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Hydrochemical Characterization of Groundwater of West Jaintia Hills, Meghalaya for Irrigation Purpose

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Abstract: *The agrarian area under study is a part of the West Jaintia Hills of Meghalaya, although the rainfall is of the order of 986 cm/annum but still the area is classified as water scanty due to total available water for irrigation and potable use. Forty groundwater samples were collected and analyzed for pH, electrical conductivity, total dissolved solids, hardness, major anions (F^-, Cl^-, NO_3, HCO_3^-, SO_4^{2-}) and cations (Ca^{2+}, Mg^{2+}, Na^+, K^+). Hydrochemical characterisation of groundwater was carried out to check for its suitability for irritation purpose. This characteization includes parameters such as Sodium absorption ratio (SAR), Soluble sodium percentage (SSP), Percentage of sodium (PS), Kelley's ratio (KR), Residual sodium carbonate (RSC), Corrosivity ratio (CR), Gibbs ratios (GR), Chloro alkaline indices (CAI). The results indicate that groundwater is fresh but rich in sulphate with TDS ranging from 11.71 to 292 ppm and samples fall within permissible irrigational range.*

Keywords: *Gibbs Ratio, Groundwater, Hydro-chemical facies, Irrigation, Sodium Absorption Ratio*

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I. Introduction

Groundwater is a major source for water supply in private, domestic and industrial sector. It plays a major role in ensuring livelihood security across the world, especially in economies that depend on agriculture. Groundwater quality is considered as great importance with the rising pressure on agriculture and rise in standard of living. Insufficient rainfall as well as long arid winters has led to be deficient in water, thus increasing the demand for the groundwater. Consequently this study was undertaken to hit upon the suitability of groundwater sources for irrigational purposes. In the study area, people are dependent on agriculture. Although plenty of agriculture land is available, the scope for irrigation is very limited due to non-availability of sufficient fresh water. In the present study an attempt has been made to determine the hydro-chemical processes that control the groundwater composition and to assess its suitability for domestic and irrigation uses.

II. Study area

Nartiang and Nangbah are adjoining villages in West Jaintia Hills district of Meghalaya, bounded by North latitudes 25°30'0" and 25°36'0" and East Longitudes 92°10'50" and 92°19'30"and is included in parts of Survey of India Topographic Sheet Numbers 83 C/2 and 83 C/6.

2.1 Geology

The study area falls within the Shillong Plateau which is constituted mainly of Precambrian rocks of 'Gneissic Complex ' which represent the oldest group of rocks exposed in the area, they are composed of migmatitic and gneissic rocks associated with some schists. The most abundant rocks are biotite bearing granite gneisses. The gneissic rocks are commonly traversed by quartz of feldspathic and quartz veins. The granitic rocks are leucocratic, medium grained, and display well developed gneissossity defined by thin segregations of quartzo-feldspathic layers alternating with biotite rich layers. In general the gneisses exhibit a porphyroblastic texture with feldspar crystals mainly forming the porphyroblasts which show a distinct tendency of elongation aligned parallel to the gneissosity. Some amphibolitic and epidioritic rocks occur as intrusive/ eruptive bodies in the Gneissic Complex and the Shillong Group of rocks. This can be seen in the Nartiang-Nongbah road section near the Shillong Group - Gneissic complex contact. The sedimentaries occur as isolated patches mostly in the form of cappings over the Biotite Granite in the north and Gneissic complex in the south [1].

2.2 Hydrology

Hydrologically the area is constituted of consolidated formation. These include the oldest rock formation occupying about 1300 km^2 of the Jaintia hills district. Peneplained gneissic complex, quartzites etc constitute this unit. The depth of weathering varies from place to place and is 15 to 20 m at places. The presence of substantial weathered mantle is confined to their secondary porosities, which form excellent repository of ground water in hard rock area. The storage and movement of ground water in hard rock is controlled by physiography, zone of weathering and interconnected places of weakness. Ground water occurs under unconfined condition and in semi-confined condition in the interconnected secondary structural weakness/ features like joints, fractures of the underlying hard rocks[2].

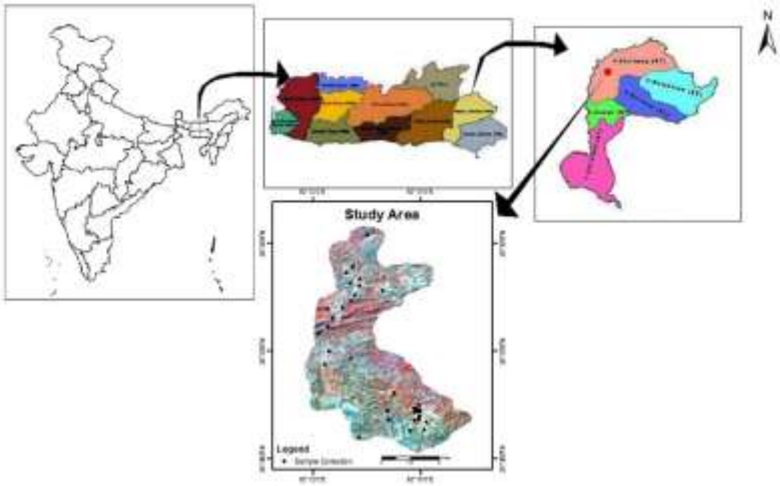


Figure 1: Location of Study area

III. Chemical Studies

Forty groundwater samples were collected in pre-cleaned polythene container from dug well and bore well. Chemical analyses were carried out for the major ion concentrations using the standard procedures recommended by APHA[3]. The analyses method for each parameter is given below in Table 1.

Parameter	Analysis Method
pH	pH meter
Electrical Conductivity	Conductivity Meter
Cl^{-},Ca^{2+}, Mg^{2+}	Titration
TDS,SO_4^{2-},NO^{3-}	Gravimetric
Na^{+}	Flame photometric

Table 1: Details of parameter and the analysis method

The result of the chemical analysis of groundwater samples is given in Table 2, the TDS value ranges from 11.71 to 292 ppm. The groundwater of the area according to Carroll [4] classification falls under fresh water type (>1000 ppm). TDS vs Electrical Conductivity (EC) plot (Fig. 2) shows a linear trend.

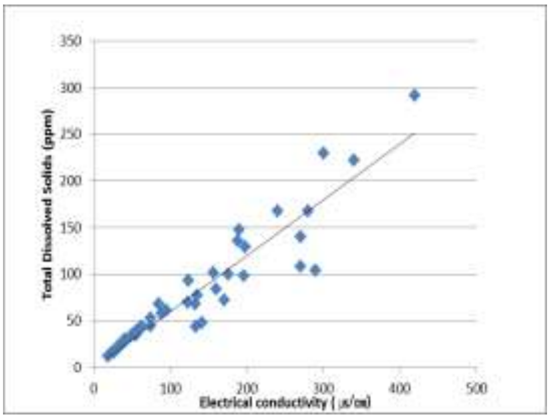


Figure 2: Variation of TDS vs EC for groundwater samples

One of the most common methods used for comparing the results of chemical analyses of ground water is with piper diagram. This diagram consists of two lower triangles that show the percentage distribution, on the milliequivalent basis, of the major cations (Mg^{2+}, Ca^{2+}, and Na^{+} plus K^{+}) and the major anions (Cl^{-}, $SO_4^{2-}$and CO_3^{2-} plus HCO_3^{-}) and a diamond-shaped part above that summarizes the dominant cations and anions to indicate the final water type.

This classification system shows the anion and cation facies in terms of major-ion percentages. The water types are designated according to the area in which they occur on the diagram segments [5]. The Piper Diagram (Fig. 3) of groundwater quality of Nartiang Nangbah area indicates that the water type found in the area is of Calcium Magnesium Bicarbonate facies and Calcium Magnesium Sulfate Chloride.

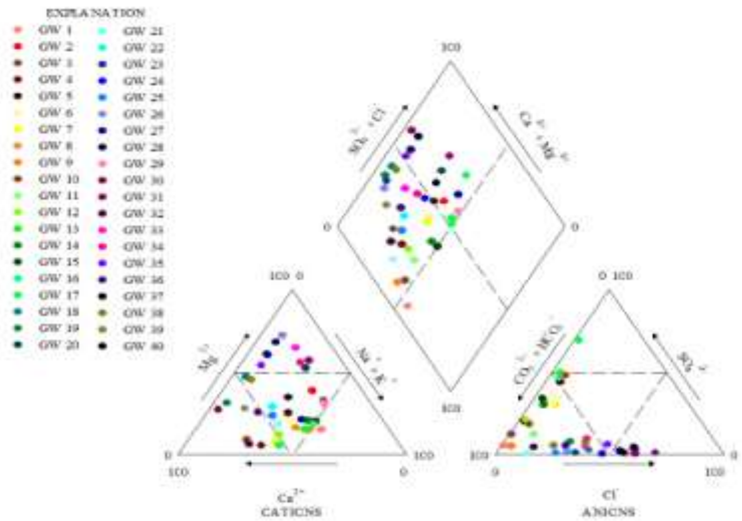


Figure 3: Piper Diagram showing hydrochemical facies

Further, to classify the groundwater suitability for irrigation purposes (Table3) hydrochemical characteristics was calculated which includes Sodium Absorption Ratios, Soluble Sodium Percentages, Sodium percentage, Kelley's Ratios, Residual Sodium Carbonates, Corrosivity Ratios, Gibb's Ratios and Chloro Alkaline Indices. A detailed results of these hydrochemical parameters studied is given in Table 4.

3.1 Sodium Absorption Ratios (SAR)

SAR is an important parameter for determination of suitability of irrigation water. The sodium hazard is typically expressed as the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium (Na^{+}) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a sample. It is calculated as:

SAR = [Na/{(Ca+Mg)/2}1/2]……………….(1)

It is expressed in meq/l and plotted against EC in the diagram to determine the suitability of water for irrigation purpose (Fig.4). The observed values for all the samples are less than 10 (0.007 to 0.815). The plot indicates that the samples falls under the category of 'good water' and is suitable for irrigation in term of sodium and salinity.

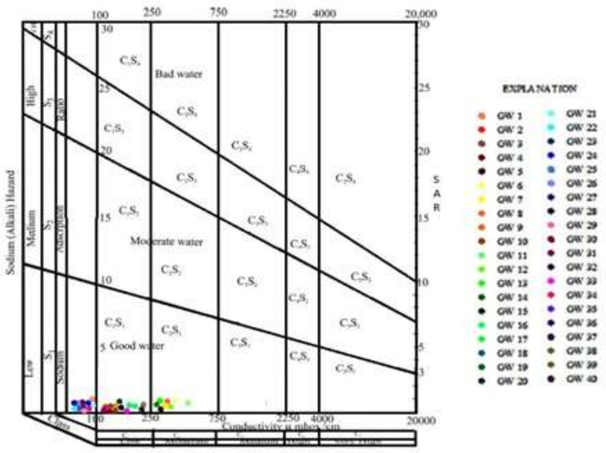


Figure 4: Plots of SAR values against EC

3.2 Soluble Sodium Percentages (SSP)

Soluble Sodium Percentages indicates the proportion of sodium ions in solution in relation to the total cation concentration. It is calculated as:

$$SSP= [\{(Na+K)/(Na+K+Ca+Mg)\}*100]............(2)$$

where, the ionic concentration are expressed in meq/l. The SSP of the groundwater samples ranges from 4.023 to 55.398% (<60) indicating that the groundwater of the area is within permissible limit.

3.3 Sodium percentage (SP)

Wilcox [6] classified groundwater for irrigation purposes based on percent sodium and Electrical conductivity. Eaton [7] recommended the concentration of residual sodium carbonate to determine the suitability of water for irrigation purposes. The sodium percentage was calculated as:

$$SP = [\{Na / (Ca+Mg+Na+K)\}*100].................. (3)$$

The sodium percentage in the study area ranges between 1.889 to 44.397%. The sodium percentage is plotted in Wilcox diagram (Fig.5) and it indicates that the groundwater samples collected come under 'good to excellent' category.

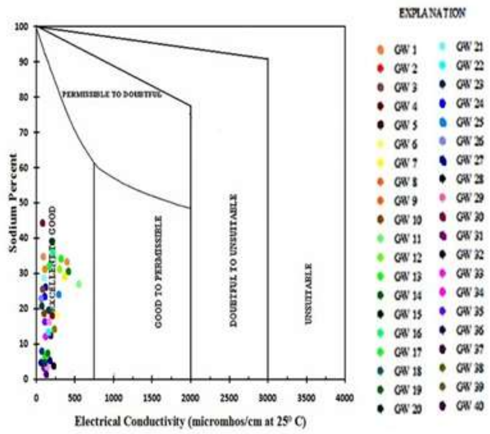


Figure 5: Plots of SP values against EC

3.4 Kelley's Ratios (KR)

Kelley (1940) introduced an important parameter to evaluate irrigation water based on the level of Na against Ca and Mg, expressed in meq/l. The KR values ranges from 0.038 to 0.815 (<1) suggesting that the water is good for irrigation purpose. It is calculated as:

$$KR= [Na/(Ca+Mg)]............ (4)$$

3.5 Residual Sodium Carbonates (RSC)

RSC is a significant factor that has a great influence on the suitability of water for irrigation purposes. It is estimated from the following expression

$$RSC [(HCO_3+CO_3) - (Ca+Mg)]............ (5)$$

RSC of the groundwater samples collected ranges from -1.279 to 0.799 (<1.5 meq/l; good category) and can be used for irrigation

3.6 Corrosivity Ratios (CR)

It is the tendency of water to corrode steel pipelines during the transportation of irrigation water or deposition of scaling film on the pipes.

$$CR= [\{(Cl/35.5) +2*(SO_4/96)\}/ \{2*(HCO_3+CO_3)/100\}]......... (6)$$

The groundwater with corrosivity ratio < 1 is considered to be safe for transport of water in any type of pipes, whereas >1 indicate corrosive nature and hence not to be transported through metal pipes [9, 10]. The Corrosivity Ratio of the groundwater sample collected shows that 35 samples are safe whereas 05 samples are corrosive in nature and need non-corrosive pipe for transporting and lifting of groundwater.

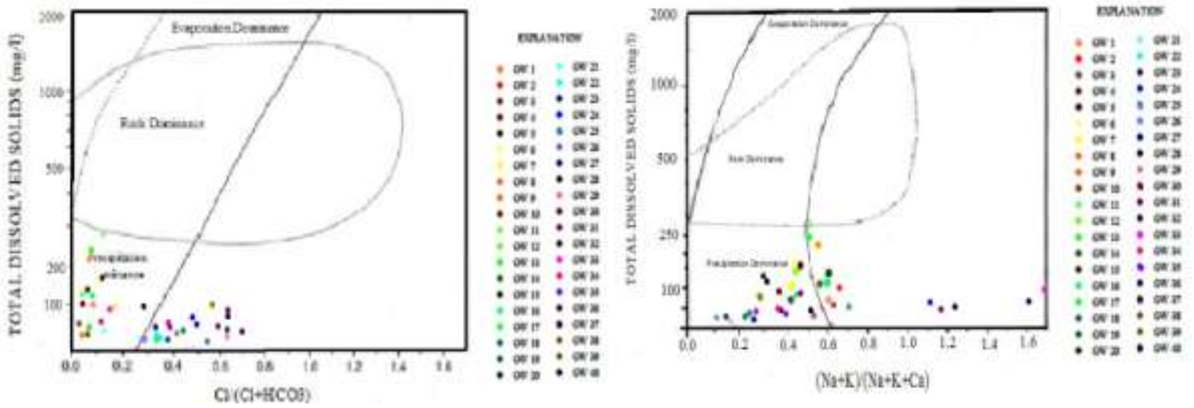
3.7 Gibb's Ratios (GR)

It is used to determine whether the water is in evaporation or rock or precipitation dominance. Gibb's Ratios I is used for the major anion whereas Gibb's Ratios II is used for the major cations. GR are expressed in meq/l and it can be estimated using the following formula [11]

$$GR\text{-}I= [Cl/(Cl+HCO_3)]............ (7)$$

$$GR\text{-}II= [(Na+K)/(Na+K+Ca)]..................(8)$$

The plot (Fig.6a) suggests that major anions i.e. Cl^- and HCO_3^- in ground water are concentrated due to evaporation. The plot (Fig.6b) indicates major cations such that Na^+, K^+ and Ca^{2+} are also concentrated in groundwater due to precipitation.



(a) (b)

Figure 6: Plots of (a) TDS vs Gibbs Ratio-I, (b) TDS vs Gibbs Ratio-II

3.8 Chloro Alkaline Indices (CAI)

Chloro Alkaline Indices shows the reactions in which ion exchange between the groundwater and aquifer environment occurs during the periods of residence and movement [12]

$$CAI\text{-}I= Cl-(Na+ K)/Cl\ldots\ldots\ldots\ldots. (9)$$

$$CAI\text{-} II= Cl- (Na+K) /(SO_4+HCO_3+CO_3+NO_3)\ldots\ldots\ldots\ldots(10)$$

The CAI-I and CAI-II of 23 groundwater samples collected from the study area have negative ratios indicating Base Exchange reaction whereas 17 groundwater samples have positive ratios indicates there is no base exchange between (Na+K) with (Ca+Mg).

Parameter	**Range**	**Class**
TDS [4]	0 -1000	Fresh water
	1000 – 10, 000	Brackish water
	10, 000- 100, 000	Salty water
	> 100, 000	Brine
SAR [13]	< 10	Good
	10-18	Moderate
	18-26	Doubtful
	>26	Bad
SSP [14]	0-20	Excellent
	20-40	Good
	40-60	Permissible
	60-80	Doubtful
	80-100	Unsuitable
KR [8]	<1	Good
	>1	Unsuitable
RSC [7]	<1.5	Good
	1.5-2.5	Doubtful
	>2.5	Unsuitable
CR [9]	<1	Safe
	>1	Unsafe

Table 3: Classification for groundwater suitability for irrigation purposes

IV. Conclusion

The groundwater of Nartiang Nangbah is mainly fresh water. As per Piper diagram the groundwater of the study area belongs to the Calcium Magnesium Bicarbonate and Calcium-Magnesium-Sulfate-Chloride hydrogeochemical facies. The calcium-magnesium-bicarbonate ($Ca\text{-}Mg\text{-}HCO_3$) water type is mainly due to the geology of the area which comprises igneous rocks of crystalline nature, in which the major units are gneisses and granites. Ground water in the study area occurs under unconfined water table conditions and is mostly present in the weathered and fractured granite gneisses and can be classified as moderately hard to hard. The residence time as per the water type (piper diagram) indicates that the groundwater of the study area has shorter residence time within the groundwater flow system.

The suitability of water for irrigation was evaluated based on SAR, Sodium percentage, Residual Sodium Carbonate (RSC), Kelley's Ratio and salinity hazards suggest that groundwater of the study area are suitable for irrigation purpose. The groundwater is considered to be highly beneficial for potable uses. The area having higher corrosivity ratio (>1) GW 2, 5, 13, 16, 17 need noncorrosive pipe during water supply.

Sample No.	**pH**	**EC (µS/cm)**	**TDS (ppm)**	**Na^+ (ppm)**	**K^+ (ppm)**	**Ca^{2+} (ppm)**	**Mg^{2+} (ppm)**	**HCO_3^- (ppm)**	**CO_3^{2-} (ppm)**	**NO_3^- (ppm)**	**Cl^- (ppm)**	**SO_4^{2-} (ppm)**
GW 1	6.8	85.2	68.5	4.5	4.0	3.2	0.9	63.4	0	7.9	0.4	3.7
GW 2	7.5	160.5	84.3	7.0	10.6	6.4	6.7	4.8	0	61.6	0.4	4.8
GW 3	7.8	132.8	68.9	7.5	9.6	4.8	4.8	39.1	0	34.7	0.3	4.4
GW 4	7.9	176.9	100.4	6.5	8.2	17.6	0.9	14.6	0	60.9	0.3	3.1
GW 5	7.4	280.5	168.1	11.5	11.6	17.6	6.7	9.7	0	101.7	0.7	6.8
GW 6	6.5	240.4	168.9	6.5	12.0	12.8	3.8	9.6	0	93.9	0.6	4.9
GW 7	7.1	290.2	104.5	14.5	6.6	22.4	1.9	9.6	0	93.4	1.8	4.1
GW 8	6.8	340.1	222.5	17.0	12.2	14.4	3.8	24.4	0	98.7	1.4	10.6
GW 9	6.9	133.3	44.4	7.5	4.4	8.0	1.9	19.2	0	35.1	0.5	0.8
GW 10	7.1	141.0	48.6	8.0	4.8	24.0	1.9	9.6	0	42.3	0.4	1.6
GW 11	7.3	420.5	292.8	15.0	14.6	16.0	5.7	14.6	0	108.7	1.2	1.7
GW 12	7.6	270.8	140.5	15.5	5.4	20.8	2.8	29.2	0	85.7	0.7	6.1
GW 13	6.1	300.6	230.6	18.0	10.0	16.0	3.8	19.5	0	92.1	0.8	16.9
GW 14	6.5	270.5	108.6	15.5	9.2	12.8	4.8	14.6	0	95.3	0.8	5.5
GW 15	6.8	190.4	148.4	15.0	6.2	9.6	3.8	19.5	0	65.5	0.7	8.5
GW 16	6.2	188.8	136.5	10.0	8.2	8.0	2.8	9.7	0	64.1	0.5	7.5
GW 17	7.8	170.9	72.5	10.5	4.4	14.4	0.9	9.6	0	36.7	0.4	18.9
GW 18	6.5	35.5	24.9	0.5	0.2	4.2	2.4	18.7	0	0.1	7.5	0.7
GW 19	6.7	33.7	21.9	0.3	0.1	4.6	1.2	18.7	0	1.1	5.0	1.8
GW 20	7.2	40.1	28.0	2.9	1.6	2.4	3.6	8.0	0	1.2	7.5	0.7
GW 21	7.8	88.6	57.5	7.2	2.4	10.6	2.4	53.8	0	2.6	5.0	0.8
GW 22	7.6	48.3	33.8	1.8	4.1	6.1	2.4	18.9	0	1.2	5.0	0.5
GW 23	7.3	27.6	18.4	0.5	0.2	2.3	2.4	16.1	0	0.1	5.0	0.2
GW 24	7.2	94.1	61.1	6.5	2.7	8.2	4.8	24.1	0	3.6	12.5	0.3
GW 25	6.9	21.3	14.6	0.6	0.2	2.6	2.4	10.7	0	0.1	7.5	0.4
GW 26	7.7	40.3	30.2	2.3	1.1	4.8	1.2	24.1	0	0.4	5.0	0.3
GW 27	7.7	26.1	16.4	0.9	1.1	2.3	4.8	18.7	0	0.9	5.0	0.8
GW 28	7.8	135.3	77.1	9.1	8.5	10.6	3.6	16.1	0	4.9	15.0	0.5
GW 29	7.0	18.3	11.7	0.9	0.2	2.5	3.6	8.1	0	0.2	7.5	0.8
GW 30	7.5	74.1	52.6	10.4	1.8	4.9	3.6	18.7	0	1.4	15.0	0.8
GW 31	7.3	122.9	70.1	0.6	0.1	10.5	2.4	16.1	0	0.2	15.0	0.8
GW 32	6.7	54.5	34.3	1.8	6.0	2.7	4.8	10.7	0	0.9	15.0	0.3
GW 33	9.1	156.3	101.9	6.5	7.5	22.1	1.2	72.4	0	2.6	7.5	3.2
GW 34	7.3	73.9	44.2	1.8	1.4	2.6	4.8	20.1	0	0.5	7.5	1.2
GW 35	7.1	62.2	43.3	2.4	1.6	2.8	3.6	13.4	0	0.1	5.0	1.8
GW 36	7.1	54.8	38.6	0.4	1.6	4.4	3.6	13.4	0	0.2	7.5	1.3
GW 37	7.5	60.3	42.1	1.1	1.6	4.6	1.2	20.1	0	0.8	5.0	1.3
GW 38	6.6	196.3	98.5	0.6	2.0	2.7	1.2	13.4	0	0.2	10.0	0.8
GW 39	6.6	30.3	21.1	0.9	0.5	2.6	1.2	13.4	0	0.1	5.0	1.5
GW 40	7.5	198.2	128.3	0.4	1.3	4.5	1.2	13.4	0	0.3	2.5	0.8
WHO*(ppm)	6.5-8.5	1400	500	200	-	200	150	500	500		600	500
IS* (ppm)	6.5-8.5	1400	1000	200	-	200	100	600	600		1000	400

Table 2: Chemical analyses of the groundwater samples

Sample No.	**SAR**	**SSP**	**SP**	**KR**	**RSC**	**CR**	**Gibbs 1**	**Gibbs 2**	**CAI1**	**CAI2**
GW 1	0.437	55.398	36.366	0.815	0.799	0.079	0.010	0.650	-25.451	-0.171
GW 2	0.392	39.554	20.911	0.345	-0.799	1.305	0.123	0.642	-50.093	-0.123
GW 3	0.491	47.194	26.912	0.509	-0.001	0.171	0.013	0.704	-62.438	-0.174
GW 4	0.294	33.909	19.457	0.294	-0.720	0.325	0.036	0.358	-53.639	-0.103
GW 5	0.464	35.631	22.354	0.347	-1.279	1.112	0.118	0.475	-36.226	-0.102
GW 6	0.315	38.061	18.237	0.294	-0.799	0.841	0.106	0.479	-29.791	-0.081
GW 7	0.575	38.445	30.319	0.492	-1.119	0.811	0.159	0.416	-25.276	-0.111
GW 8	0.787	50.277	35.343	0.711	-0.639	0.654	0.068	0.593	-34.891	-0.133
GW 9	0.471	43.932	32.653	0.582	-0.240	0.125	0.046	0.523	-26.81	-0.148
GW 10	0.307	25.713	19.012	0.255	-1.199	0.351	0.065	0.281	-40.774	-0.142
GW 11	0.639	44.495	28.285	0.509	-1.039	0.367	0.123	0.561	-29.351	-0.123
GW 12	0.625	38.821	32.213	0.526	-0.801	0.353	0.040	0.438	-39.043	-0.117

GW 13	0.798	48.118	36.258	0.698	-0.799	1.202	0.068	0.564	-42.893	-0.139
GW 14	0.735	46.655	34.573	0.648	-0.799	0.638	0.089	0.586	-37.434	-0.123
GW 15	0.815	50.342	40.489	0.815	-0.479	0.661	0.059	0.628	-38.981	-0.152
GW 16	0.602	50.187	33.846	0.679	-0.479	1.136	0.089	0.617	-39.869	-0.128
GW 17	0.523	41.571	33.344	0.571	-0.640	2.681	0.077	0.441	-41.094	-0.174
GW 18	0.018	6.445	5.187	0.055	-0.092	0.006	0.407	0.255	0.870	0.458
GW 19	0.015	6.057	5.175	0.055	0.008	0.004	0.314	0.239	0.863	0.114
GW 20	0.101	29.925	22.477	0.321	-0.268	0.006	0.615	0.442	0.192	0.046
GW 21	0.188	34.997	29.195	0.449	0.180	0.004	0.138	1.254	-1.676	-0.085
GW 22	0.056	26.895	11.508	0.157	-0.192	0.004	0.314	0.668	-0.306	-0.036
GW 23	0.020	8.413	6.772	0.074	-0.036	0.004	0.348	0.155	0.804	0.301
GW 24	0.159	30.778	24.685	0.357	-0.404	0.010	0.471	1.111	-0.010	-0.001
GW 25	0.024	9.613	7.993	0.088	-0.124	0.006	0.546	0.164	0.849	0.679
GW 26	0.092	30.340	23.325	0.335	0.096	0.004	0.262	0.461	0.072	0.015
GW 27	0.018	9.845	4.627	0.051	-0.192	0.004	0.314	0.209	0.612	0.130
GW 28	0.224	43.649	28.211	0.501	-0.536	0.012	0.615	1.739	-0.467	-0.055
GW 29	0.027	9.037	7.814	0.086	-0.268	0.006	0.615	0.179	0.812	0.733
GW 30	0.309	49.161	44.397	0.873	-0.192	0.012	0.578	1.167	-0.144	-0.037
GW 31	0.016	4.023	3.637	0.038	-0.436	0.012	0.615	0.559	0.931	0.937
GW 32	0.033	28.739	6.695	0.094	-0.324	0.012	0.706	0.503	0.523	0.415
GW 33	0.129	28.405	16.888	0.236	-0.012	0.006	0.151	2.052	-1.254	-0.095
GW 34	0.058	19.245	13.206	0.164	-0.170	0.006	0.390	0.338	0.436	0.173
GW 35	0.077	25.846	18.061	0.244	-0.180	0.004	0.390	0.379	0.010	0.004
GW 36	0.007	9.491	1.889	0.021	-0.280	0.006	0.490	0.305	0.752	0.290
GW 37	0.040	22.467	11.351	0.146	0.030	0.004	0.299	0.374	0.383	0.097
GW 38	0.042	30.764	12.947	0.187	0.020	0.008	0.561	0.278	0.684	0.544
GW 39	0.019	9.421	7.681	0.085	0.020	0.004	0.390	0.142	0.852	0.367
GW 40	0.019	15.536	5.877	0.070	-0.080	0.002	0.242	0.310	0.216	0.033

Table 4: Analyses hydrochemical parameters

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