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Hydrogeochemical assessment of Groundwater in Sagar Island Region, South 24-Parganas, West Bengal, India Debabrata Das

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Abstract

An attempt has been made here to study the assessment of groundwater quality for its suitability for agricultural and domestic uses and a statistical study on groundwater quality parameters using the correlation coefficient and regression analysis method in the Sagar Island region of south 24-Parganas district, WB. Fifty ground water samples (pre and post monsoon periods) were collected from tube wells tapping water from ~180 meters to ~330 meters in the entire Sagar Island area and surface water (river water, seawater and pond water) samples were collected from Muriganga River, pond and Bay of Bengal. The quality analysis is performed through the estimation of physical quality, chemical quality, diagrammatic representation of geochemical data, salinisation of groundwater and quality criteria for groundwater use. The chemical characteristics of the water samples reveal slight seasonal variations. All samples of both periods are soft to moderately soft for domestic uses. Irrigation water classification has indicated that all the groundwater samples of both the periods are permissible to excellent category for entire Sagar Island area. The ratio of seawater contamination of the groundwater samples revealed that insignificant seawater intrusion at the deeper aquifers in Sagar Island region. From the evaluation, it can be inferred that the water quality are suitable for both domestic and irrigation purposes. The statistical analysis result revealed that the systematic calculations of correlation coefficient between water quality parameters and regression analysis provide useful mean for rapid monitoring of water quality and a parsimonious set of variables that efficiently predicts the response variable and assessing the relationship among physicochemical properties of groundwater samples.

Keywords: Hydrogeochemistry; Water quality; Sagar Island; Sea Water Contamination(SWC), Regression equation; Correlation coefficient.

1. Introduction

Man has demonstrated control of some of undesirable chemical constituents in water before it enters the ground. But once the water has entered the soil mantle, man's control over the chemical quality of the percolating water is significantly reduced (Johnson, 1979).

Coastal aquifers are highly heterogeneous and prone to maximum anthropogenic effects (high density of population) on groundwater (Y.R.Satyaji Rao, et al. 2003). Keeping in view of the importance of regional groundwater quality in a coastal aquifer, groundwater quality of deep wells has been analysed in Sagar Island.

In Sagar Island during rainy seasons, the salinity of the water of the tanks decreases and turns to brackish water. There are 46 villages spread over 235 km² with a total population of 0.30 million. Presently there is rapid increase in population with the development of tourism and harbour. For water supply, villagers are totally depending on the sweet ground water tapped from confined aquifer through deep tube wells having depth more than 200 meters (Majumdar et al., 2006; Majumdar and Das, 2007 and Majumdar and Das, 2011).

To assess the quality of water, geochemical studies are done for sweet groundwater samples from deep confined aquifer, surface water, river water and sea water.

Regression and correlation analysis is widely used in geochemistry; it is useful for interpreting commonly collected groundwater quality data and relating them to specific hydrogeological processes. The basic purpose of such



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an analysis to the study of the hydrogeochemistry of an aquifer is to find a set of factors, few in number, which can explain a large amount of variances of the analytical data (Ruiz et. al., 1990). This technique is based to study and calculate the correlation coefficients between various physicochemical parameters of groundwater at studied wells for Sagar Island.

Correlation and multiple linear regression are used for relating the given tube-well ground water chemical quality parameters to a set of independent chemical variables. The application has been broadened to study the relationship between two or more hydrologic variables and also investigate the dependence between successive values of a series of hydrologic data. This study presents an application of multiple linear regression (MLR) model for modeling Sagar Island groundwater quality parameters.

2. Study area

Sagar Island, the largest island in the Ganga Delta [$\{21^{\circ} 37' \text{ N} (21.6167)^{\circ} \text{ N}\}$ to $21^{\circ} 52' \text{ N}$, $\{(21.8667)^{\circ} \text{ N}\}$, $88^{\circ} 2' 35'' \text{ E} \{(88.0430)^{\circ} \text{ E}\}$ to $88^{\circ} 11' \text{ E} \{(88.1834)^{\circ} \text{ E}\}$], is elongated in N-S direction (~30 km) and has varying width in E-W direction. The southern portion of the Island widens to ~12 km (Fig.1). It is bordered in the north, west, east and south by Hooghly, Gabtala, Muriganga rivers and Bay of Bengal respectively (Fig.1).

3. Materials and Methods

Geochemical study consists of (1) collection of water samples, (2) chemical analysis of water, and (3) processing of analytical data.

Samples of groundwater (pre-monsoon and postmonsoon) were collected from tube wells tapping water from ~180 meters to ~330 meters and surface water (river water, seawater and pond water) were collected from Muriganga River, pond and Bay of Bengal. Thirty five (35) pre-monsoon water samples were collected during March 2005, May 2005, March 2006 and February 2007 and Sixteen (16) post-monsoon water samples were collected in October 2006. The groundwater samples were collected in clean 2000 ml polyethylene bottles. The sampling bottles were soaked in 1:1 diluted HCl solution for 24 hours and washed twice with distilled water before sampling. They were washed again in the field with groundwater sample filtrates. The groundwater samples were collected from tube wells after pumping the water for about 10 minutes. The sample locations are shown in Fig.1 and few groundwater samples were collected in two seasons (pre monsoon and post monsoon) for the same site in transparent polyethylene bottles. The concentration of major cations (Na⁺, K⁺, Ca⁺⁺, Mg⁺⁺, Fe⁺⁺ and As^{++}), major anions (Cl⁻, CO₃⁻, HCO₃⁻, and SO₄⁻), pH, total dissolved solid (TDS) and specific electrical conductance (EC) of the all samples are analyzed. Hazardous heavy metals like zinc (Zn^{++}) , lead (Pb⁺⁺), cupper (Cu⁺⁺) and mercury (Hg⁺⁺) are analyzed for some groundwater samples. All measured in parts per million (ppm).

All collected water samples are analyzed in the chemical laboratory of Centre for Study of Man and Environment (CSME), Salt Lake, India.

EC and pH were measured using portable digital meters. Samples were analysed for major ions in the laboratory using the standard recommended methods (APHA, 1998). Sulphate concentration in the groundwater samples was analysed using a UV visible spectrophotometer. Sodium and potassium content was determined by using a flame photometer and calcium, magnesium, chloride, carbonate and bicarbonate by titration technique. Total ions measurement precision was checked by calculating the ion balance error (IBE). The IBE was within $\pm 10\%$. Total dissolved solids (TDS) were calculated by using the formula: TDS (mg/l) = EC (μ S/cm) x 0.64; total hardness (TH) was calculated by using: TH = 2.497Ca + 4.115Mg in mg/l. Iron concentrations was determined by atomic absorption spectroscopy (AA method) (VARIAN, Model-AA280 FS).

Before carrying out the statistical analysis on the data, initial filtration of data, partial visual inspection of the data files and the creation of scatter plots are done. Once the identified input errors from the data are removed, a general regression analysis assuming certain water quality parameters as independent variables and some water quality parameters as dependent variable are performed. Using the filtered data, correlation between different water qualities parameters are obtained for the data set. Multiple linear regression and correlation analysis study has been made by collecting thirteen (locations nos. 3, 6, 8, 10, 16, 20, 25, 29, 32, 34, 40, 44 and 49) groundwater (tube wells) samples during premonsoon and post-monsoon season.

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Fig. 1: Locations map of the study area.

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Multiple Linear Regression (MLR) Models:

A general linear model is an the form of -

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 $Y = C + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n$ $+ \varepsilon \dots (8)$

where Y is the dependent variable; X_1 , X_2 , X_3 X_n are independent variables; β_1 , β_2 , β_3 β_n are unknown parameters; C is the constant and ε is error term.

Selection of dependent variables for regression analysis:

The model is useful for predictive purpose if it includes as many independent variables as possible, so that reliable fitted values can be determined. Further, the coefficient of determination (R^2) gives the proportion of the variation in the dependent variables, which is explained by the fitted regression model. The coefficient of determination is the ratio of the sum of squares due to regression to the total sum of squares corrected for the mean i.e.

where \hat{Y} is the predicted value based on the regression equation; \tilde{Y} is the mean value of the observed data set; and Y is the observed value.

 R^2 can be used as a measure of ability of the regression line to explain the variations for the dependent variable in monitoring of a large number of independent variables as possible. One has to make compromise between these extremes, which is usually called selecting the best regression variables and consequently the best model. There is no unique statistical procedure for doing this (Draper and Smith, 1981). However, many researchers had suggested different statistical approaches, such as all possible regression, backward elimination, forward elimination in stepwise regression and stage wise regression which may help in optimum model formulation (Montgomery & Peck, 1982; Weisberg, 1980). In the present case, the best subset regression approach has been used to select the best set of independent variables.

Best Subset regression:

Different best subsets of independent variable can be selected using the proportion of variation explained in the dependent variable (R^{2}). Assessment of each subset was made on the priority of value of R^2 achieved, F value and the number of observations used in developing the model. The model obtained from the large data set and achieving higher values of R^2 and F value is always preferred. Jain et al. (1998) had explained the criteria of R^2 and F value adopted in this study.

4. Results and Discussion

pH:

The pH values in the water samples of the study area are ranging from 7.2 to 8.0 during pre-monsoon period (Table-1a) and from 6.90 to 7.34 during post-monsoon period (Table-1b).

Electrical Conductivity [EC]:

In the present study, EC values are ranging from 750 to 1270μ s/cm during pre-monsoon ground water samples whereas the same is ranging from 800 to 1130μ s/cm for post monsoon ground water samples (Tables-1a and 1b). The maximum permissible limit for drinking purposes is 1400 µs/cm as prescribed by World Health Organization (WHO, 2004). All the samples of study area for both the periods are within permissible limit for drinking purpose.

Total Dissolved Solid [TDS]:

Gorrel (1958) presented a very simple classification based on the total dissolved solids. The water samples in the present area belong to the "Fresh water" category, having a range of 490 to 710 mg/l during post-monsoon season and 465 to 783 mg/l during pre-monsoon season. So, relatively high TDS values are found during post-monsoon on the southeastern part of Sagar Island. According to Raju (2006), the TDS values are higher during postmonsoon than that of pre-monsoon season. All samples fall into the "Fresh water" category.

Waters can be classified for drinking and other purposes based on the concentration of TDS (Wilcox, 1955; ICMR, 1975). The classification is given below:

Up to 500 mg/l - Desirable for drinking

Up to 1000 mg/l - Permissible for drinking

Up to 3000 mg/l - Useful for irrigation

Above 3000 mg/l - Unsafe for drinking and irrigation

Based on the above classification, almost all samples in both the periods are within desirable and permissible limit of drinking.

TDS versus EC:

TDS versus electrical conductivity (EC) plots show a linear trend with strong correlation for both the periods. The ratio of TDS and EC is 0.619 with an equation, Y = 1.616*X - 1.62 for pre- monsoon water sample (Fig.2.a) and the same is 0.618 with an equation Y = 1.57*X + 27.8 for post-monsoon water samples (Fig.2.b). These ratios are similar to the ratio (0.627) for the water from sands of Gangetic alluvium and Tarai-Bhabar determined by Chaterji and Karanth, 1963.



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Sample No	pН	EC (ms/cm)	TDS (mg/L)	CaCO ₃	HCO ₃	Cl	SO_4	Sum of total anions (epm)	Na	K	Ca	Mg	Fe	Sum of total cations (epm)
1(ppm)	-	840	507	0	110	150	13.7	-	84	15	28.85	20.5	0.71	-
1(epm)	-	-	-	0	1.8	4.23	0.29	6.32	3.65	0.38	1.44	1.69	0	7.16
3(ppm)	7.2	820	500	0	301.6	90	0.22	-	130	12	27.3	17.52	0.35	-
3(epm)	-	-	-	0	4.94	2.54	0	7.48	5.65	0.31	1.36	1.44	0	8.76
5(ppm)	7.28	750	465	0	295.8	74	0.3	-	115	13	28.9	20.46	0.33	-
5(epm)	-	-	-	0	4.85	2.09	0.01	6.95	5	0.33	1.44	1.68	0	8.45
6(ppm)	7.25	920	560	0	295.8	120	12.1	-	145	22	25.7	15.57	0.42	-
6(epm)	-	-	-	0	4.85	3.38	0.25	8.48	6.31	0.56	1.28	1.28	0	9.43
8(ppm)	7.31	840	510	0	365.4	60	0.2	-	150	20	20.9	13.62	0.35	-
8(epm)	-	-	-	0	5.99	1.69	0	7.68	6.52	0.51	1.04	1.12	0	9.19
9(ppm)	7.23	820	505	0	377.4	62	0.3	-	150	18	25.7	13.62	0.35	-
9(epm)	-	-	-	0	6.19	1.75	0.01	7.95	6.52	0.46	1.28	1.12	0	9.38
10(ppm)	7.22	820	502	0	353.5	76	0.2	-	155	20	22.5	10.7	0.4	-
10(epm)	-	-	-	0	5.79	2.14	0	7.93	6.74	0.54	1.12	0.88	0	9.28
12(ppm)	-	880	550	0	270	140	0.9	-	155	12	20.03	16.1	0.43	-
12(epm)	-	-	-	0	4.42	3.95	0.02	8.39	6.74	0.31	1	1.32	0	9.37
13(ppm)	-	970	615	0	340	125	0.4	-	145	11	16.03	16.6	0.52	-
13(epm)	-	-	-	0	5.57	3.53	0.01	9.11	6.31	0.28	0.8	1.37	0	8.76
16(ppm)	-	1200	735	0	335	200	38.7	-	205	11	28.85	27.3	0.65	-
16(epm)	-	-	-	0	5.49	5.64	0.81	11.94	8.92	0.28	1.44	2.25	0	12.89
17(ppm)	-	820	515	0	370	90	0.9	-	160	4	19.23	17.5	0.6	-
17(epm)	-	-	-	0	6.06	2.54	0.02	8.62	6.96	0.1	0.96	1.44	0	9.46
18(ppm)	-	890	557	0	340	90	0.4	-	197	12	20.83	13.6	0.62	-
18(epm)	-	-	-	0	5.57	2.54	0.01	8.12	8.57	0.31	1.04	1.12	0	11.04
20(ppm)	-	1000	635	0	315	130	29	-	170	12	22.44	23.4	0.61	-
20(epm)	-	-	-	0	5.16	3.67	0.6	9.43	7.39	0.31	1.12	1.93	0.02	10.77
22(ppm)	-	900	582	0	300	80	0.9	-	165	8	14.42	8.8	0.5	-
22(epm)	-	-	-	0	4.92	2.26	0.02	7.2	7.18	0.2	0.72	0.72	0.02	8.84
24(ppm)	-	990	615	0	365	130	32.7	-	169	8	21.64	16.1	0.72	-
24(epm)	-	-	-	0	5.98	3.67	0.68	10.33	7.35	0.2	1.08	1.32	0.03	9.98
25(ppm)	7.6	1270	783	0	300	167.3	71	-	150.3	5.5	41.7	22.4	0.04	-
25(epm)	-	-	-	0	4.92	4.72	1.48	11.12	6.54	0.14	2.08	1.84	0	10.6
28(ppm)	-	910	546	0	300	110	0.4		165	15	16.03	8.8	0.81	
28(epm)	-	-	-	0	4.92	3.1	0.01	8.03	7.18	0.38	0.8	0.72	0.03	9.11
29(ppm)	7.7	1210	740	0	245	143.9	110.9	-	142.5	5.5	40.1	22.4	0.06	-
29(epm)	-	-	-	0	4.02	4.06	2.31	10.39	6.2	0.14	2	1.84	0	10.18
30(ppm)	-	970	598	0	295	120	35.7	-	160	13	19.23	16.6	0.55	-
30(epm)	-	-	-	0	4.83	3.38	0.74	8.95	6.96	0.33	0.96	1.37	0.02	9.64

Table -1a: Chemical compositions of groundwater samples in the Sagar Island (pre-monsoon)

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31(ppm)	-	900	580	0	280	155	19.5	-	198	22	20.8	12.7	0.7	-
31(epm)	-	-	-	0	4.59	4.37	0.41	9.37	8.61	0.56	1.04	1.05	0.03	11.29
32(ppm)	8	980	599	0	300	85.6	36.6	-	154.2	3.9	12.8	7.8	0.05	-
32(epm)	-	-	-	0	4.92	2.41	0.76	8.09	6.71	0.1	0.64	0.64	0	8.09
33(ppm)	-	990	610	0	355	80	0.9	-	165	20	12.82	14.6	0.45	-
33(epm)	-	-	-	0	5.82	2.26	0.02	8.1	7.18	0.51	0.64	1.2	0.02	9.55
34(ppm)	7.79	950	582	0	290	85.6	0.28	-	158.1	4.2	12.8	13.7	0.08	-
34(epm)	-	-	-	0	4.75	2.41	0.01	7.17	6.88	0.11	0.64	1.13	0	8.76
37(ppm)	-	920	580	0	385	75	1.1	-	182	21	11.22	8.77	0.49	-
37(epm)	-	-	-	0	6.31	2.12	0.02	8.45	7.92	0.54	0.56	0.72	0.02	9.76
38(ppm)	-	810	498	0	385	44	0.4	-	190	16	11.2	7.8	0.39	-
38(epm)	-	-	-	0	6.31	1.24	0.01	7.56	8.26	0.41	0.56	0.64	0.01	9.88
39(ppm)	-	950	595	0	410	75	1.3	-	180	20	4.8	13.7	0.72	-
39(epm)	-	-	-	0	6.72	2.12	0.03	8.87	7.83	0.51	0.24	1.13	0.03	9.74
40(ppm)	-	1040	645	0	419	84	7.1	-	225	20	9.6	8.8	0.38	-
40(epm)	-			0	6.88	2.37	0.15	9.4	9.79	0.51	0.48	0.72	0.01	11.51
42(ppm)	-	920	560	0	305	76	33.7		188	19	16	7.8	0.44	-
42(epm)	-			0	5	2.14	0.7	7.84	8.18	0.49	0.8	0.64	0.02	10.13
43(ppm)	-	750	470	0	344	50	0.4		191	17	9.6	6.8	0.35	-
43(epm)	-	-	-	0	5.65	1.41	0.01	7.07	8.31	0.43	0.48	0.56	0.01	9.79
44(ppm)	-	810	495	0	305	52	3.6	-	180	16	9.6	7.8	0.39	-
44(epm)	-	-	-	0	5	1.47	0.08	6.55	7.83	0.41	0.48	0.64	0.01	9.37
45(ppm)	-	860	535	0	380	58	0.4	-	195	18	9.6	7.8	0.47	-
45(epm)	-	-	-	0	6.23	1.64	0.01	7.88	8.48	0.46	0.48	0.64	0.02	10.08
46(ppm)	-	790	510	0	380	52	0.4	-	173	14	11.2	13.6	0.39	-
46(epm)	-	-	-	0	6.23	1.47	0.01	7.71	7.53	0.36	0.56	1.12	0.01	9.58
48(ppm)	-	940	574	0	360	96	8.1	-	219	25	8.01	7.8	0.72	-
48(epm)	-	-	-	0	5.9	2.71	0.17	8.78	9.53	0.64	0.4	0.64	0.03	11.24
49(ppm)	-	1180	735	0	505	95	0.9	-	230	15	12.82	9.74	0.4	-
49(epm)	-	-	-	0	8.28	2.68	0.02	10.98	10	0.38	0.64	0.8	0.01	11.83
50(ppm)	-	1210	745	0	540	60	1.6	-	194	32	11.22	17.6	0.85	-
50(epm)	-	-	-	0	8.85	1.69	0.03	10.57	8.44	0.82	0.56	1.45	0.03	11.3
P(ppm)	-	2700	1950	0	290	900	168.5	-	589	20	12.8	86.9	1.2	-
P(epm)	-	-	-	0	4.75	25.39	3.51	33.65	25.62	0.51	0.64	7.15	0	33.92
R1(ppm	-	14600	9783	0	135	5450	443	-	3025	22	75.3	343	1.8	-
R1(epm)	-	-	-	0	2.21	153.7	9.23	165.1	131.5	0.56	3.76	28.2	0	164.1
B(ppm)														
B(epm)	-	-	-	0	1.97	396.1	33.23	431.3	403.7	0.9	9.6	75.4	0.04	489.7
WHO (ppm)	65 8.5	1400	1200	500	500	600	500		200	-	200	150	-	
IS (ppm)	6.5- 8.5	1400	1500	600	600	1000	400		200	-	200	100	1	

Hardness:

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Hardness is due to the presence of divalent cations of which calcium (Ca++) and magnesium (Mg++) are

the most abundant in groundwater and is usually expressed as the equivalent of CaCO3.

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Total Hardness (TH) = 2.497 * (Ca++) + 4.115 * (Mg++) where Ca++ and Mg++ are all measured in ppm. (Karanth, 2004)

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The waters of the study area are classified according to hardness as suggested by Hem (1985). All samples of pre-monsoon period have hardness value ranging between 50 and 160 mg/l, excepting three samples (location nos. 25, 16 and 29) having hardnesses 169 mg/l, 184 mg/l and 200mg/l respectively (Table-2a) and all samples of post-monsoon period, have hardness value between 50 and 160 mg/l, except two samples (location nos.15 and 19), having hardnesses 193 mg/l and 170 mg/l respectively (Table-2b).

So, all samples of both periods are moderately soft (Table-3) for domestic purposes excepting three samples from pre monsoon and two samples from post monsoon period, which are relatively hard.

Table 3: Hardness Classification of Water (after Sawyer and McCarty, 1967)

Hardness, mg/l	Water Class	Observed
as $CaCO_3$		values
0-75	Soft	Pre monsoon
75-150	Moderately	period – 52 mg/l
	Soft	to 200 mg/l
150-300	Hard	Post monsoon
Above 300	Very Hard	to 193 mg/l

Sodium Adsorption Ratio [SAR]:

Plants are detrimentally affected, both physically and chemically, by excess salts in soils and high levels of exchangeable sodium. Increase of sodium concentration in water deteriorate the soil properties reducing permeability (Kelley, 1951; Tijani, 1994; Pandian and Sankar, 2007). Hence, the assessment of sodium concentration is necessary while considering the suitability for irrigation. The degree to which irrigation water tends to enter into cation-exchange reactions in soil can be indicated by the sodium adsorption ratio (U.S. Salinity Laboratory, 1954). Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure. It becomes compact and impervious. SAR is an important parameter for the determination of the suitability of irrigation water because it is responsible for the sodium hazard (Todd, 1980). The waters were classified in relation to irrigation based on the ranges of SAR values (Richards, 1954).

According to the SAR classification for irrigation uses, SAR value below 6.0 is excellent, between 6.0 and 12.0 is good and between 12.0 and 18.0 is permissible (Table-4).

Most of the water samples in both the seasons fall in excellent to good category and can be used for irrigation on almost all soils. Therefore, none of the samples are unsuitable for irrigation in either of the seasons.

Integrated effect of EC and SAR (after US Salinity Laboratory, 1954, Diagram):

The SAR and EC values of water samples of the study area were plotted in the graphical diagram of irrigated water (U.S. Salinity Laboratory, 1954) (Fig.3). The groundwater samples from both the periods fall into C2S1 (medium salinity with low sodium) and C3S2 (medium to high salinity with medium sodium) and only four samples fall into C3S3 (high salinity with high sodium) indicating that the groundwater can be used for irrigation purpose for almost all types of soil with little danger of exchangeable sodium.

Table	-1b:	Chemical	compositions	of	groundwater	samples	in	the	Sagar	Island	(post-monsoon))
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Sample No	рН	EC (ms/cm)	TDS (mg/L)	CaCO ₃	HCO ₃	Cl	SO ₄	Sum of total anions (epm)	Na	К	Ca	Mg	Sum of total cations(epm)
2(ppm)	7.04	840	510	0	337.5	75	42	-	143	8.6	24.04	12.2	-
2(epm)	-	-	-	0	5.53	2.12	0.88	8.52	6.22	0.22	1.2	1	8.64
4(ppm)	6.98	800	490	0	250	115	7.71	-	138	7.8	20.04	17.1	-
4(epm)	-	-	-	0	4.1	3.24	0.16	7.5	6	0.2	1	1.41	8.61
7(ppm)	7.34	820	510	0	250	125	18	-	141	10.8	28.06	12.2	-
7(epm)	-	-	-	0	4.1	3.53	0.23	7.85	6.13	0.28	1.4	1	8.81
11(ppm)	6.98	990	605	0	275	115	49.2	-	201	12.7	24.05	24.4	-
11(epm)	-	-	-	0	4.51	3.24	1.03	8.78	8.74	0.32	1.2	2.01	12.28
14(ppm)	7.24	1030	630	0	212.5	220	65	-	154.5	16.9	16.03	24.4	-
14(epm)	-	-	-	0	3.84	6.21	1.35	11.04	6.72	0.43	0.8	2.01	9.96
15(ppm)	6.9	1000	612	0	262.5	160	48.9	-	139.7	12.2	28.06	29.9	-
15(epm)	-	-	-	0	4.3	4.51	1.02	9.83	6.08	0.31	1.4	2.46	10.25

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19(ppm)	7.06	1000	610	0	325	105	83.5	-	162.3	12.5	28.06	24.3	-
19(epm)	-	-	-	0	5.33	2.96	1.74	10.03	7.06	0.32	1.4	2	11.78
21(ppm)	7.07	1020	620	0	350	95	74.2	-	180	13	24.05	17.1	-
21(epm)	-	-	-	0	5.74	2.68	1.55	9.96	7.83	0.33	1.2	1.41	10.77
23(ppm)	7.1	960	590	0	362.5	65	21	-	190	18	16.03	14.6	-
23(epm)	-	-	-	0	5.94	1.83	0.44	8.21	8.26	0.46	0.8	1.2	10.73
26(ppm)	7.13	1010	610	0	350	100	29	-	174	16.7	20.04	7.3	-
26(epm)	-	-	-	0	5.74	2.82	0.6	9.16	7.57	0.45	1	0.6	9.6
27(ppm)	7.09	820	530	0	312.5	85	28.4	-	150	12	20.04	9.7	-
27(epm)	-	-	-	0	5.12	2.4	0.59	8.11	6.52	0.31	1	0.8	8.63
35(ppm)	7.17	1130	710	0	375	140	20		198	16	24	9.7	-
35(epm)	-	-	-	0	6.15	3.95	0.42	10.51	8.61	0.41	1.2	0.8	11.02
36(ppm)	7.23	1100	700	0	325	135	43.9	-	191	15	20	17.1	-
36(epm)	-	-	-	0	5.33	3.81	0.91	10.05	8.31	0.38	1	1.41	11.1
41(ppm)	7.09	1090	675	0	312.5	100	123	-	220	13	24	2.4	-
41(epm)	-	-	-	0	5.12	2.82	2.56	10.5	9.57	0.33	1.2	0.2	11.3
47(ppm)	7.24	840	530	0	325	60	19.2	-	143	12.7	4.01	19.5	-
47(epm)	-	-	-	0	5.33	1.69	0.4	7.42	6.22	0.32	0.2	1.6	8.35
50(ppm)	7.15	1130	710	0	525	50	21	-	238.6	17.6	8.02	7.3	-
50(epm)	-	-	-	0	8.6	1.41	0.44	10.45	10.38	0.45	0.4	0.6	11.83
WHO (ppm)	6.5- 8.5	1400	1200	500	500	600	500		200	-	200	150	
IS (ppm)	6.5- 8.5	1400	1500	600	600	1000	400		200	-	200	100	

Residual Sodium Carbonate [RSC]:

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earth and boron, and the quantity of bi-carbonate and carbonate in excess of alkaline earths also influence

the suitability of water for irrigation purposes. This excess is denoted by 'Residual Sodium Carbonate' (RSC) and is determined as suggested by Eaton (1950) and Richards (1954).

RSC = (HCO3- + CO3-) - (Ca+ + Mg+ +)where the concentrations are expressed in epm.

Table-2a: Chemical parameters of groundwater samples in the Sagar Island (Pre-monsoon)

Sample		Hardness				Gibbs'	Gibbs'					
No	SAR	(mg/L, CaCO ₃)	SSP	RSC	SWC	Ratio- I	Ratio- II	CAI-I	CAI-II	MR	CR	PS
1	2.92	156	66.73	-1.33	1.366	0.774	0.576	0.047	0.0956	53.9	2.05	56
3	4.77	140	68.03	2.14	0.514	0.838	0.2298	-1.346	-0.692	51.4	0.421	68.1
5	4	156	63.07	1.73	0.43	0.815	0.2001	-1.55	-0.666	53.8	0.353	63
6	5.56	128	72.85	2.29	0.696	0.866	0.2886	-1.032	-0.684	50	0.613	72.9
8	6.27	108	76.49	3.83	0.282	0.89	0.141	-3.159	-0.891	51.8	0.231	76.5
9	5.95	120	73.65	3.79	0.282	0.867	0.1411	-2.988	-0.843	46.6	0.232	74.4
10	6.74	100	78.44	3.79	0.369	0.886	0.1769	-2.401	-0.887	44	0.303	78.4
12	6.25	116	82.21	2.1	0.518	0.892	0.3414	-0.784	-0.698	56.1	0.733	75
13	6.06	108	82.89	3.4	0.367	0.906	0.2688	-0.866	-0.548	63.1	0.519	75
16	6.56	184	79.36	1.8	0.597	0.882	0.373	-0.631	-0.565	60.9	0.961	71

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17	6.35	120	81.7	3.66	0.243	0.895	0.1956	-1.779	-0.743	60	0.343	75
18	8.24	108	85.85	3.41	0.264	0.909	0.2093	-2.496	-1.136	51.8	0.374	80
20	5.99	152	79.88	2.11	0.412	0.89	0.2921	-1.098	-0.699	63.2	0.677	71
22	8.44	80	88.16	3.48	0.266	0.923	0.2105	-2.265	-1.036	50	0.378	84
24	6.7	120	82.42	3.58	0.35	0.891	0.2626	-1.057	-0.582	55	0.594	76
25	4.67	196	70.85	1	0.959	0.788	0.358	-0.415	-0.306	46.9	1.031	63
28	8.22	76	87.87	3.4	0.366	0.918	0.2682	-1.438	-0.904	47.3	0.517	83
29	4.47	200	70.31	0.18	0.99	0.786	0.3701	-0.561	-0.36	47.9	1.298	62.3
30	6.45	116	82.84	2.5	0.406	0.899	0.2891	-1.156	-0.701	58.7	0.641	76
31	8.43	136	86.77	2.5	0.553	0.913	0.3563	-1.098	-0.96	50.2	0.852	82
32	8.38	64	88.77	3.64	0.489	0.925	0.2219	-1.825	-0.774	50	0.528	84.1
33	7.48	92	86.09	3.98	0.225	0.935	0.1839	-2.402	-0.929	65.2	0.32	80
34	7.32	88	85.96	3.01	0.507	0.926	0.2279	-1.9	-0.962	63.8	0.416	79.8
37	9.88	64	91.03	5.03	0.194	0.947	0.163	-2.99	-1.001	56.2	0.277	86
38	10.67	60	87.84	2.59	0.33	0.94	0.1025	-5.991	-1.175	53.3	0.162	87.8
39	9.47	68	91.53	5.35	0.182	0.976	0.1546	-2.933	-0.921	82.4	0.26	86
40	12.62	60	89.57	3.93	0.46	0.962	0.1666	-3.345	-1.128	60	0.299	89.5
42	9.46	72	85.76	3.31	0.45	0.928	0.1994	-3.051	-1.145	44.4	0.466	85.7
43	11.53	52	89.37	3.05	0.34	0.955	0.1265	-5.198	-1.295	53.8	0.205	89.4
44	10.46	56	88.03	3.07	0.35	0.953	0.1456	-4.605	-1.332	57.1	0.252	88
45	11.33	56	88.87	3.05	0.39	0.956	0.1324	-4.451	-1.169	57.1	0.216	88.8
46	8.22	84	82.45	2.7	0.34	0.943	0.1203	-4.367	-1.028	66.6	0.193	82.4
48	13.2	150	90.72	2.75	0.72	0.968	0.2105	-2.752	-1.229	61.5	0.399	90.7
49	11.78	72	91.56	6.84	0.188	0.95	0.1583	-2.873	-0.908	55.5	0.266	88
50	8.42	100	88.69	6.84	0.111	0.952	0.1001	-4.479	-0.852	72.1	0.159	82
Р		388	85.92			0.979	0.756	-0.029	-0.089	91.7	4.976	
R1		1596	87.91			0.975	0.975	0.14	1.887	88.2	60.27	
В						0.979	0.991	-0.021	-0.24	88.7	178.6	

Table-2b: Chemical parameters of groundwater samples in the Sagar Island (post-monsoon)

Sample		Hardness				Gibbs'	Gibbs'			Mg		
No	SAR	(mg/L, CaCO ₃)	SSP	RSC	SWC	Ratio-I	Ratio- II	CAI-I	CAI-II	Ratio	CR	PS
2	5.93	110.23	71.99	3.33	0.383	0.863	0.1818	-2.037	-0.673	45.4	0.442	74.5
4	5.47	120.4	69.68	1.7	0.79	0.879	0.315	-0.913	-0.694	58.5	0.68	72
7	5.59	120.26	69.58	1.7	0.86	0.843	0.3333	-0.815	-0.665	41.6	0.779	72.8
11	6.9	160.45	71.17	1.3	0.718	0.898	0.5086	-1.796	-1.05	62.6	1.536	73.8
14	5.67	140.43	67.46	0.67	1.784	0.914	0.5087	-0.151	-0.181	71.5	1.776	71.8
15	4.37	193.1	59.31	0.44	1.048	0.844	0.3786	-0.416	-0.353	63.7	1.052	62.3
19	5.41	170.06	59.93	1.93	0.555	861	0.2441	-1.493	-0.625	58.8	0.722	68.5
21	6.86	130.41	72.7	3.13	0.466	0.889	0.2134	-2.044	-0.751	54	0.603	75.7
23	8.26	100.1	76.98	3.94	0.308	0.928	0.152	-3.765	-1.079	60	0.312	81.3
26	8.46	80.07	78.85	4.14	0.491	0.904	0.2222	-1.843	-0.82	37.5	0.488	83.4
27	6.88	89.95	75.55	3.32	0.468	0.899	0.213	-1.845	-0.775	44.4	0.477	79.1
35	8.62	99.96	78.13	4.15	0.642	0.898	0.2718	-1.283	-0.771	40	0.581	81.9

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36	5.57	120.4	74.86	2.93	0.714	0.911	0.2934	-1.28	-0.782	58.5	0.725	78.3
41	11.45	69.92	84.69	3.72	0.55	0.906	0.2424	-2.51	-0.921	14.2	0.86	87.6
47	6.55	90.25	74.49	3.53	0.317	0.974	0.1558	-2.869	-0.846	88.8	0.321	78.3
50	14.67	50.06	87.74	7.6	0.163	0.969	0.0869	-6.68	-1.042	60	0.175	91.5

SAR- Sodium Adsorption Ratio, SSP- Soluble Sodium Percentage, RSC-Residual Sodium Carbonate, SWC- Sea Water Contamination, CAI-Chloro Alkaline Index, MR-Magnesium Ratio, CR-Corrosivity Ratio, PS-Percentage of Sodium.

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In the present study area, 50 % of samples are having RSC values above 2.5 and rests are below 2.5 for the post-monsoon groundwater samples (Table-2a). For pre-monsoon period, RSC values of 60 % samples are above 2.5 and rests are below 2.5 (Table-2b). So, most of the samples of both seasons are moderately suitable for irrigation purposes in term of RSC.



Fig-2a: Specific Electrical Conductance (EC) variation with TDS for pre-monsoon period



Fig-2b: Specific Electrical Conductance (EC) variation with TDS for post-monsoon period



Fig-3: The quality of water in relation to salinity and sodium hazard (after US Salinity Laboratory, Rechard, L.A. 1954)

Magnesium Ratio [MR]:

Generally, calcium and magnesium maintain a state of equilibrium in most waters. In equilibrium more Mg++ in waters will adversely affect the crop yield.

It is expressed as-

MR = [(Mg++) *100] / [(Ca++)+(Mg++)]

where all the ions are expressed in meq/l.

It may be described as the excess amount of magnesium over the calcium and magnesium amount where otherwise generally calcium and magnesium will be in concision of equilibrium (Das, et. al. 1988). Excess of magnesium affects the quality of soil causing poor yield of crops.

The magnesium ratio of post-monsoon groundwater varies from 14.2 % to 88.8 % (Table-1b) and the same of the pre-monsoon period varies from 44.0 % to 82.4 % (Table-1a). Magnesium ratio of groundwater samples for most of the samples in both the periods lies between 50% and 60% with minimum and maximum values of 14.2% and 88.8% respectively. High Mg ratio in the subsurface groundwater may due to its reaction with the kankar and magnesium bearing formation during its passage. One has to choose the type of plants which grow well and yield with little excess of MR.

Corrosivity Ratio [CR]:

The corrosivity ratio is defined by the formula

Coorosivity Ratio (CR) = $\frac{[(Cl-)/35.5 + 2*(SO4--)/96]}{2*[(HCO3-) + (CO3--)/100]}$

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where all the ions are expressed in ppm of groundwater.

SR

It denotes susceptibility of groundwater to corrosion and is expressed as ratio of alkaline earths to saline salts in groundwater. High CR decreases the hydraulic capacity of metallic pipes [Ryner (1944); Raman (1985)].

In the present study, CR of all samples for both seasons are below 1.0 except two samples of premonsoon and three samples of post-monsoon periods which are above 1.0 but below 2.0 (Table-1a and 2b). So, any type of metallic pipes can be used in the study area for both the periods. In the area where groundwater has CR values above 1.0, polyvinyl chloride pipes should be used.

Chloro Alkaline Indices [CAI]:

Knowledge of the changes brought about in the chemical composition of the groundwater during its travel underground is essential. Control on the dissolution of undesirable constituents in water is impossible during the subsurface run off but it is essential to know the various changes undergone by water during its travel (Johnson, 1979; Raju, 2006). The ion exchange between the groundwater and its host environment during residence or travel can be understood by studying the chloroalkaline indices (CAI-I and CAI-II) (Schoeller, 1967):

 $CAI-I = [(Cl-)- {(Na+)+ (K+)}] / (Cl-)$

and

 $CAI-II = [(Cl-) - {(Na+)+(K+)}] / ((SO4--) + (HCO3-) + (CO3--) + (NO3--)]$

CAI is negative when there is exchange between sodium and potassium (Na + K) in water with calcium and magnesium (Ca + Mg) in rocks. If the ratio is positive, then there is no base exchange.

Here CAI-I and CAI-II values are negative for the samples (excepting sample no.1) in both the periods (Table-1a and 2b). So, there is exchange between sodium and potassium (Na + K) in water with calcium and magnesium (Ca + Mg) in rocks.

Gibb's Diagram:

Gibbs (1970) proposed a diagram to understand the relationship of the chemical components of waters from their respective aquifer lithologies. Viswanathaiah et al. (1978), Ramesam and Barua (1973), Rengarajan and Balasubramanian (1990), and Sreedevi (2004) referred Gibbs diagram to understand the controlling factors of groundwater chemistry in various parts of India.

The Gibbs ratios are calculated with the formulae as given below:

Gibbs Ratio I (for anion) = [(Cl-) / {(Cl-) + (HCO3-)}]

 $\begin{array}{l} Gibbs \ Ratio \ II \ (for \ cation) = [\{(Na+) + (K+)\} \ / \\ \{(Na+) + (K+) + (Ca++)\}] \end{array} \end{array}$

Where all ions are expressed in meq/l.

Gibbs ratios for the study area samples are plotted against their respective total dissolved solids to know whether the ground water chemistry is due to rock dominance, evaporation dominance or precipitation dominance. In the present study, Gibbs ratios I and II for pre- monsoon and post-monsoon periods samples are shown in Figs-4a and b; and Figs-5a and b respectively. It is observed from the diagrams that the samples of both periods fall into the rock dominance area, indicating the interaction between rock/soil and water in the subsurface formation.

Piper diagram:

Collins (1923) first proposed a graphical method of representation of chemical analysis. The method was later modified by Piper (1944, 1953), based on the concentration of dominant cations and anions, and a trilinear diagram was proposed to show the



Fig-4a: Mechanism controlling the quality of groundwater (TDS versus Gibbs ratio-I) for pre-monsoon period (after Gibbs, 1970)



Fig-4b: Mechanism controlling the quality of groundwater (TDS versus Gibbs ratio-I) for post-monsoon period (after Gibbs, 1970)

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Fig-5a: Mechanism controlling the quality of groundwater (TDS versus Gibbs ratio-II) for pre-monsoon period (after Gibbs, 1970)

percentages at milli equivalents per litre of cations and anions in water samples. The Piper diagram was modified by Davis and Dewiest (1967).

The Piper diagram (Fig-6) consists of 2 triangular and 1 intervening diamond-shaped field. All 3 sides of the 2 triangular fields and the 4 sides of the diamond-shaped field are divided into 100 parts. The percentage reacting values at the 3 cation groups-Ca, Mg and (Na+K)—are plotted as a single point in the left triangular field and the 3 anion groups-(HCO3+CO3), SO4 and Cl-similarly are plotted as a single point on the right triangular field. The two points in each triangular field show the relative concentration of several dissolved constituents of the water sample. Later, a third point is plotted in the central diamond-shaped field after computing percentage reacting values for anions and cations separately. This field shows the complete chemical character of the water samples that gives the relative composition of groundwater about the cation-anion point. These 3 fields reflect the chemical character of groundwater according to the relative concentration of its constituent but not according to the absolute concentrations. Later Piper (1953) classified the

diamond-shaped field of the trilinear diagram into 9 areas to know quickly the quality of water.



Fig-5b: Mechanism controlling the quality of groundwater (TDS versus Gibbs ratio-II) for post-monsoon period (after Gibbs, 1970)



Fig-6: Piper's trilinear diagram. Analyses of a sample is represented by three points

Classes of Water	TDS (ppm/L)	Electrical Conductivity (µs/cm)	Sodium Absorption Ratio [Na/Ö(Ca+Mg)/2] in epm	Residual Sodium Carbonate: [(HCO3+CO3)- (Ca+Mg)] in epm	Soluble Sodium Percentage:[Na/(Na+K+ Ca+Mg)]*100 in epm
Excellent	<175	<250	0-6	<1.25	<60
Good	175-525	250-750	12-Jun		
Permissible	525- 1400	750-2000	18-Dec	1.25-2.5	60-75
Doubtful	1400- 2100	2000-3000	18	>2.5	>75
Unsuitable	>2100	>3000	26		
Range of observed values from present study of groundwater samples	425-735	750-1200	2.92-6.90	0.44-3.79	59.31-85.85

Table 4: Suitability irrigation water classifications based on United States Department of Agriculture (USDA) classification

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In the present study, fifty groundwater samples from different locations in the study area of both the periods fall under area-8 and 9 and only 6 samples fall under area-7. River water, pond water and sea water samples fall into area-7. In most of the samples, carbonate alkali exceeds 50 % as shown in the Piper trilinear diagram (Fig-6). So, geochemically, groundwater samples are classified as Na-HCO3.

Sea Water and Saline Water Intrusion:

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During excessive pumping of groundwater in the coastal aquifer areas, the hydrodynamic equilibrium may change causing intrusion of saline water from adjacent sea into the fresh water bearing zones and the freshwater may be contaminated with the saline water.

The seawater contamination (SWC) value can be calculated using the formula, SWC = [Cl/(HCO3+CO3) in meq/l. The SWC value for Bay of Bengal is 243 and below 0.5 for freshwater (Raghunath, 1982).

Calculated values of SWC for most of the samples in the both periods are below 0.6, except 3 samples (maximum 1.36) from pre monsoon period (Table-2a) and 6 (maximum 1.78) samples from post monsoon period (Table-2b). The marginal high values of SWC for these samples are due to its locations near to river and sea (Fig-1). So, there is no seawater intrusion in the freshwater aquifer of entire Sagar Island.

The descriptive statistics of major anions and cations for the data sets of Pre-monsoon and post-monsoon, 2005 are shown in Table-5. The degree of linear association between any two of the water quality parameters, as measured by the simple correlation coefficient (R) is presented as a correlation matrix for pre-monsoon period, 2005 (Table-6). The correlation between Sodium (Na+) and other parameters except chlorine (Cl-) is significantly positive, where as Calcium (Ca2+) and Magnesium (Mg2+) are significantly negative for pre-monsoon period, 2005. The best combinations of independent variables for dependents variables are identified as Electrical conductivity (EC), Bi-carbonate (HCO3-), Sodium (Na+) and Chlorine (Cl-) in the premonsoon, 2005, and the MLR model (R2 value, F value) values for Na is given in Table-7. From these tables the best combinations of independent variables are selected for further selecting the best model for dependent variable for EC, HCO3, Na and Cl. The criteria are adopted for selecting the best model for EC, HCO3, Na and Cl with maximum R2 value, F value and minimum number of variables.

Each dependent variable combinations are preferred having R2 value greater than 0.85 and minimum impendent variables only and Calibration of selected MLR models are-

Table-5: Descriptive statistics (13 samples) ofground water quality parameters during pre-monsoonseason 2005

		Pre-monsoo	on, 2005		
	Minimum	Maximum	Mean	Standard Deviation	
1. EC	750	1210	910.0	107.41	
TDS	465	745	563.0	66.67	
Na	84	195	160.5	30.03	
К	4	32	15.76	6.92	
Ca	9.6	28.90	17.75	6.03	
Mg	7.8	20.50	13.72	4.60	
HCO ₃	110	540	333.9	91.97	
Cl	58	150	91.00	30.11	
SO ₄	0.2	33.70	6.74	11.79	

Table-6: Correlation matrix for water qualityparameters of pre-monsoon period, 2005

	EC	TDS	HCO ₃	CL	SO_4	Na	Ca	Mg	К
EC	1.00								
TDS	0.98	1.00							
HCO ₃	0.64	0.67	1.00						
CL	-0.1	-0.1	-0.67	1.00					
SO_4	0.14	0.10	-0.19	0.32	1.00				
Na	0.55	0.59	0.79	-0.5	0.05	1.00			
Ca	-0.5	-0.5	-0.65	0.54	0.21	-0.8	1.0		
Mg	-0.0	-0.0	-0.16	0.38	-0.0	-0.6	0.7	1.00	
К	0.6	0.5	0.482	4	0.1	0.3	0.4	-0.1	1.000

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Fig-7a: Validation of MLR Model for Sodium (Na)



Fig-7b: Validation of MLR model for Bicarbonate (HCO3)



Fig-7c: Validation of MLR model for Electrical Conductance (EC)

Table-7, shows that Ca, HCO3 and SO4 are the most significant independent chemical variables in pre-monsoon, 2005.

The calibrated MLR model for EC, HCO3, Na and Cl in pre-monsoon period, 2005, data sets are validated with pre-monsoon period, 2006 data sets. The validation (between observed value and calculated value from calibrated model) of MLR models are shown in Figures-7a, 7b and 7c. Some notable difference in observed (2006) and MLR computed (calculated values from the corresponded data of year 2005) values are found for Na (locations

nos. 5, 7 and 8), HCO3 (locations nos. 16 and 20) and EC (locations nos. 16, 25 and 49) out of thirteen samples for the year 2006. Sometime, one can find these differences in coastal aquifers system (Raju, 2006a).

Table 7: Procedure for MLR model (R² value, Fvalue) for Na (pre-monsoon, 2005)

No of	Variables	R ²	F
Variables	v arrables	value	Value
1	EC	0.3112	4.965
	К	0.1114	1.381
	Ca	0.797	43.251
	Mg	0.4471	8.9
	Cl	0.2866	4.42
	HCO ₃	0.5988	16.3
	SO_4	0.0059	0.028
2	Ca, K	0.8016	20.221
	Ca, Mg	0.7996	19.96
	Ca, Cl	0.8002	20.06
	Ca, SO ₄	0.8584	30.319
	Ca, HCO ₃	0.8613	30.365
	Ca, EC	0.8015	20.369
3	Ca, HCO _{3,} K	0.8798	21.926
	Ca, HCO _{3,} Mg	0.9118	30.569
	Ca, HCO ₃ , Cl	0.8649	19.237
	Ca, HCO ₃ , SO ₄	0.926	39.34
	Ca, HCO _{3,} EC	0.8593	18.512
4	Ca, HCO ₃ , SO ₄ , K	0.9489	36.408
	Ca, HCO ₃ , SO ₄ , Mg	0.9553	41.102
	Ca, HCO ₃ , SO ₄ , Cl	0.9309	26.261
	Ca, HCO ₃ , SO ₄ , EC	0.9532	41.016
5	Ca, HCO ₃ , SO ₄ , Mg, K	0.9657	38.661
	Ca, HCO ₃ , SO ₄ , Mg, Cl	0.9643	36.789
	Ca, HCO ₃ , SO ₄ , Mg, EC	0.9574	32.404
6	Ca, HCO _{3,} SO _{4,} Mg, K, Cl	0.9708	31.489
	Ca, HCO ₃ , SO ₄ , Mg, K, EC	0.9652	28.016
7	Ca, HCO ₃ , SO ₄ , Mg, K,	0.9774	27.816

The validity of models based on RMSE, coefficient of determination (R2) and Percentage

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Error in Deepest Level Fluctuation (%EDLF) are shown in Table-9.

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Tables-7 and 8 and Figures-7a, 7b and 7c indicate that the MLR models performed equally well in the estimations of Na and HCO3.

Table-8: Selected MLR models for Calibration

Parameters	MLR equation	MLRE	F
	-	(R ²)	value
Na	<i>Model 1</i> = 0.108*	0.9260	39.340
	HCO ₃ -3.373*Ca+		
	184.517		
HCO ₃	Model $2 =$	0.9247	36.817
	3.053*Na+12.921*Mg		
	-		
	1.184*Cl-225.855		
EC	<i>Model 3</i> = 1.756*	0.9152	10.742
	HCO ₃ + 6.713*SO ₄		
	+ 3.439*Cl +		
	3.763*K-		
	31.858*Ca –		
	7.051*Na+1626.374		
Cl	R ² value is less than		
	0.85, not considered		
	for any model		

Table-9: Validation results of MLR models.

	Model-1	Madel-2	Model-3
RootMeanSquaredError(RMSE)	27.50060105	75.26246537	206.5162533
Coefficient of Determination (\mathbf{R}^2)	0.9725	0.9461	0.9132
Percentage error in deepest level fluctuation (% EDLF)	11.2444	3.0297	34.0157

Model-1 for Sodium (Na), Model-2 for Bicarbonate (HCO₃), Model-3 for Specific electrical conductance (EC)

The methodology will be useful for maintaining continuous water quality database, reliable data and reduce the laboratory analysis.

5. Conclusions

Flowing conclusions can be drawn from above studies:

1. Groundwater in this region is neutral to slightly alkaline and shows marginal seasonal changes. The percentage of hydrogen-ion (pH) concentration in post-monsoon samples varies from 6.9 to 7.24 and for pre-monsoon samples it varies from 7.2 to 8.0 indicating slight alkaline nature.

2. Based on the concentration of TDS, the water of the Island in the both seasons are useful for

irrigation and all the samples of both seasons are safe for drinking. Based on (Wilcox, 1955) classification, 32% of the groundwater samples belong to good and 68% belong to permissible category in the pre monsoon period while 19% of the groundwater samples belong to good category and 81% belong to permissible category for the post-monsoon period. In general, the TDS increases after rain due to dissolution of minerals from the overlying material by the infiltrating water.

3. All samples of pre-monsoon period have hardness value ranging between 50 to 160 mg/l, excepting three samples in pre-monsoon period and all samples of post-monsoon period have hardness value between 50 to 160 mg/l excepting two samples. All samples of both periods are soft to moderately soft for domestic purposes.

4. Irrigation water classification based on SAR alone has indicated that 68%, 31% and 1% of premonsoon groundwater samples belong to excellent category, good and permissible category respectively, while 43%, 56% and 1% of postmonsoon ground water samples show excellent, good and permissible category respectively.

5. Graphical representation of the chemical data in the irrigation suitability diagram (USSL, 1954) (SAR vs. EC) shows that 34% of groundwater samples fall into C3S1 (medium to high salinity with low sodium), 59% fall into C3S2 (medium to high salinity with medium sodium) and rest 7% fall into C3S3 (medium to high salinity with high sodium) for both periods. The waters are satisfactory for irrigation use in almost all soil types.

6. Based on Gibbs' ratios, groundwater samples from pre and post-monsoon seasons fall in the rock dominance area indicating the interaction between rock (alluvium soil) and the percolating water in the sub-surface.

7. The Chloroalkaline (CAI) indices for most post and pre-monsoon water samples belong to the negative ratios indicating that there is exchange between sodium and potassium (Na + K) in water with calcium and magnesium (Ca + Mg) in rocks (alluvium soil).

8. Wilcox classification has revealed that in pre-monsoon groundwater samples, 6%, 80% and 14% fall under the good to permissible, permissible to doubtful and doubtful to unsuitable category respectively and 87% and 13% fall under permissible to doubtful and doubtful to unsuitable category for post-monsoon groundwater samples respectively. Most of the samples for both the periods are moderately suitable for irrigation purposes expecting few samples.

9. Spatially, all the groundwater samples of both the periods show the variations of major cations and anions within permissible limit for drinking purpose (2004), excepting those samples, which are proximal to the sea, river and saline water carrying creeks. The chemical characteristics of the water

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samples reveal slight seasonal variation. The seasonal variation in groundwater quality may be due to agricultural and domestic activities causing

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infiltration and percolation during monsoon. 10. The water samples in Sagar Island area show enrichment in Sodium cations and bicarbonate anions. An average value of Sodium concentration for ground water samples during pre-monsoon is 171.93 mg/l and the same is 172.75 mg/l during post-monsoon. An average value of bicarbonate content is 341.46 mg/l during pre-monsoon period and the same is 321.88 mg/l during post-monsoon period. Most of the samples of both periods fall under area-8 in Piper trilinear diagram, and sodium and bicarbonate alkali both exceed 50%. So geochemically, groundwater samples are classified as Na-HCO3.

11. All concentration of major cations and anions in groundwater is relatively higher during post monsoon than that of pre monsoon seasons, except HCO3. During post-monsoon time after the precipitation, the infiltrated groundwater may react with the surrounding soils/alluvial sediments/rocks and may enrich with cation and anion. This may elevate the concentration of cations and anions in groundwater during the post-monsoon period. But this change in concentration from pre-monsoon to post-monsoon is not remarkable and within the prescribed permissible limit for drinking and irrigation purposes.

12. SWC for most of the samples in the both periods are below 0.6 and only three samples are having SWC value between1.0 and 1.7 and these marginal high values are due to their locations near to river and sea. So, there is no significant seawater intrusion in the entire Sagar Island.

13. Finally with overall assessment, the concentration of major inorganic water quality parameter are mostly within the permissible limit for drinking and irrigation purposes, barring a few patches especially in the south, south-west and extreme northern part of Sagar Island.

14. Statistical groundwater quality models of MLR are developed for EC, HCO3 and Na parameters during the pre-monsoon, 2005 and validated with the data of pre-monsoon, 2006. Validation of these models here reveal that MLR are able to estimate HCO3 and Na with good amount of accuracy. So, the MLR models may provide reliable estimates of dependent variables.

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