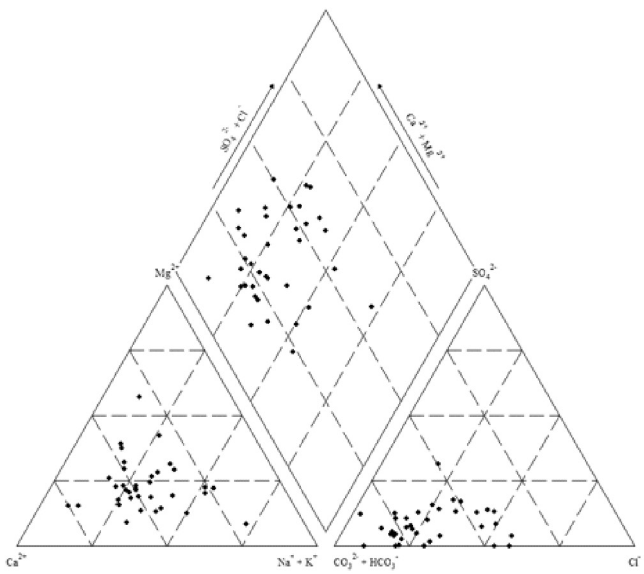


Figure 2: Piper's trilinear diagram.

OH^-, CO_3^{2-}, Cl^-, Ca^{+2} etc. The groundwater samples showed variation in EC in different locations of the study area. It was varied from 164 µmho/cm to 1990 µmho/cm, whereas the permissible limit is 300 µmho/cm prescribed by USPHS. Almost all the groundwater samples exceeded the permissible limit except five locations.

Total Hardness

The hardness of ground water results from the presence of divalent metallic cations of which calcium and magnesium are the most abundant. Total hardness in water is derived from the dissolved carbon dioxide, released by bacterial action in the soil, in percolating rain water. The total hardness values are categorized in all the four categories of Twort et al. (1974) such as soft, moderately soft, hard and very hard. Based on classification of total hardness, 5% samples are soft (excellent), 42% of samples are moderately soft (good) and 45% are moderately hard (fair), which are suitable for use for drinking purpose. Rests 8% of samples are very hard (poor), which are unsuitable for drinking purpose (Table 4).

Industrial Suitability

For industrial use waters must be of much higher quality than cooling waters. Quality requirements for industrial water may vary widely according to potential use. The purest water is required for the manufacture of pharmaceuticals and paper, while for certain phases of mining industry, quality requirements are less exacting. Based on the standards set by the American Water Quality Works Association, one can conclude that the ground water of the study area is suitable for industrial purposes, because all the samples show total hardness and TDS within the permissible limits.

Table 4: Suitability of ground water for drinking based on total hardness as $CaCO_3$ (mg/l)

Total hardness (mg/l)	*Water class*	*Number of water samples (out of 36)*
<75	Soft (Excellent)	02 (05%)
75-150	Moderately soft (Good)	15 (42%)
151-300	Moderately hard (Fair)	16 (45%)
>300	Very hard (Poor)	03 (08%)

Corrosivity Ratio (CR)

The corrosivity ratio is the susceptibility of ground water to corrosion. It is expressed as ratio of alkaline earths to saline salts in ground water. The corrosivity ratio is defined by the formula,

$$\text{Corrosivity Ratio (CR)} = \frac{\frac{Cl}{35.5} + \frac{2(SO_4)}{96}}{2\frac{(HCO_3 + CO_3)}{100}}$$

where all the ions are expressed in ppm.

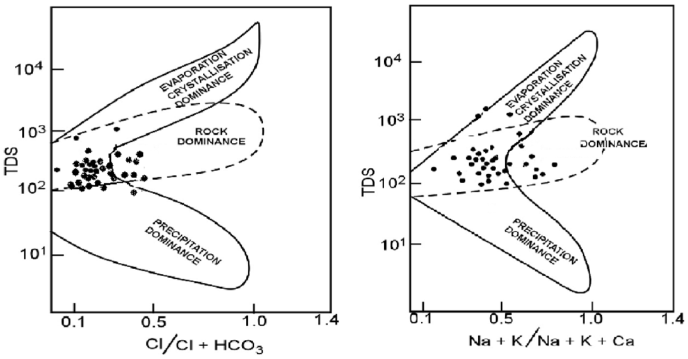
Ryner (1944), Raman (1985), Balasubramanian (1986), Sankar (1995) and Aravindan et al. (2004) have used the ratio to evaluate corrosive tendency of ground water on metallic pipes of various regions. 86% of water samples have corrosivity ratio (CR) less than one (safe zone), while 14% of samples have corrosivity ratio (CR) more than one (unsafe zone) (Table 5). In the area, where ground water has corrosivity ratio (CR) value more than 1, polyvinyl chloride (PVC) pipes should be used.

Table 5: Corrosivity ratio of groundwater samples of Rourkela

Corrosivity ratio (CR)	*Water category*	*Number of water samples (out of 36)*
<1	Safe zone	31
>1	Unsafe zone	05

Gibb's Diagram

Based on aquifer lithology, the mechanism controlling chemical relationship of ground water had been studied by Gibb (1970) and Viswanathaiah et al. (1978). In the Gibb's diagram, three kinds of fields are recognized namely, precipitation dominance, evaporation dominance and rock-water dominance. In case of anion of the water samples, 33 samples are pointed towards rock dominance of the chemistry of groundwater in the region, which reflects the influence of the chemistry of aquifer lithology vis-à-vis groundwater. Rest of the samples are in the field of precipitation dominance (Figure 3a). Similarly, in case of cations of the water samples, 33 samples (out of 36 water samples) are plotted in the field of rock dominance (Figure 3b) and three samples are in the field of evaporation crystalisation dominance. Hence from both the diagrams of Gibb, it can be established that the ground water of the study area is mainly dominated by the lithology of aquifer of the concerned region.



a. Gibb's plot for anion b. Gibb's plot for cation

Figure 3: Gibb's plot for cation and anion.

Conclusion

From the chemical analysis, it is revealed that the ground water of the study area is acidic or weakly acidic in nature. Graphical representation of the chemical data on Piper's Trilinear diagram reveals that calcium and magnesium are the major cations and bicarbonate is the major anion in the study area. The higher concentrations of the bicarbonate indicate chemical weathering of the rocks. The ground water belongs to Ca-Mg-HCO_3 facies. The Ca, Mg and HCO_3 indicate the temporary hardness, alkalinity and dominance of alkaline earth and weak acids. Based on TDS classification, 39% of water samples are excellent and 50% samples are classified under good class for drinking purpose. Based on classification of total hardness, 5% samples are soft (excellent), 42% of samples are moderately soft (good), 45% are moderately hard (fair). Rests 8% of samples are very hard (poor) and are unsuitable for drinking purpose.

All the chemical parameters demonstrate that the ground water of the study area is safe for drinking except few locations. Chemical composition of ground water is a reflection of rock weathering, decomposition and anthropogenic interventions, causing changes in time and space. Gibb's diagrams are plotted to infer water quality for industrial use. The chemical parameters indicate that the ground water of the study area is also safe for industrial purpose. The diagrams of Gibb reveal that the ground water of the study area is mainly dominated by the lithology of aquifer of the concerned region. The chemical quality of the study area is well within the permissible limit meant for drinking and industrial purpose. As water quality is interlinked with water quantity, regular monitoring should be undertaken to maintain the quality of ground water, as groundwater consumption is bound to increase due to erratic monsoon pattern and higher demand due to population growth.

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