

# Hydro-geochemistry and Water Quality Assessment of Surface and Groundwater Resources of Deogarh District, Jharkhand, India

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*Received May 14, 2012 revised and accepted March 25, 2015*

**Abstract:** The hydrogeochemical study of surface and sub-surface water resources of Deogarh district of Jharkhand state was undertaken to assess major ion chemistry and water quality in relation to domestic and irrigation uses. Analytical results show mildly acidic to alkaline nature of water and dominance of  $\text{Ca}^{2+}$  and  $\text{Na}^+$  in cationic and  $\text{HCO}_3^-$  and  $\text{Cl}^-$  in anionic abundance. In general, alkaline earth elements ( $\text{Ca}^{2+}+\text{Mg}^{2+}$ ) exceed alkalies ( $\text{Na}^++\text{K}^+$ ) and weak acids dominate ( $\text{HCO}_3^-$ ) over strong acids ( $\text{SO}_4^{2-}+\text{Cl}^-$ ) in majority of water samples. Ca-Mg- $\text{HCO}_3$  is the dominant hydrochemical facies both in surface and groundwater of the area. Weathering of rock forming minerals and ion exchange processes mainly controlled solute chemistry with secondary contribution from anthropogenic sources. Assessments of water quality for drinking purposes pointed that majority of water samples are suitable for drinking. Concentration of TDS, TH,  $\text{F}^-$ ,  $\text{Cl}^-$  and  $\text{NO}_3^-$  are exceeding desirable levels prescribed for drinking water at some sites. However, these parameters are well within the maximum permissible limit except for some cases. SAR, RSC, %Na, MH and PI values suggest that both surface and groundwater are good for irrigation uses except at some sites, where salinity, MH and PI values are higher than the prescribed levels.

**Key words:** Water quality, groundwater, Deogarh district, SAR, RSC.

## Introduction

Water is a common chemical substance that is essential for the survival of all known forms of life. In typical usage, water refers only to its liquid form or state, but the substance also has a solid (i.e. ice) and a gaseous (water vapour or steam) state. Water moves continually through a cycle of evapotranspiration, precipitation and runoff and winds carry water vapour over land at the same rate as runoff into the sea. Clean and fresh drinking water is essential to human and other life forms. However, in many parts of the world especially in developing countries water is in critical condition. It

is estimated that by 2025 more than half of the world population will be facing water-based vulnerability. India has 2.4% of the world's landmass and 4% of the global water resource but it has to support 16% of the world's human population (Kumar et al., 2005). Apart from availability, continuous water pollution due to disposal of sewage, industrial and mining wastes also threaten to reduce the available quantity of usable water. More and more ground and surface water resources including lakes, ponds and rivers in many parts of the country are categorized as polluted (Subramanian, 2000; Kumaresan and Riyazddin, 2006; Mohan et al., 2000; Kumar et al., 2006; Ramesh et al., 1995; Das, 1999; Singh et al., 2007).

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The state of Jharkhand has unique set in terms of physiography, rainfall and hydrology. The average rainfall of the state is 1200 mm. However, the rainfall is not well distributed and water retention capacity of the soil is rather poor, affecting availability of groundwater in many parts of the state. Besides groundwater availability, the other major water problem in the Jharkhand state is the quality of water. Public ignorance to environmental considerations, lack of provisional basic social services, indiscriminate disposal of increasing anthropogenic and mining wastes, unplanned application of agrochemicals and discharges of improperly treated sewage/industrial effluents, resulting in excess accumulation of pollutants and contamination of available water resources (Singh and Hasnain, 1999; Singh et al., 2007; Tiwary, 2001; Sarkar et al., 2007). For better utilization and effective management of water resources, a baseline water quality data is prerequisite. However, such information is lacking for many districts of the Jharkhand State including Deogarh. The present study aimed to generate water quality database for surface and groundwater resources of the Deogarh district and assess its suitability for domestic and irrigation uses.

### Study Area

Deogarh district is one of the twenty-four districts of Jharkhand state created in 1983 and located in north-eastern part of the state. It is located at latitude of 24°02'N to 24°40'N and longitude of 86°20'E to 87°05'E having an average elevation of 254 metres. The district is bordered by Banka and Jamui districts of Bihar State in north and north-west, Giridih district in west, Jamtara in south and Dumka district in east (Figure 1). Deogarh district has an area of about 2479 km<sup>2</sup> and a population of 1,165,390 with a population density of 376/km<sup>2</sup>. The landscape of Deogarh is characterized by mountainous tracts of granitic gneisses with isolated flat topped hills, steeper escarpments and intermontane valleys. In general the area shows a general slope from north to south and the land surface is rugged and uneven ranging from flat lands to steep slopes. Gradual slopes have been worked into terraced paddy fields at several places. The cultivation is primarily rain-fed and the major crop produced in the district is paddy. Deogarh is considered a health resort due to its pleasant climate, having the temperatures ranging from 23°C to 37°C in the summer and dipping to 7°C-28°C in the winter.

Average annual rainfall of the district is 1162 mm and 75% of the annual rainfall occurs in the months

of July, August and September. The economy of Deogarh is mainly dependent on its industries and agriculture. The district has shown a lot of progress in pharmacy. Deogarh also produces coal, and Chitra is the major coalfield of the district. Ajay and More are two important rivers of this district. More is also called Mayurakshi, emerged from Tiur Hill and passes through the heartland of the Deogarh and Dumka districts. The river Ajay originates from Munger district in Bihar and irrigates northern and eastern parts of Deogarh district. During rainy season these rivers often get flooded. During summer, narrow strip of water flows through masses of sand. Minor rivers/rivulets like Dadhwa, Patro, Jayanti and Kendua merge with Ajay river at different places.

The district is largely covered by Chotanagpur granites and gneissic complex associated with some metasediments and metabasic rocks. The Gondwanas has been developed in tectonic basin fill deposits and are resting on Archaean basements. The Gondwanas mainly consists of sandstones, shales, coal seams and are exposed in Karon and Madhupur blocks of the district (Mahadevan, 2002). Alluvium occurring along the river channels and adjoining areas are mainly composed of fine to coarse sand and clays. Weathering, fractures and jointing have introduced secondary porosities in these hard rocks and govern the occurrence and movement of groundwater in these rocks. The water level depth in the district varies between 6.37 and 10.35 m during pre-monsoon and 2.55-5.47 m below ground level during post-monsoon season (CGWB, 2009).

### Material and Methods

For the assessment of surface and sub-surface water quality of Deogarh district, a systematic sampling was carried out in June 2008. Representative 21 surface water and 25 groundwater samples were collected at different sites including rural, urban, industrial and mining areas (Figure 2). Water samples were collected from both surface (ponds, rivers, lakes, mine pit) and subsurface (dug and tube wells) water resources in one litre narrow-mouth pre-washed polyethylene bottles. Electrical conductivity (EC) and pH were measured in the field using a portable conductivity and pH meter. Turbidity was measured by Turbidity meter (TN-100). Water samples were filtered through 0.45 µm Millipore membrane filters to separate suspended particles. Acid titration and molybdosilicate method was used to determine the concentration of bicarbonate (HCO<sub>3</sub><sup>-</sup>) and dissolved silica (H<sub>4</sub>SiO<sub>4</sub>) respectively (APHA, 1998). Major anions

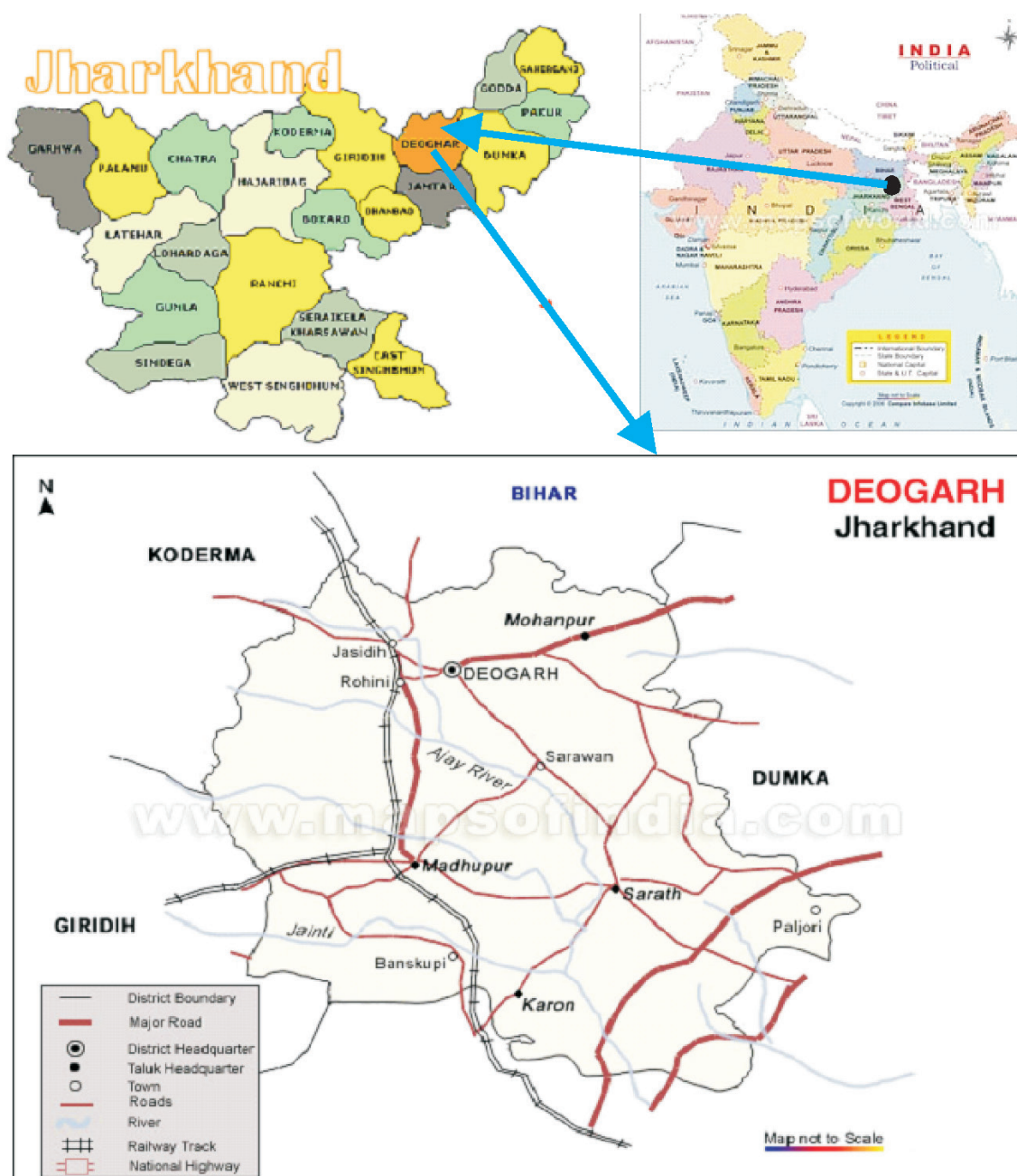


Figure 1: Location map of the Deogarh district.

(F, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>) were analyzed by ion chromatograph (Dionex Dx-120) using anions AS12A/AG12 columns coupled to an anion self-regenerating suppressor (ASRS) in recycle mode. Major cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>) were measured by Double Beam Atomic Absorption Spectrophotometer (Varian 280-FS) after calibrating the instrument with known standards prepared from 1000 ppm Merck stock solution. The analytical precision for measurement of ions was determined by calculating the ionic charge balance error, which is within  $\pm 10\%$ .

## Results and Discussion

### Hydro-geochemistry

The analytical result of geochemical analysis of surface and groundwater samples is given in Table 1. One groundwater sample collected from dug well at site W-2 shows very high EC (8710  $\mu\text{S cm}^{-1}$ ) and ionic concentration with extraordinary higher values of F<sup>-</sup>, Cl<sup>-</sup> and Ca<sup>2+</sup>. This well is not used by villagers for domestic purposes and water sample has been omitted

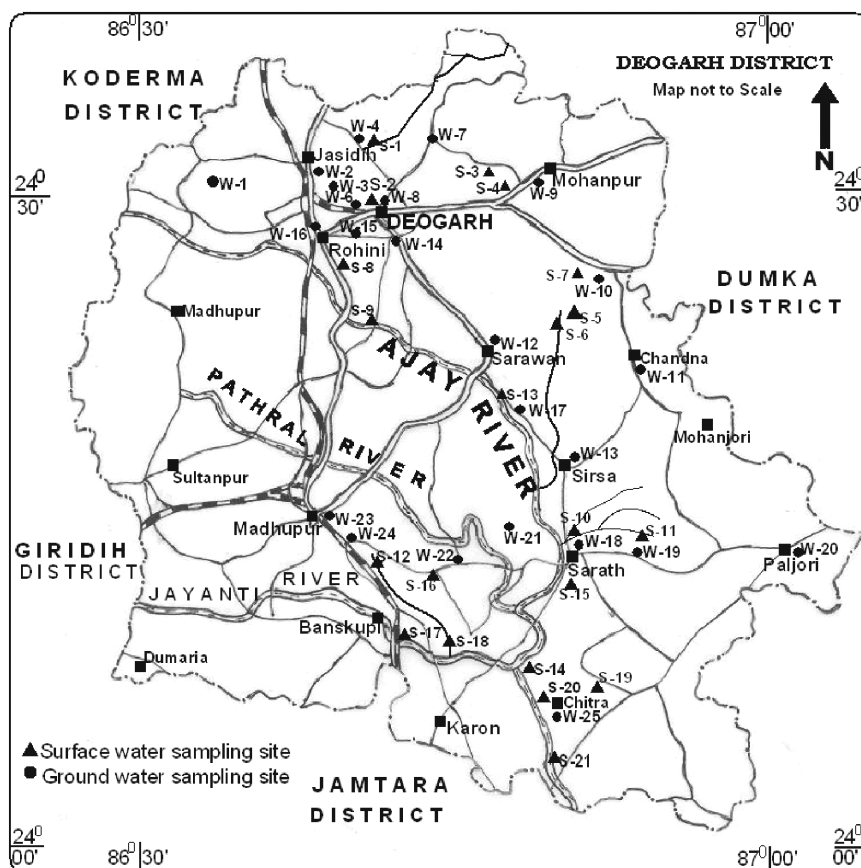


Figure 2: Map of the Deogarh district showing sampling sites (S 1-21: Surface water; W 1-25: Groundwater).

for statistical calculation and in further discussion. Table 2 shows calculated parameters to assess geochemical processes and water quality for irrigation uses. Statistics of parameters of different chemical compositions of surface and groundwater samples, prescribed limits of World Health Organization (WHO, 1997) and Indian Standards (BIS, 1991) for drinking water are shown in Table 3.

The pH varies between 6.9 and 8.3 (Avg. 7.9) in surface water and 6.7 to 7.8 (Avg. 7.2) in groundwater samples, indicating mildly acidic to alkaline nature of water in the Deogarh district. The electrical conductivity (EC) varied from  $134 \mu\text{S cm}^{-1}$  to  $1478 \mu\text{S cm}^{-1}$  for surface water and  $245 \mu\text{S cm}^{-1}$  to  $1541 \mu\text{S cm}^{-1}$  in subsurface water. The total dissolved solid (TDS), which is sum of the dissolved ionic concentration, varies from 122 to  $947 \text{ mg l}^{-1}$  in surface and 223 to  $1217 \text{ mg l}^{-1}$  in groundwater samples of the district. Average values of EC ( $750 \mu\text{S cm}^{-1}$ ) and TDS ( $614 \text{ mg l}^{-1}$ ) for groundwater is found to be higher than the average value for surface water ( $421 \mu\text{S cm}^{-1}$  and  $314 \text{ mg l}^{-1}$ ). The higher EC and TDS content of groundwater may be attributed to low

velocity of groundwater movement, longer residence time of solution in the subsurface environment for water-rock interaction and a larger interfacial area between the phases (Singh, 2002). The spatial differences between the values of EC and TDS may reflect variation in the lithology and anthropogenic activities in the region.

The anion chemistry shows that  $\text{HCO}_3^-$  and  $\text{Cl}^-$  are the dominant ions both in surface and subsurface waters. In the surface water, concentration of  $\text{HCO}_3^-$  varies from a minimum of  $58.6 \text{ mg l}^{-1}$  (S-6) for river water (Morakshi River) to a maximum value of  $245.8 \text{ mg l}^{-1}$  found for a mine pit water of Chitra coal mine (S-19). In the water of subsurface aquifer, its concentration ranges between  $96.8 \text{ mg l}^{-1}$  (W-12) and  $414.8 \text{ mg l}^{-1}$  (W-8) with an average value of  $222.4 \text{ mg l}^{-1}$ . Bicarbonate contributes on an average 59% and 48% to the total anions (TZ) in surface and groundwater, respectively, in equivalent units. The  $\text{HCO}_3^-$  is derived mainly from the soil zone  $\text{CO}_2$  and at the time of weathering of parent minerals. The soil zone in the subsurface environment contains elevated  $\text{CO}_2$  pressure (produced as a result of decay of organic matter and root respiration), which in



Table 1: Chemical characteristics of surface and groundwater resources of Deogarh district

Sample code	Sampling site	Water type	pH	EC	TDS	F <sup>-</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>	H <sub>4</sub> SiO <sub>4</sub>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	TH	Turbidity
S-1	Dandhwa Rivulet	R/W	8.3	298	231	0.97	21.0	122	7.2	2.9	18.8	24.0	7.1	25.6	2.0	89	1.4
S-2	Baidyanath Temple	P/W	8.0	621	466	1.18	125.0	181	7.8	1.1	23.2	19.5	10.0	82.6	15.1	90	52.1
S-3	Korao village	P/W	7.7	618	479	2.44	113.8	195	6.1	1.23	18.6	16.9	5.6	107.3	11.8	65	105.0
S-4	Khadagdih village	P/W	7.4	574	412	3.10	122.2	116	9.3	26.9	20.6	29.6	12.8	56.3	15.4	127	99.5
S-5	Mahadev Rivulet	R/W	8.0	134	122	0.49	4.3	70	1.1	1.7	19.3	11.7	1.8	9.9	1.4	37	1.9
S-6	Morakshi River	R/W	7.5	166	122	0.84	8.8	59	2.1	2.2	20.0	13.6	2.1	12.2	1.7	42	4.3
S-7	Ghodmara village	P/W	6.9	242	156	0.96	30.9	59	8.5	4.1	7.6	10.6	2.4	30.2	2.4	37	25.9
S-8	Satsang Nagar	P/W	7.5	1478	947	1.09	410.0	120	70.3	55.8	14.4	49.8	29.2	182.1	14.5	244	156.0
S-9	Rohini Rivulet	R/W	7.9	333	252	1.32	37.7	124	8.6	4.0	19.2	26.3	8.7	20.1	2.4	102	3.5
S-10	Pahadpur Rivulet	R/W	7.7	342	246	1.80	33.7	139	3.4	2.6	7.8	27.7	10.4	17.9	2.2	112	4.0
S-11	Katai Rivulet	R/W	8.2	268	218	1.21	11.9	116	8.7	9.3	24.8	23.7	8.8	12.5	1.6	96	2.2
S-12	Dahawa Rivulet	R/W	8.0	270	221	1.12	19.0	124	3.6	5.0	22.1	24.0	9.0	12.0	1.6	97	2.1
S-13	Ajay River	R/W	7.9	228	193	1.45	15.5	108	4.4	7.7	12.0	18.4	7.0	16.4	1.9	75	186.0
S-14	Amratandh Rivulet	R/W	7.9	190	175	1.15	8.5	93	6.0	10.3	21.1	17.3	6.9	8.8	1.8	72	357.0
S-15	Sarath	P/W	7.9	718	472	1.18	142.0	154	20.6	10.8	8.1	26.6	20.6	73.5	13.9	151	18.5
S-16	Patro River	R/W	8.0	215	186	1.12	18.2	97	5.3	5.0	21.2	17.3	7.3	11.3	2.3	73	65.7
S-17	Jayanti River	R/W	7.9	197	185	1.23	8.1	101	5.8	8.6	22.8	19.3	8.7	8.5	1.8	84	193.0
S-18	Johadi Nala water	R/W	8.0	318	247	1.18	32.8	139	5.1	7.1	4.8	24.3	12.7	16.7	3.3	113	2.8
S-19	Chitra Mine	M/W	8.0	718	541	1.13	12.8	246	132.5	5.3	8.5	66.3	52.1	8.0	8.2	380	2.2
S-20	Chitra Mine	M/W	8.3	693	516	1.12	19.8	196	143.5	23.1	12.5	57.3	46.8	7.8	8.1	335	11.5
S-21	Ajay River	R/W	8.2	223	185	1.51	17.1	97	5.7	5.5	20.9	18.0	7.8	10.4	1.7	77	135.0
W-1	Andherigadar	W/W	7.0	521	419	1.89	20.1	150	23.4	85.5	34.3	67.6	19.7	14.2	1.7	250	0.8
W-2*	Jassidih	T/W	6.9	8710	6075	7.12	3654	223	119.9	96.5	22.3	1412	391.5	142.0	6.4	5139	7.1
W-3	Tabha ghat	W/W	7.8	1514	1172	2.11	382.0	352	50.7	38.9	46.7	94.5	30.2	171.9	2.7	360	0.4
W-4	Dabar gram	T/W	6.8	845	742	2.25	150.8	284	40.6	50.3	48.5	63.3	46.0	54.8	1.1	347	9.0
W-5	Barmasia	T/W	6.9	1006	792	2.06	134.2	234	54.2	151.0	37.8	62.4	43.9	71.5	0.8	337	2.2
W-6	Gidhani	T/W	7.6	530	463	1.78	12.5	325	2.2	2.6	20.5	38.6	25.5	31.1	3.1	201	0.4
W-7	Rikhia	T/W	6.9	900	815	2.38	212.8	196	121.8	27.8	59.6	85.9	30.9	76.4	1.1	342	8.9
W-8	Deoghar	T/W	7.1	1189	1053	1.96	158.8	415	62.0	110.8	29.2	67.2	69.3	133.4	5.3	453	1.0
W-9	Mohanpur	T/W	7.7	579	453	1.97	23.7	298	7.1	5.7	28.3	23.5	20.7	42.7	1.8	144	0.5
W-10	Ghodmara	T/W	7.5	305	273	1.12	12.8	175	6.4	0.2	20.3	12.1	26.6	17.3	1.4	139	2.9

(contd.)

Table 1. (contd.)

Sample code	Sampling site	Water type	pH	EC	TDS	F <sup>-</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>	H <sub>4</sub> SiO <sub>4</sub>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	TH	Turbidity
W-11	Chandana	T/W	6.8	1009	739	1.83	308.0	124	3.3	63.9	43.8	117.0	35.5	39.6	2.2	438	3.3
W-12	Sarwan	T/W	7.2	245	223	1.06	16.4	97	2.2	47.0	12.8	22.4	8.7	14.7	1.1	92	1.2
W-13	Sirsa	T/W	7.4	576	491	1.69	63.5	256	16.5	13.6	29.2	56.5	23.3	28.9	1.4	237	4.3
W-14	Deoghar city	T/W	7.1	898	746	2.23	131.2	315	40.3	55.4	22.6	75.0	43.4	58.4	2.6	366	5.4
W-15	Satsang Nagar	T/W	7.2	1249	980	1.67	290.0	316	52.8	42.7	34.7	110.0	35.5	96.4	0.7	421	5.2
W-16	Rohini	T/W	7.3	1541	1217	0.76	305.0	350	91.2	109.0	41.5	140.4	42.4	123.8	12.7	525	4.2
W-17	Sarwan	T/W	6.7	1051	737	1.37	275.0	150	21.1	54.8	25.8	145.5	28.0	32.1	3.0	479	39.2
W-18	Sarath	T/W	7.2	675	580	1.23	135.3	173	37.5	56.2	45.3	76.1	29.9	22.2	2.6	313	1.4
W-19	Dharampur	T/W	7.1	328	318	1.49	3.7	211	10.2	0.3	26.2	34.8	11.3	17.1	1.7	133	15.2
W-20	Paljori	T/W	7.2	678	572	2.10	176.9	158	22.7	49.3	25.6	78.5	31.3	27.1	1.1	325	6.5
W-21	Babhangama	T/W	7.4	256	238	0.56	43.6	112	8.8	4.4	12.6	33.0	6.1	15.9	1.2	107	5.7
W-22	Sirsa	T/W	6.9	428	320	0.40	73.4	97	21.2	14.1	25.8	46.1	12.4	27.1	2.7	166	2.9
W-23	Madhupur	T/W	7.3	479	412	1.01	71.7	157	39.8	17.4	29.7	45.8	28.0	19.0	2.7	230	6.6
W-24	Pathroal	T/W	7.0	611	450	0.98	73.8	185	44.0	2.8	27.3	52.8	32.3	29.7	1.5	265	28.0
W-25	Chitra Mine	T/W	6.9	579	545	0.78	28.2	208	137.5	24.3	24.0	56.9	32.3	31.8	1.1	275	2.7

\* Well is not used for domestic uses and excluded for further calculation and discussion.

**Units:** Concentration in mg l<sup>-1</sup>, except pH, EC (μS cm<sup>-1</sup>), Turbidity (NTU).

**Abbreviation:** S-1-21 = Surface water, W-1-25 = Ground water, R/W = River/Rivulets water, P/W = Pond water, M/W = Mine water, T/W = Tube well, W/W = Dug well, EC = Electrical conductivity, TDS = Total dissolved solids, TH = Total hardness.

**Table 2: Calculated parameters to assess geochemical processes and water quality**

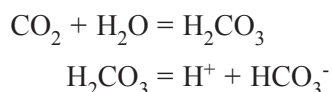
<i>Samp. code</i>	<i>Gibbs ratio-I</i>	<i>Gibbs ratio-II</i>	<i>CAI-I</i>	<i>CAI-II</i>	<i>SAR</i>	<i>%Na</i>	<i>RSC</i>	<i>PI</i>	<i>MH</i>
S-1	0.53	0.15	-0.97	-0.26	1.18	39.5	1.10	87	33
S-2	0.83	0.41	-0.13	-0.14	3.79	68.9	2.06	99	46
S-3	0.88	0.37	-0.55	-0.53	5.78	79.2	2.54	108	35
S-4	0.71	0.51	0.18	0.24	2.17	52.9	0.63	77	42
S-5	0.49	0.06	-2.87	-0.29	0.71	38.9	0.78	129	20
S-6	0.51	0.13	-1.32	-0.32	0.82	40.4	0.54	110	20
S-7	0.75	0.35	-0.58	-0.42	2.17	65.3	0.59	112	27
S-8	0.80	0.77	0.28	0.76	5.07	62.9	-0.50	73	49
S-9	0.46	0.23	0.12	0.06	0.87	31.5	1.01	79	35
S-10	0.42	0.20	0.12	0.05	0.74	27.2	1.15	76	38
S-11	0.37	0.09	-0.74	-0.11	0.56	23.4	0.94	78	38
S-12	0.36	0.13	-0.05	-0.01	0.53	22.6	1.05	79	38
S-13	0.50	0.13	-0.74	-0.16	0.82	33.7	1.02	93	39
S-14	0.38	0.08	-0.79	-0.10	0.45	23.0	0.80	89	40
S-15	0.77	0.48	0.11	0.14	2.60	54.0	1.01	77	56
S-16	0.44	0.16	-0.07	-0.02	0.57	27.3	0.85	90	41
S-17	0.35	0.07	-0.81	-0.10	0.40	19.8	0.81	81	43
S-18	0.45	0.19	0.12	0.05	0.69	26.5	1.14	75	46
S-19	0.20	0.05	-0.54	-0.03	0.18	6.8	0.21	30	56
S-20	0.22	0.09	0.02	0.00	0.19	7.5	-0.16	30	57
S-21	0.40	0.15	-0.03	-0.01	0.52	24.4	0.81	86	42
W-1	0.19	0.12	-0.16	-0.02	0.39	11.7	-0.04	39	32
W-3	0.65	0.52	0.30	0.43	3.94	51.2	2.15	67	35
W-4	0.47	0.35	0.43	0.29	1.28	25.8	1.16	49	55
W-5	0.54	0.36	0.17	0.09	1.70	31.8	0.45	52	54
W-6	0.47	0.04	-3.07	-0.20	0.95	26.3	3.30	68	52
W-7	0.47	0.52	0.44	0.43	1.80	32.9	-0.21	50	37
W-8	0.67	0.28	-0.33	-0.15	2.73	39.6	2.23	57	63
W-9	0.65	0.07	-1.85	-0.24	1.55	39.8	3.44	86	59
W-10	0.61	0.07	-1.19	-0.14	0.64	22.0	1.46	69	78
W-11	0.26	0.71	0.79	2.21	0.82	16.9	-2.37	30	33
W-12	0.41	0.14	-0.44	-0.08	0.67	26.6	0.67	77	39
W-13	0.35	0.20	0.28	0.10	0.82	21.5	1.82	55	40
W-14	0.45	0.29	0.30	0.16	1.33	26.3	1.48	49	49
W-15	0.47	0.48	0.49	0.57	2.05	33.4	0.96	51	35
W-16	0.49	0.47	0.34	0.31	2.35	35.2	0.47	49	33
W-17	0.19	0.65	0.81	1.66	0.64	13.4	-2.33	27	24
W-18	0.25	0.44	0.73	0.61	0.55	14.2	-0.30	37	39
W-19	0.35	0.02	-6.48	-0.18	0.64	22.8	2.13	76	35
W-20	0.26	0.53	0.76	0.98	0.65	15.7	-0.67	36	40
W-21	0.34	0.28	0.41	0.24	0.67	25.2	0.76	72	23
W-22	0.39	0.43	0.40	0.36	0.92	27.3	-0.08	54	31
W-23	0.32	0.31	0.56	0.31	0.55	16.3	0.26	45	50
W-24	0.37	0.29	0.36	0.19	0.79	20.1	0.37	46	50
W-25	0.37	0.12	-0.77	-0.09	0.84	20.4	0.64	47	48

TH = Total hardness, CIA = Chloro-alkaline indices, SAR = Sodium adsorption ratio,

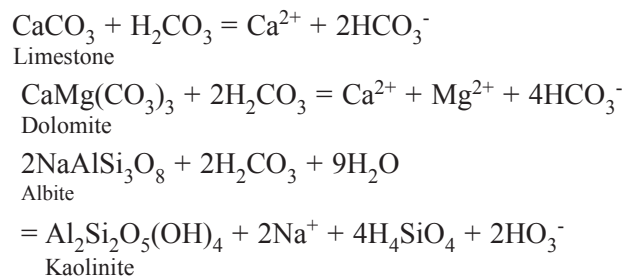
RSC = Residual sodium carbonate, PI = Permeability index, MH = Magnesium hazard,

Gibbs ratio-I =  $\text{Na}+\text{K}/(\text{Na}+\text{K}+\text{Ca})$ ; Gibbs ratio-II =  $\text{Cl}/(\text{Cl}+\text{HCO}_3)$

turn combines with rainwater to form bicarbonate by the following reactions:



Bicarbonate may also be derived from the dissolution of carbonates and/or silicate minerals by the carbonic acid from the reactions:



The chloride concentration in analyzed samples varies from 4.3 to 410 mg l<sup>-1</sup> in the surface water and 3.7 to 382 mg l<sup>-1</sup> in the groundwater. Mean concentrations of Cl<sup>-</sup> in surface and sub-surface water are 57.8 and 129.3 mg l<sup>-1</sup>, constituting 28% and 35% of the total anions (TZ<sup>-</sup>), respectively. Chloride is present in lower concentrations in common rock types, than any of the other major constituents of natural water. It is assumed that bulk of the chloride in water is primarily either from atmospheric source or from sea water. However, abnormal concentration of Cl<sup>-</sup> may result from leaching of salt and saline residues in the soil and municipal, industrial, domestic and animal wastes. In the present case, the large lateral variations and high concentrations of chloride in some surface and groundwater may be attributed to the local recharge and contamination by anthropogenic sources such as domestic waste effluents and untreated industrial discharge.

Concentration of sulphate varies from 1.1 to 143.5 mg l<sup>-1</sup> in surface water with an average value of 22.2 mg l<sup>-1</sup>, and in groundwater it ranges from 2.2 to 137.5 mg l<sup>-1</sup> with an average value of 38.2 mg l<sup>-1</sup>. SO<sub>4</sub><sup>2-</sup> is contributing 8% to the total anionic balance in surface water and 9% in groundwater. Concentration of SO<sub>4</sub><sup>2-</sup> is relatively high in the mine water samples collected from Chitra coal mine (S-19 and S-20) and in the groundwater at sites W-7 and W-25. On global basis, one third of the SO<sub>4</sub><sup>2-</sup> in aquatic systems is derived from the rock weathering and about 60% from fossil fuel burning and minor amounts from volcanism and cycling salts (Berner and Berner, 1987). Weathering of pyrites (FeS<sub>2</sub>) associated with the coal seams of the area and fossil fuels burning are the major source of sulphate in the study area.

Nitrate is an important pollutant in the environment being generally derived from atmospheric precipitation, agricultural fertilizers, human and animal excreta, biological fixation and nitrification of organic N and NH<sub>4</sub> (Appelo and Postma, 1993). The anthropogenic source of NO<sub>3</sub><sup>-</sup> are point source including industrial sewage, refuse dumps etc. discharged directly in to the surface water and diffuse source including runoff and leaching from rural and urban land. Concentration of NO<sub>3</sub><sup>-</sup> ranges from 1.1 to 55.8 mg l<sup>-1</sup> (Avg. 9.5 mg l<sup>-1</sup>) in the surface water and 0.2 to 151.0 mg l<sup>-1</sup> (Avg. 42.8 mg l<sup>-1</sup>) in the groundwater of the study area. The concentration of nitrate is relatively high in some subsurface water samples, attributing to agricultural and anthropogenic sources. Concentration F<sup>-</sup> varied from 0.5 to 3.1 mg l<sup>-1</sup> (Avg. 1.3 mg l<sup>-1</sup>) in surface and 0.4 to 2.4 mg l<sup>-1</sup> (Avg. 1.5 mg l<sup>-1</sup>) in groundwater samples of the area. The fluoride is usually derived from the weathering of fluoride bearing minerals like muscovite, biotite, fluorite, fluoroapatite etc. The observed high values of fluoride in some surface and groundwater samples may be attributed to the weathering product of the fluoride bearing minerals.

The cationic chemistry is dominated by Ca<sup>2+</sup> (40%) and Na<sup>+</sup> (30%) followed by Mg<sup>2+</sup> (28%) and K<sup>+</sup> (2%). In general, concentration of cations is higher in the groundwater as compared to surface water (Table 3). However, average concentration of K<sup>+</sup> is found relatively higher in surface water (5.5 mg l<sup>-1</sup>) as compared to the groundwater (2.4 mg l<sup>-1</sup>). Calcium concentration in groundwater was reported to be in the range of minimum value of 12.1 mg l<sup>-1</sup> (W-10) to maximum of 145.5 mg l<sup>-1</sup> (W-17) with an average value of 66.9 mg l<sup>-1</sup>. Concentration of the same ion in surface water varies from 10.6 to 66.3 mg l<sup>-1</sup> (Avg. 25.8 mg l<sup>-1</sup>). On an average, calcium accounts for 37% and 43% of the total cations (TZ<sup>+</sup>) respectively in surface and groundwater. Ca<sup>2+</sup> and Mg<sup>2+</sup> together contributed about 69% of the total cations in water resources of Deogarh district. In overall cationic abundance, calcium (43%) is followed by magnesium (31%), sodium (25%) and potassium (1%) in groundwater, while in surface water Ca<sup>2+</sup> (37%) is followed by Na<sup>+</sup> (34%), Mg<sup>2+</sup> (26%) and K<sup>+</sup> (3%).

### Hydro-geochemical Processes

The chemical composition of water is controlled by many factors that include composition of rainwater, geological structure and mineralogical composition of the watersheds and hydrological conditions and anthropogenic activities in the catchment area (Andre et al., 2005; Berner and Berner, 1987; Appelo and Postma,



**Table 3: Range in values of geochemical parameters in mine water and WHO (1997) and Indian Standards (IS-10500) for drinking water**

Parameters	Surface water (n = 21)			Groundwater (n = 24)			WHO (1997)		BIS (1991) IS:10500	
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Max. Desirable	Highest Permissible	Max. Desirable	Highest permissible
pH	6.9	8.3	7.9	6.7	7.8	7.2	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
EC	133	1478	421	215	1541	750	750	1500	-	-
TDS	122.1	946.9	314.4	223.1	1216.8	614.5	500	1500	500	2000
F <sup>-</sup>	0.5	3.1	1.3	0.4	2.4	1.5	0.6-0.9	1.5	1.0	1.5
Cl <sup>-</sup>	4.3	410.0	57.8	3.7	382	129.3	250	600	250	1000
HCO <sub>3</sub> <sup>-</sup>	58.6	245.8	126.3	96.8	414.8	222.4	200	600	200	600
SO <sub>4</sub> <sup>2-</sup>	1.1	143.5	22.2	2.2	137.5	38.2	200	600	200	400
NO <sub>3</sub> <sup>-</sup>	1.1	55.8	9.5	0.2	151.0	42.8	-	50	45	100
H <sub>4</sub> SiO <sub>4</sub>	4.8	49.3	18.0	12.6	59.6	31.3	-	-	-	-
Ca <sup>2+</sup>	10.6	66.3	25.8	2.1	145.5	66.9	75	200	75	200
Mg <sup>2+</sup>	1.8	52.1	13.2	6.1	69.3	29.7	30	150	30	100
Na <sup>+</sup>	7.8	182.1	34.8	14.2	171.9	44.9	50	200	-	-
K <sup>+</sup>	1.4	15.4	5.5	0.7	12.7	2.4	100	200	-	-
TH	36.5	379.8	118.9	91.8	525.1	289.4	100	500	300	600
Turbidity	1.4	357	68.0	0.4	39.2	6.6			<10.0	

Units: Concentration in mg l<sup>-1</sup>, except pH, EC (μS cm<sup>-1</sup>), Turbidity (NTU);  
EC = Electrical conductivity, TDS = Total dissolved solid

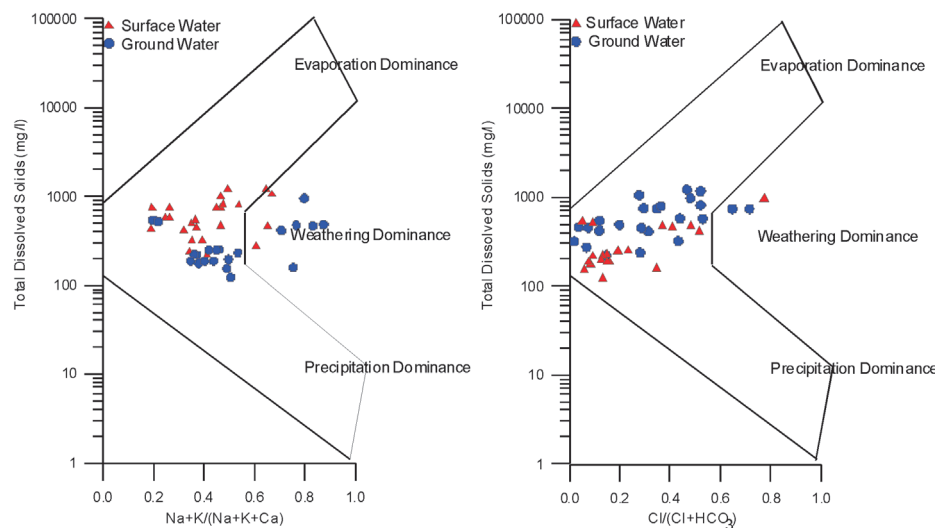
1993). The contribution of atmospheric sources to the dissolved salts in the aquatic water can be assessed by considering the rainwater chemistry or by taking the ratios of elements to Cl<sup>-</sup> (Sarin et al., 1989; Appelo and Postma, 1993; Zhang et al., 1995). The average Na<sup>+</sup>/Cl<sup>-</sup> and K<sup>+</sup>/Cl<sup>-</sup> ratios for the subsurface (1.23 and 0.053) and surface water (1.29 and 0.149) in the present study area are found to be higher as compared with marine aerosols (Na<sup>+</sup>/Cl<sup>-</sup> = 0.85 and K<sup>+</sup>/Cl<sup>-</sup> = 0.0176). This suggests limited contributions from atmospheric precipitation and high levels of major ions in the water are sustained most likely by weathering of rock forming minerals and anthropogenic sources. Further, the plot of geochemical data on Gibbs's diagram (Gibbs, 1970), that represent ratios of (Na+K)/(Na+K+Ca) and Cl/(Cl+HCO<sub>3</sub>) as a function of TDS, indicates rock weathering as a major controlling factor in determining water chemistry of the area (Figure 3). Evaporation increases salinity by increasing concentration of Na<sup>+</sup> and Cl<sup>-</sup>. High temperature, semi-arid climate, lack of good drainage conditions in the study area and longer residence time of groundwater also contribute in enhancing the salinity and concentration of Na<sup>+</sup>, K<sup>+</sup> and Cl<sup>-</sup>.

The ion exchange between the groundwater and its host environment during residence or in movement processes are the important controlling factors for water chemistry of the region. The ion exchange process can be understood by chloro-alkaline indices, also known as Schoeller index (Schoeller, 1977) and expressed as:

$$\text{CAI-I} = \text{Cl}^- - (\text{Na}^+ + \text{K}^+)/\text{Cl}^-$$

$$\text{CAI-II} = \text{Cl}^- (\text{Na}^+ + \text{K}^+)/\text{SO}_4^{2-} + \text{HCO}_3^- + \text{NO}_3^-$$

The chloro-alkaline indices (CAI-I and CAI-II) can be either positive or negative depending on whether exchange of Na<sup>+</sup> and K<sup>+</sup> is from water with Mg<sup>2+</sup> and Ca<sup>2+</sup> in rock/soil, or vice versa. If Na<sup>+</sup> and K<sup>+</sup> are exchanged in water with Mg<sup>2+</sup> and Ca<sup>2+</sup>, the value of the ratio will be positive, indicating a base-exchange phenomenon. The negative values of the ratio will indicate chloroalkaline disequilibrium and the reaction as a cation-anion exchange reaction. In the present case, about 66% of the groundwater and 28% of the surface water samples have positive values indicating base-exchange reaction. In 72% of the surface water and 34% of the groundwater samples, the negative Schoeller index values indicate chloro-alkaline disequilibrium

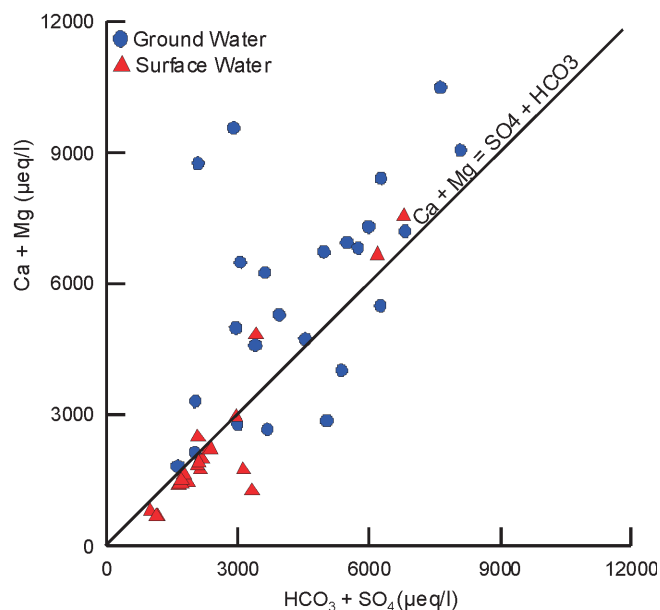


**Figure 3: Gibbs's diagrams representing ratio of (i)  $\text{Na}+\text{K}/(\text{Na}+\text{K}+\text{Ca})$  and (ii)  $\text{Cl}/(\text{Cl}+\text{HCO}_3)$  as a function of TDS (After Gibbs, 1970).**

and the reaction as a cation-anion exchange reaction (Table 2).

The source of the dissolved constituents in groundwater can also be evaluated by looking the relative abundance of individual ions and inter-elemental correlation. The plot of  $(\text{Ca}^{2+}+\text{Mg}^{2+})$  Vs  $(\text{HCO}_3^-+\text{SO}_4^{2-})$  will be close to 1:1 line in case of dissolution of calcite, dolomite and gypsum. Ion exchange tends to shift the plotted points towards right due to a large excess of  $\text{HCO}_3^-+\text{SO}_4^{2-}$  and towards the left in case of reverse

ion exchange and dominance of  $\text{Ca}^{2+}+\text{Mg}^{2+}$  over  $\text{HCO}_3^-+\text{SO}_4^{2-}$  (Cerling et al., 1989; Fisher and Mulican, 1997). The plot of  $(\text{Ca}^{2+}+\text{Mg}^{2+})$  Vs  $(\text{HCO}_3^-+\text{SO}_4^{2-})$  shows that majority of the groundwater samples fall above the equiline, indicating predominance of reverse ion exchange process in the groundwater system. However, at lower concentration plotted points of both surface and groundwater fall along or below equiline and suggest dominance of weathering and ion exchange processes (Figure 4).

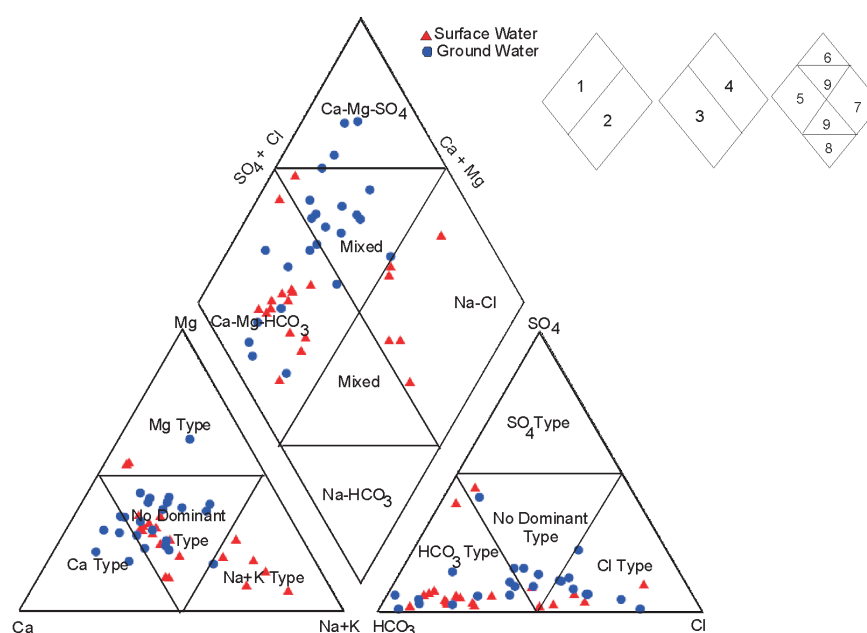


**Figure 4: Scatter diagram between  $(\text{Ca}+\text{Mg})$  Vs  $(\text{HCO}_3+\text{SO}_4)$ .**

### Hydrochemical Classification and Hydrochemical Facies

The trilinear diagram of Piper (1944) is very useful in determining relationships of different dissolved constituents and classification of water on the basis of its chemical character. The Piper diagram is an ingenious construction which consists of two triangles at the lower left and lower right, describing the relative composition of cations and anions and an intervening diamond shaped field that represent the composition of water with respect to both cations and anions. The triangular cationic field of Piper diagram reveals that 58% groundwater and 62% surface water samples fall into no dominant type, whereas 38% of the groundwater falls in Ca type and 29% of the surface water in Na+K type. In anion facies, 62% of the surface and 46% of the groundwater samples shows  $\text{HCO}_3$  type of water. About 38% of the groundwater and 29% of the surface water fall into chloride field of anion facies (Figure 5).

The plot of chemical data on diamond shaped field which relate cation and anion triangles reveal that the



**Figure 5: Trilinear diagram showing chemical character of surface and groundwater and hydrochemical facies (After Piper, 1944).**

majority of the surface waters fall in the fields of 1, 2, 3, 4, 5 and 7 and groundwater in 1, 3, 4, 5, 6 and 9 fields. In all the groundwater and 71% of surface water samples alkaline earth ( $\text{Ca}^{2+} + \text{Mg}^{2+}$ ) exceeds alkalies ( $\text{Na}^{+} + \text{K}^{+}$ ) and plotted points fall in the field 1. However, plotted points of 29% surface water samples fall in the field 2 indicating dominance of alkalies over alkaline earth. About 67% surface water and 42% groundwater samples exhibit dominance of weak acids ( $\text{HCO}_3^{-}$ ) over strong acids ( $\text{SO}_4^{2-} + \text{Cl}^{-}$ ) and plotted points fall in the field 3. The plotted points of 42% groundwater and 66% surface water samples in the field 5 signify carbonate hardness (secondary salinity) exceeds 50%. Only 17% of the groundwater samples show non-carbonate hardness (secondary salinity) exceeds 50% (field 6), while 29% of the surface water samples fall in the field 7 signifying non-carbonate alkali (primary salinity) exceeds 50%. Ten samples (42%) of groundwater fall in the field 9 which indicate water of an intermediate (mixed) chemical character having no one cation-anion pair exceeds 50%. The facies mapping approach applied to the present study shows that  $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{HCO}_3^{-}$  is the dominant hydrochemical facies both in surface (62%) and groundwater (42%) of the area.  $\text{Na}^{+} - \text{Cl}^{-}$  and  $\text{Ca}^{2+} - \text{Mg}^{2+} - \text{SO}_4^{2-}$  are the dominant hydrochemical facies in 29% surface water and 17% of groundwater samples (Back, 1966).

### Water Quality Assessment

The data obtained by chemical analyses were evaluated in terms of its suitability for drinking and general domestic, irrigation, livestock and industrial uses.

(i) *Suitability for Drinking and General Domestic Uses*  
To assess the suitability for drinking and public health purposes, the hydrochemical parameters of the surface and subsurface water of the study area are compared with the prescribed specifications of WHO (1997) and Indian standard for drinking water, i.e. IS-10500 (BIS, 1991). Table 3 shows that most of the surface and sub-surface water of the study area are suitable for drinking and domestic uses with few exceptions. pH of the analysed waters (6.7-8.3) are found well within the safe limit of 6.5-8.5, prescribed for drinking water by BIS (1991) and WHO (1997). The turbidity is important physical parameter for water quality, defining the presence of suspended solids in water, which causes the muddy or turbid appearance of water body. In the study area it ranges from 1.4 to 357 NTU in the surface water and 0.4 to 39.2 NTU in the groundwater. The average turbidity of surface water (68 NTU) is much higher than the groundwater (6.6 NTU). Turbidity value exceeds the maximum permissible limit of 10 NTU in two groundwater samples.

Total dissolved solid (TDS) concentration exceeds drinking water desirable limit i.e. 500  $\text{mg l}^{-1}$  in 15%

surface water and 54% groundwater samples. TDS of three groundwater samples (W-3, W-8 and W-16) exceeded the maximum permissible limit of 1000 mg l<sup>-1</sup> specified for drinking uses. TDS of the majority of analyzed water samples (95%) are falling in the fresh water (<1000 mg l<sup>-1</sup>) category. Water hardness is the property attributed to presence of alkaline earths. Water can be classified in to soft (TH <75 mg l<sup>-1</sup>), moderately hard (75-150 mg l<sup>-1</sup>), hard (150-300 mg l<sup>-1</sup>) and very hard (TH >300 mg l<sup>-1</sup>) on the basis of total hardness. Total hardness (TH) of the analysed surface and sub-surface water of the study area varies between 37 mg l<sup>-1</sup> and 525 mg l<sup>-1</sup>, indicating soft to very hard types of water. The analytical data indicate that 12 groundwater and two surface water samples have hardness higher than 300 mg l<sup>-1</sup>, which is the desirable limit for drinking water (BIS, 1991). Hardness has no known adverse effect on health but it can prevent formation of lather with soap and increases boiling point of the water. High hardness of water may cause precipitation of calcium carbonate and encrustation on water supply distribution systems. A long-term consumption of extremely hard water might lead to an increased incidence of urolithiasis, anencephaly, parental mortality, some types of cancer and cardio-vascular disorders (Agrawal and Jategia, 1997; Durvey et al., 1991).

Chloride concentration exceeds drinking water desirable limit i.e. 250 mg l<sup>-1</sup> in 17% groundwater samples. Excess concentration of Cl<sup>-</sup> in drinking water gives a salty taste and has a laxative effect in people not accustomed to it. Concentration of NO<sub>3</sub><sup>-</sup> is also found to be higher than the recommended level of 45 mg l<sup>-1</sup> in 45% groundwater samples. Excessive NO<sub>3</sub><sup>-</sup> in drinking water can cause a number of disorders including methaemoglobinaemia in infants, gastric cancer, goiter, birth malformations and hypertension (Majumdar and Gupta, 2000). Fluoride is an essential element for maintaining normal development of healthy teeth and bones. However, higher F<sup>-</sup> concentration causes dental and skeletal fluorosis such as mottling of teeth, deformation of ligaments and bending of spinal cord. Fluoride concentration exceeded highest permissible level i.e. 1.5 mg l<sup>-1</sup> in 14% surface water and 54% groundwater samples. Concentrations of SO<sub>4</sub><sup>2-</sup> in all the analyzed water samples are found well within the safe limit of 200 mg l<sup>-1</sup> (BIS, 1991).

Among the cations, Na<sup>+</sup> is most important ions for human health and a higher sodium intake may cause hypertension, congenital heart diseases, nervous disorder and kidney problems. The recommended limit for sodium concentration in drinking water is 200 mg l<sup>-1</sup>

(WHO, 1997; BIS, 1991). Concentrations of Na<sup>+</sup> are within the recommended limit in the analyzed water samples of the area. Calcium and magnesium are essential nutrients for plants and animals and presence of Ca<sup>2+</sup> and Mg<sup>2+</sup> in drinking water provide nutritional benefits for people. It is an essential element for bone, nervous system and cell development. Ca<sup>2+</sup> and Mg<sup>2+</sup> are the main contributors toward the water hardness. One possible adverse effect from ingesting high concentration of Ca<sup>2+</sup> for long periods of time may be an increased risk of kidney stones. Concentration of Ca<sup>2+</sup> and Mg<sup>2+</sup> are slightly exceeding the prescribed drinking water desirable limit of 75 and 30 mg l<sup>-1</sup>, respectively, in some water samples. However, it is well within the maximum permissible limit of 200 and 100 mg l<sup>-1</sup> (BIS, 1991).

#### (ii) Suitability for Irrigation Uses

The parameters like total salt concentration (EC), sodium adsorption ratio (SAR), sodium percentage (Na%), residual sodium carbonate (RSC), permeability index (PI) and magnesium hazard (MH) are important in assessing the suitability of water for irrigation (Ayers and Wascot, 1985). These parameters were determined and furnished in Table 2 and discussed in following paragraphs.

#### Salinity (EC) and Sodium Adsorption Ratio (SAR)

Electrical conductivity (EC) and sodium concentration are very important in classifying irrigation water. Salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. The total concentration of soluble salts in irrigation water can thus be expressed for the purpose of classification of irrigation water as low (EC = <250 µS cm<sup>-1</sup>), medium (250-750 µS cm<sup>-1</sup>), high (750-2250 µS cm<sup>-1</sup>) and very high (2250-5000 µS cm<sup>-1</sup>) salinity classes (Richards, 1954). While a high salt concentration (high EC) in water leads to formation of saline soil, a high sodium concentration leads to development of an alkaline soil. Excessive solutes in irrigation water are a common problem in semiarid areas where water loss through evaporation is maximal. Salinity problems encountered in irrigated agriculture most likely arise where drainage is poor which allows the water table to rise close to the rooting zone of plants causing the accumulation of sodium salts in the soil solution through capillary rise following surface evaporation of water. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of



sodium adsorption ratio (SAR) and it can be estimated by the formula:

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

There is a significant relationship between SAR values of irrigation water and the extent to which sodium is adsorbed by the soils. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. The calculated value of SAR in the study area ranges 0.18-5.78 in the surface and 0.39-3.94 in the groundwater. The plot of data on the US salinity diagram, in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that majority of the water samples fall in the category C1S1 and C2S1, indicating low to medium salinity and low alkali water, which can be used for irrigation in most soils and crops with little danger of development of exchangeable sodium and salinity (Figure 6). About 41% of the groundwater samples fall in the zone of C3S1 indicating high salinity and low alkali water. High saline water cannot be used on soils with restricted drainage and requires special management for salinity control.

#### Percent Sodium (%Na)

Percent sodium is widely used for evaluating the suitability of water quality for irrigation (Wilcox, 1955). As per the Indian Standard (BIS, 1991) maximum sodium of 60% is recommended for irrigation water. The sodium percentage (%Na) in the water samples is calculated with respect to relative proportions of cations present in water using the following equation:

$$\% \text{Na} = \frac{\text{Na} + \text{K}}{\sqrt{(\text{Ca} + \text{Mg})(\text{Na} + \text{K})}} \times 100$$

The sodium percentage (%Na) in the study area ranges between 6.8-79.2 % in surface and 11.7-51.2% in groundwater. Plot of analytical data on Wilcox (1955) diagram relating electrical conductivity and sodium percent shows that water are excellent to good and good to permissible quality for irrigation (Figure 7).

#### Residual Sodium Carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths ( $\text{Ca}^{2+} + \text{Mg}^{2+}$ ) also influence the suitability of water for irrigation purposes. When the sum of  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  is in excess over sum of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ , there may be possibility of complete precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  as carbonate (Karanth, 1989). Effects of

carbonate and bicarbonate and suitability of water for irrigation can be assessed by computing the residual sodium carbonate (RSC) values.

$$\text{RSC} = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

all concentration in meq l<sup>-1</sup>

A high value of RSC in water leads to an increase in the adsorption of sodium on soil (Eaton, 1950). Irrigation waters having RSC values greater than 5 meq l<sup>-1</sup> have been considered harmful to the growth of plants, while waters with RSC values above 2.5 meq l<sup>-1</sup> are unsuitable for irrigation. A RSC value between 1.25 and 2.5 meq l<sup>-1</sup> is considered as the marginal quality and value <1.25 meq l<sup>-1</sup> as the safe limit for irrigation. The calculated RSC values of surface water ranges between 0.2 and 2.5 meq l<sup>-1</sup> and in groundwater between 0.3 and 3.4 meq l<sup>-1</sup>. Except in three groundwater samples, RSC values are found well below the 2.5 meq l<sup>-1</sup> limit, suggesting that water is safe to marginally suitable category for irrigation uses.

#### Permeability Index (PI)

The soil permeability is affected by long term use of water rich in  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ . The permeability index are also used for assessment of suitability of water for irrigation uses and defined as:

Permeability index (PI)

$$= \frac{\text{Na} + \sqrt{\text{HCO}_3^-}}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+} \times 100$$

where concentration in meq l<sup>-1</sup>

Doneen (1964) classified irrigation waters based on the Permeability Index (PI) in to three classes. Class I and Class II water types are suitable for irrigation with 75 percent or more of maximum permeability and Class III types of water with 25 percent maximum permeability and unsuitable for irrigation. Plot of data on the Doneen's chart shows that majority of the surface and groundwater sample falls in Class I and II, implying that the water is good for irrigation uses with 75% or more of maximum permeability (Domenico and Schwartz, 1990). Six groundwater samples belong to the Class III of unsuitable category (Figure 8).

#### Magnesium Hazard (MH)

Szabolcs and Darab (1964) proposed magnesium hazard (MH) value to assess suitability of water for irrigation uses. The magnesium ratio is the excess amount of magnesium over calcium and magnesium. The excess of Mg affects the quality of soil resulting in poor



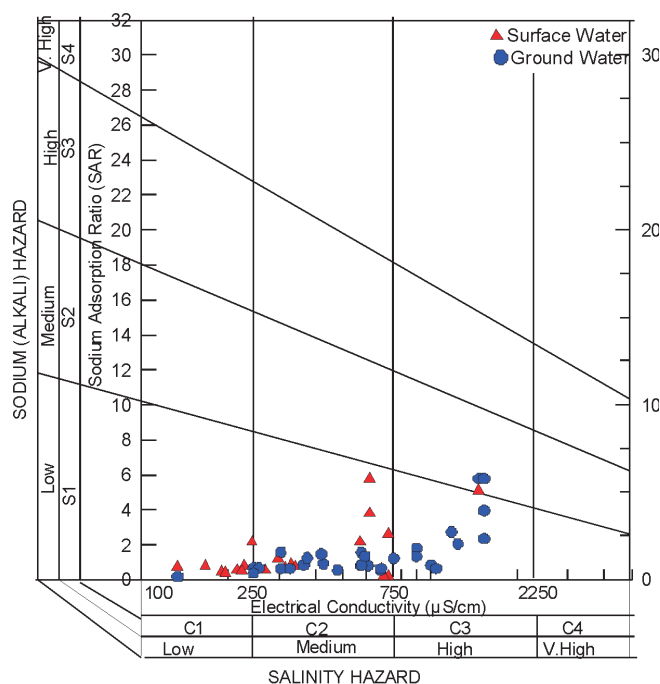


Figure 6: U.S. Salinity diagram for classification of irrigation water (after Richards, 1954).

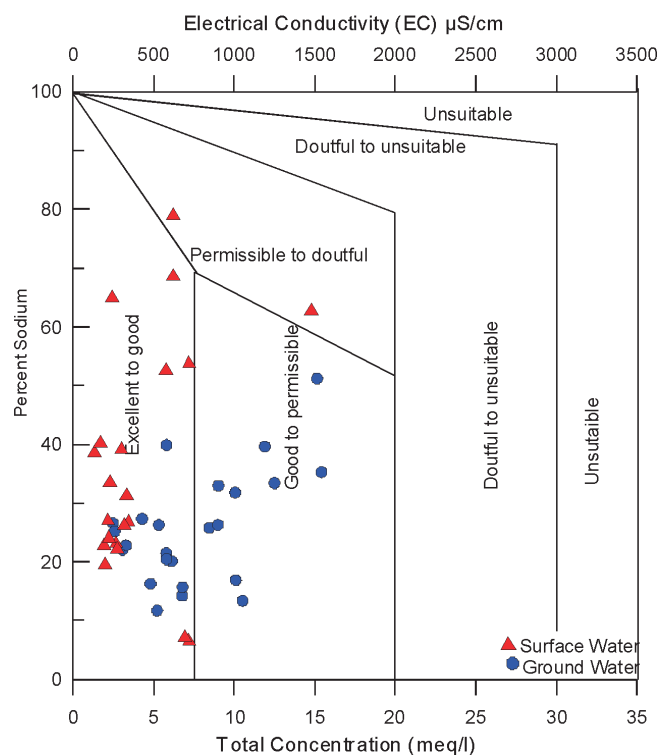


Figure 7: Wilcox (1955) diagram for classification of groundwater based on EC and %Na.

agricultural returns. Magnesium ratio >50 percent are considered harmful and unsuitable for irrigation use. The magnesium ratio value in the water resources of

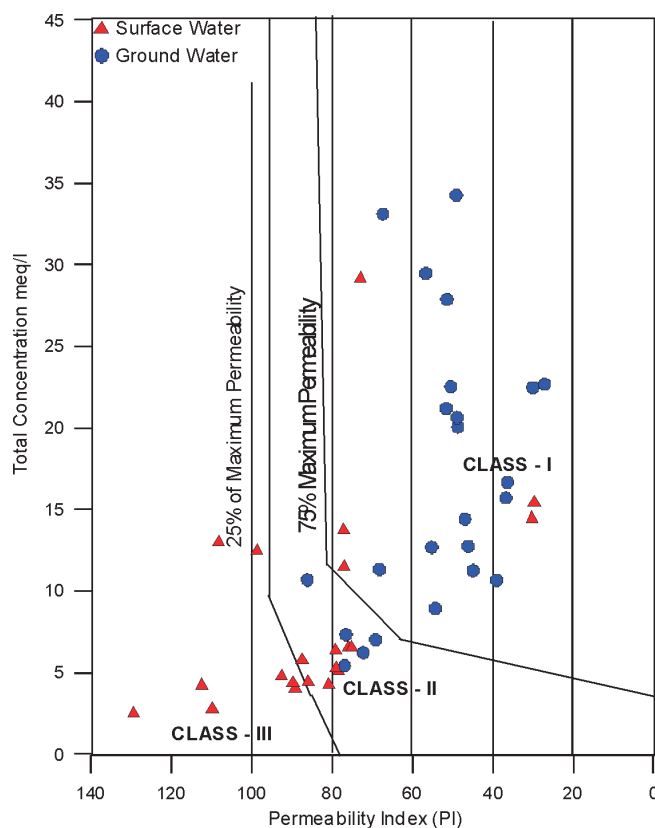


Figure 8: Classification of irrigation water based on the permeability index (After Doneen, 1964).

Deogarh district varies between 20.0 and 57.4 (Avg. 40.1) in surface water and 23.2-78.4 (Avg. 43.1) in groundwater. MH value exceeds 50% limit in three surface and six ground samples of the area, indicating that water is in general suitable for irrigation.

## Conclusions

The geochemical study of surface and groundwater resources of the Deogarh district shows that the water is mildly acidic to alkaline in nature.  $\text{Ca}^{2+}$  and  $\text{Na}^{+}$  are the dominant cations and  $\text{HCO}_3^{-}$  and  $\text{Cl}^{-}$  are the dominant anions. The water chemistry is largely controlled by rock weathering and ion exchange processes with minor contribution from anthropogenic sources. Observed high concentration of  $\text{SO}_4^{2-}$  and TDS in the mine water and groundwater near the Chitra coal mine indicate input from the weathering of sulphide minerals. Higher concentrations of  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^{-}$ ,  $\text{Cl}^{-}$  and TDS in some samples indicate mining and anthropogenic impact on water quality. The chloroalkaline indices indicate that majority of groundwater samples have positive values, suggesting a base-exchange reaction. Negative

chloroalkaline indices in 72% surface water samples suggest chloroalkaline disequilibrium and the reaction as a cation-anion exchange reaction.  $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$  is the dominant hydrochemical facies both in surface and subsurface water. The quality assessment of surface and subsurface water shows that water is suitable for domestic purposes with few exceptions. The high value of TDS, TH,  $\text{F}^-$  and  $\text{NO}_3^-$  at some sites restricts direct use of water for drinking purposes. The calculated parameter of SAR, %Na, RSC, MH and PI shows that in general water is suitable for irrigation. However, higher salinity, %Na, MH and PI at certain sites restrict suitability of the water for irrigation and demands suitable water management and treatment.

### Acknowledgements

Authors are grateful to Director, Central Institute of Mining and Fuel Research, Dhanbad for his kind permission to publish this paper. Help and encouragement rendered by the lab-colleagues of Geo-environment Division, CIMFR is thankfully acknowledged.

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