

A Correlation and Regression Study on the Ground Water Quality in Rural Areas Around Angul-Talcher Industrial Zone

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The quality of ground water samples collected from 7 representatives tubewells in rural areas around Angul-Talcher industrial zone, Orissa was assessed in the rainy, winter and summer from July 2001 to June 2003. A total of 20 physico-chemical characteristics were analysed. Some parameters were found within and some parameters beyond the desirable limit for drinking purpose. A systematic correlation and regression study showed significant linear relationship among different pairs of water quality parameters.

KEYWORD

Ground water, Correlation and regression study, Physico-chemical parameter.

INTRODUCTION

Ground water is one of earth's most important, renewable and widely distributed resources. It is generally considered least polluted compared to other inland water resources. However, studies indicate that ground water is not absolutely free from pollution though it is likely to be free from suspended solids. Due to rapid growth of population, industrialization and urbanization, there have been intense human activities and interference into nature leading to an over-exploitation of and severe pollution stress on natural water-bodies. Improper waste disposal and unscientific anthropogenic practices over the years have adversely affected the surface and ground water quality. The major problem with the ground water is that once contaminated, it is difficult to restore its quality. The solution is non-trivial because of complex dynamics involved in the ground water flow, which requires simultaneous solution of complicated geochemical and hydrological equations. Hence there is a need for and concern over the protection and management of ground water quality.

It is well known that no straightforward reasons can be ascribed for deterioration of water quality, as it is dependent on several water quality parameters. There exist strong correlations among different parameters and a combined effect of their inter-relatedness indicates the water quality. Therefore, a systematic

statistical study of correlation and regression coefficients of the quality parameters not only helps to assess the overall water quality but also quantify relative concentration of various pollutants in water and provide necessary cue for implementation of rapid water quality management programmes. Many workers (Aravinda, 1991; Singanan and Rao, 1995; Srivastava and Sinha, 1994; Biswal *et al.*, 2001; Mishra *et al.*, 2003; Mor Suman *et al.*, 2002; Keshvan and Parameswari, 2005; Prajapati and Mathur, 2005; Patowary and Bhattacharya, 2005; Mahajan *et al.*, 2005) have undertaken statistical analysis and assessed the ground water quality in different parts of the country. Present authors while assessing fluoride pollution of ground waters in the study area, have showed statistically that fluoride is significantly correlated with number of other parameters. However, to the best of our knowledge, there has been no systematic correlation and regression study involving a large number of water quality parameters in ground water sources in the area. This paper is an attempt to address the issue taking into account as many as 20 water quality parameters in the analysis.

Study area

The Angul-Talcher industrial zone is located in the central part of Orissa in the district of Angul about 160 km from the Bay of Bengal shore line at an average height of 139 m above the mean sea level (MSL). It falls in the range 20° 37'N-21°10'N latitude and 84° 53'E-85° 21'E longitude. It is a major industrial zone in the state and has been recognized as one of the hot-spots in the country in respect of in-

Table 1. Location of sampling stations

Location	Reference of sampling station	Aerial distance, km/direction
Tentuloi	TW-1	7/N-W
Chainpal	TW-2	10/N-E
Gótmará	TW-3	6/N-E
Banarpal	TW-4	8/E
Bonda	TW-5	5/S-E
Tulsipal	TW-6	3/S
Kulad	TW-7	0

TW-Tubewell

Table 2. Analytical methods for study of different parameters

Parameter	Analytical method
pH	Electronic method using pH meter
SS	Gravimetric method
Turb	Nephelometric method
TDS	Gravimetric method
EC	Conductometric method
Alk	Colour indicator titrimetric method
TH	Titrimetric method (EDTA)
Ca	Titrimetric method (EDTA)
Mg	By difference of TH and Ca
DO	Iodometric method (Winkler titrimetric-azide modification)
BOD	Dilution method (3 day at 27 °C)
COD	Dichromate reflex method
Na	Flame-photometric method
K	Flame-photometric method
Cl	Argentometric titration method
F	Ion-selective-electrode method
NO ₃	Cadmium reduction followed by colorimetric method (diazotisation)
SO ₄	Turbidimetric method
Fe	Colorimetric method (1, 10-phenanthroline)
Cr ⁶⁺	Colorimetric method

dustrial pollution from a series of large, medium and small scale industries. The industries include National Aluminium Company (NALCO), Talcher Thermal Power Station, NTPC, Fertilizer Corporation of India (FCI) and Orichem Ltd., within the zone and many small scale industries as well as mines around. The industrial, municipal, domestic and mining activities have wrought enough environmental damage and have put severe pollution load on the water bodies in the study area, which is located within 10 km radius of the Angul-Talcher industrial zone. The sam-

pling stations in the area were chosen taking into account population density and rate of consumption of water from the station for drinking and domestic purposes. The locations of the sampling stations are given in table 1.

MATERIAL AND METHOD

A total of 7 representative under ground water samples were collected following standard procedures (APHA, 1995) from tubewells spread over different parts of study area, whose waters are used for drinking and other domestic purposes. 20 physico-chemical parameters, namely pH, suspended solids (SS), turbidity (Turb), total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), calcium (Ca), Magnesium (Mg), alkalinity (Alk), chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), sodium (Na), potassium (K), chloride (Cl), fluoride (F), iron (Fe), hexavalent chromium (Cr⁶⁺), sulphate (SO₄) and nitrate (NO₃) were analyzed in the rainy (July to October), winter (November to February) and summer (March to June) during the study period (July 2001-June 2003). The sampling was done in each alternate month which means that water samples from each selected station were analyzed twice in a season, that is 12 times in the entire study period for each analyzed parameter. An average of 4 observations in a season in respect of each individual parameter was taken to be the relevant data for the statistical analysis of each analyzed sample.

For all the physico-chemical parameters except dissolved oxygen, the samples were collected in pre-cleaned, dried airtight plastic (Tarson) bottles of 1.5 L capacity. For dissolved oxygen, sampling was done in pre-cleaned, dried, narrow and flared mouth glass-stoppered glass bottles of 300 mL capacity and fixed immediately after collection. The analytical methods adopted in the analysis were as per the standard methods (APHA, 1995) as shown in table 2. The correlation coefficients among various constituents were calculated and regression equations were developed to compare our prediction with the observed data.

RESULT AND DISCUSSION

The statistical evaluation from physico-chemical data for the ground waters of the study area in the rainy, winter and summer during the entire study period are summarized in tables 3, 4 and 5, respectively.

Table 3. Statistical evaluation for the ground waters of rural areas around Angul-Talcher industrial zone, Orissa in rainy season (2001-2003), in mg/L

Parameter	Min	Max	Avg	SD	SE	95 % CL
pH	7.025	7.750	7.407	0.263	0.0995	7.41 ± (0.2435)
SS	2.250	8.000	5.286	2.054	0.7762	5.29 ± (1.8992)
Turb., NTU	1.325	2.550	2.125	0.438	0.1654	2.13 ± (0.4047)
TDS	611.000	1884.000	1146.357	424.907	160.60	1146.36 ± (392.974)
EC, µmho/cm	1090.000	2966.750	1952.821	598.028	226.03	1952.82 ± (553.084)
TH	151.000	489.000	311.286	128.492	48.564	311.29 ± (118.835)
Ca	40.300	83.525	63.039	16.413	6.204	63.04 ± (15.1798)
Mg	9.350	76.900	37.438	23.523	8.891	37.44 ± (21.7553)
Alk	62.000	458.000	290.571	144.046	54.444	290.57 ± (133.2204)
COD	3.350	4.400	3.864	0.376	0.1420	3.86 ± (0.3476)
BOD	0.725	1.725	1.279	0.335	0.1265	1.28 ± (0.3095)
DO	2.100	3.575	2.743	0.493	0.1862	2.74 ± (0.4556)
Na	47.000	211.000	90.929	58.911	22.266	90.93 ± (54.484)
K	10.000	48.000	20.643	13.550	5.1214	20.64 ± (12.5317)
Cl	83.900	394.025	205.979	114.274	43.192	205.98 ± (105.686)
F	0.618	1.500	1.051	0.324	0.1225	1.05 ± (0.2997)
SO ₄	8.100	59.125	26.846	19.370	7.3211	26.85 ± (17.9141)
NO ₃	10.718	44.843	24.008	10.969	4.1459	24.01 ± (10.1447)
Fe	0.122	0.343	0.221	0.069	0.0263	0.22 ± (0.0643)
Cr ⁶⁺	0.019	0.032	0.023	0.004	0.0016	0.023 ± (0.0039)

Table 4. Statistical evaluation for the ground waters of the rural areas around Angul-Talcher industrial zone, Orissa in winter season (2001-2003), in mg/L

Parameter	Min	Max	Avg	SD	SE	95 % CL
pH	7.225	7.775	7.754	0.178	0.0671	7.55 ± (0.1643)
SS	2.250	5.750	3.857	1.376	0.520	3.86 ± (1.2724)
Turb., NTU	0.825	1.650	1.279	0.288	0.1090	1.28 ± (0.2668)
TDS	687.000	1662.000	1082.214	355.869	134.506	1082.21 ± (329.1242)
EC, µmho/cm	1063.500	2669.000	1822.893	580.195	219.293	1822.89 ± (536.5905)
TH	171.000	456.000	306.429	103.094	38.966	306.43 ± (95.3457)
Ca	49.475	74.850	64.489	10.955	4.1404	64.49 ± (10.1313)
Mg	11.525	68.775	35.368	19.753	7.466	35.37 ± (18.2687)
Alk	137.000	479.000	317.000	132.610	50.1218	317.00 ± (122.6435)
COD	2.300	4.250	3.164	0.606	0.2290	3.16 ± (0.5603)
BOD	0.400	1.400	0.904	0.309	0.1167	0.904 ± (0.2855)
DO	2.400	4.000	3.229	0.549	0.2075	3.23 ± (0.5077)
Na	36.750	209.500	102.714	68.269	25.8033	102.71 ± (63.1384)
K	8.000	49.250	23.464	16.080	6.777	23.46 ± (14.8717)
Cl	100.825	296.525	200.818	80.058	30.2591	200.82 ± (74.1414)
F	0.565	1.710	1.139	0.450	0.1699	1.14 ± (0.4157)
SO ₄	6.175	68.900	32.750	24.427	9.3460	32.75 ± (22.8687)
NO ₃	7.320	26.955	17.980	6.611	2.4988	17.98 ± (6.1145)
Fe	0.127	0.371	0.224	0.082	0.0310	0.22 ± (0.0757)
Cr ⁶⁺	0.006	0.021	0.011	0.005	0.0019	0.011 ± (0.0047)

Average value of all the water quality parameters were obtained with 95 % CI. In the rainy season, the pH values of all 7 samples were in the range

7.03-7.75 with the average value with 95 % CI in the range 7.4 ± (0.2435). Suspended solids and turbidity values were found in the range 2.25-8.0

Table 5. Statistical evaluation for the ground waters of the rural areas around Angul-Talcher industrial zone, Orissa in summer season (2001-2003), in mg/L

Parameter	Min	Max	Avg	SD	SE	95 % CL
pH	7.450	7.825	7.654	0.130	0.0493	7.65 ± (0.1205)
SS	1.000	6.250	2.321	1.852	0.7002	2.32 ± (1.7132)
Turb., NTU	0.675	2.200	1.075	0.511	0.1931	1.08 ± (0.4725)
TDS	636.500	1762.000	1121.821	380.867	143.9543	1121.82 ± (352.2434)
EC, μ mho/cm	1186.750	2992.000	1894.429	614.033	232.0826	1894.43 ± (567.8857)
TH	164.000	354.000	268.071	71.544	27.0411	268.07 ± (66.1671)
Ca	45.900	68.550	56.354	7.899	3.9856	56.35 ± (0.3056)
Mg	9.275	55.025	31.618	15.111	5.7115	31.62 ± (13.9756)
Alk	58.000	404.000	252.571	125.195	47.3191	252.57 ± (115.7857)
COD	2.400	3.450	3.021	0.399	0.1507	3.02 ± (0.3688)
BOD	0.825	1.425	1.143	0.223	0.0841	1.14 ± (0.2059)
DO	1.700	2.400	2.061	0.295	0.1114	2.06 ± (0.2725)
Na	42.750	306.500	120.714	93.715	35.4210	120.71 ± (86.6721)
K	9.500	74.000	28.357	22.973	8.6829	28.36 ± (21.2462)
Cl	110.800	388.300	229.446	102.283	38.6593	229.45 ± (94.5959)
F	0.618	1.498	1.021	0.377	0.1424	1.02 ± (0.3483)
NO ₃	6.423	28.123	18.191	6.614	2.4998	18.19 ± (6.1168)
SO ₄	9.825	58.325	35.282	16.484	6.2303	35.28 ± (15.2449)
Fe	0.197	0.322	0.241	0.044	0.0167	0.24 ± (0.0408)
Cr ⁶⁺	0.006	0.028	0.016	0.008	0.0031	0.02 ± (0.0074)

mg/L and 1.33-2.55 NTU and average values were in the range $5.29 \pm (1.90)$ and $2.13 \pm (0.4047)$, respectively. Total dissolved solids were detected in the range 611-1884 mg/L with an average range of $1146.36 \pm (392.974)$. Electrical conductivity varied in the range 1090-2966.75 μ mho/cm with average values in the range $1952.82 \pm (553.084)$. Total hardness values were observed in the range 151-489 mg/L with average values in the range $311.29 \pm (118.835)$. Calcium and magnesium contents were found in the range 40.30-83.52 and 9.35-76.90 mg/L and with their average values in the range $63.04 \pm (15.1798)$ and $37.44 \pm (21.7553)$, respectively. Alkalinity varied in the range 62-458 mg/L and with an average range of $290.57 \pm (133.2204)$. COD and BOD were found in the range 3.35-4.40 and 0.73-1.73 mg/L and with their average values in the range $3.86 \pm (0.3475)$ and $1.28 \pm (0.3095)$, respectively. Dissolved oxygen were found in the range 2.10-3.58 mg/L and with average values in the range $2.74 \pm (0.4556)$. Sodium and potassium contents were found in the range 47-211 and 10-48 mg/L with the average in the range $90.93 \pm (54.484)$ and $20.64 \pm (12.5317)$, respectively. Chloride and fluoride level were observed in the range 83.9-394.03 and 0.62-1.50 mg/L with the average values in the range $205.98 \pm (105.686)$ and $1.05 \pm (0.2997)$,

respectively. Iron and hexavalent chromium content were found in the range 0.12-0.34 and 0.02-0.03 mg/L with average values in the range $0.22 \pm (0.0643)$ and $0.02 \pm (0.0039)$, respectively. Nitrate and sulphate concentration varied in the range 10.72-44.84 and 8.10-59.13 mg/L with the average values in the range $24.01 \pm (10.1447)$ and $26.85 \pm (17.9141)$, respectively.

In the winter season, the pH values were in the range 7.23-7.78 and average value with 95 % CI were in the range $7.55 \pm (0.1643)$. Suspended solids and turbidity were found in the range 2.25-5.75 mg/L and 0.83-1.65 NTU and average values in the range $3.86 \pm (1.2724)$ and $1.28 \pm (0.2668)$, respectively. Total dissolved solids were detected in the range 687-1662 mg/L with an average range of 1082.21 $\pm (329.1242)$. Electrical conductivity varied in the range 1063.5-2669 μ mho/cm with average values in the range $1822.89 \pm (536.5905)$. Total hardness values were observed in the range 171-456 mg/L with average values in the range $306.43 \pm (95.3457)$. Calcium and magnesium contents were found in the range 49.48-74.85 and 11.3-68.78 mg/L with average values varying in the range $64.49 \pm (10.1313)$ and $35.37 \pm (18.2687)$, respectively. Alkalinity varied in the range 137-479 mg/L with the ave-

Table 6. Correlation coefficient (r) for different parameters in the ground waters of rural areas around Angul-Talcher industrial zone, Orissa in rainy season (2001 - 03)

	pH	SS	TDS	Turb	EC	TH	Ca	Mg	Alk	COD
pH	1.000	0.281	0.713	0.372	0.702	0.852	0.917	0.744	0.889	-0.173
SS		1.000	0.327	0.845	0.246	0.482	0.553	0.407	0.495	-0.743
TDS			1.000	0.474	0.992	0.878	0.691	0.872	0.699	0.129
Turb				1.000	0.422	0.494	0.517	0.438	0.586	-0.412
EC					1.000	0.827	0.670	0.813	0.655	0.176
TH						1.000	0.835	0.973	0.846	-0.124
Ca							1.000	0.686	0.812	-0.492
Mg								1.000	0.782	0.042
Alk									1.000	-0.189
COD										1.000
BOD										
DO										
Na										
K										
Cl										
F										
Fe										
Cr ⁶⁺										
SO ₄										
NO ₃										

Table 6. (continue)

	BOD	DO	Na	K	Cl	F	Fe	Cr ⁶⁺	SO ₄	NO ₃
pH	0.016	-0.152	0.316	0.321	0.239	0.093	0.189	0.259	0.229	0.518
SS	-0.470	0.561	-0.217	-0.227	-0.020	0.259	0.053	-0.560	-0.176	0.318
TDS	0.159	-0.322	0.660	0.658	0.772	0.259	-0.058	0.017	0.222	0.688
Turb	0.044	0.485	0.188	0.183	0.243	0.650	0.053	-0.595	-0.542	0.548
EC	0.208	-0.328	0.675	0.675	0.803	0.248	-0.059	0.098	0.228	0.641
TH	-0.089	-0.304	0.463	0.458	0.467	0.106	-0.032	-0.087	0.285	0.664
Ca	-0.292	0.091	0.088	0.092	0.213	-0.018	0.082	0.124	0.269	0.355
Mg	0.006	-0.438	0.575	0.567	0.527	0.151	-0.072	-0.166	0.263	0.732
Alk	0.088	0.027	0.288	0.285	0.134	0.412	0.440	0.058	0.027	0.789
COD	0.801	-0.705	0.728	0.729	0.459	0.246	-0.065	0.184	-0.077	0.279
BOD	1.000	-0.279	0.718	0.722	0.367	0.694	0.170	0.056	-0.551	0.475
DO		1.000	-0.656	-0.655	-0.488	0.298	0.408	-0.140	-0.426	-0.156
Na			1.000	1.000	0.823	0.425	-0.284	-0.151	-0.184	0.604
K				1.000	0.824	0.420	-0.288	-0.139	-0.184	0.593
Cl					1.000	0.185	-0.491	-0.133	0.045	0.355
F						1.000	0.427	-0.310	-0.764	0.726
Fe							1.000	0.467	-0.044	0.415
Cr ⁶⁺								1.000	0.564	-0.151
SO ₄									1.000	-0.205
NO ₃										1.000

range of $317 \pm (122.6435)$. COD and BOD were found in the range 2.3-4.3 and 0.4-1.4 mg/L with the average values in the range $3.16 \pm (0.56$

03) and $0.90 \pm (0.2855)$, respectively. Dissolved oxygen were found in the range 2.4-4.0 mg/L with the average values in the range $3.23 \pm (0.5077)$.

Table 7. Correlation coefficient (r) for different parameters in the ground waters of rural areas around Angul-Talcher industrial zone, Orissa in winter season (2001-03)

	pH	SS	TDS	Turb	EC	TH	Ca	Mg	Alk	COD
pH	1.000	0.130	0.449	0.014	0.432	0.789	0.897	0.700	0.695	0.390
SS		1.000	-0.003	0.466	-0.062	0.012	0.186	-0.047	-0.121	-0.046
TDS			1.000	-0.413	0.988	0.789	0.522	0.826	0.879	0.646
Turb				1.000	-0.529	-0.473	-0.149	-0.550	-0.480	0.165
EC					1.000	0.798	0.519	0.838	0.906	0.542
TH						1.000	0.847	0.984	0.870	0.494
Ca							1.000	0.738	0.647	0.446
Mg								1.000	0.886	0.478
Alk									1.000	0.408
COD										1.000
BOD										
DO										
Na										
K										
Cl										
F										
Fe										
Cr ⁶⁺										
SO ₄										
NO ₃										

Table 7. (continue)

	BOD	DO	Na	K	Cl	F	Fe	Cr ⁶⁺	SO ₄	NO ₃
pH	-0.148	0.061	0.106	0.097	-0.198	0.690	0.492	0.306	-0.068	0.623
SS	-0.271	-0.161	-0.190	-0.179	-0.308	-0.275	0.144	0.034	0.496	0.312
TDS	0.472	-0.449	0.889	0.887	0.324	0.697	0.793	0.641	0.149	0.755
Turb	0.097	0.162	-0.502	-0.485	-0.925	-0.352	0.193	-0.631	0.003	-0.114
EC	0.387	-0.395	0.873	0.869	0.447	0.704	0.710	0.670	0.186	0.693
TH	0.076	-0.292	0.606	0.593	0.288	0.798	0.509	0.711	-0.090	0.811
Ca	-0.042	0.162	0.285	0.280	0.073	0.827	0.394	0.275	-0.187	0.573
Mg	0.111	-0.425	0.673	0.659	0.340	0.734	0.514	0.810	-0.051	0.837
Alk	0.114	-0.271	0.625	0.616	0.309	0.732	0.670	0.674	0.215	0.694
COD	0.832	-0.292	0.688	0.696	-0.262	0.647	0.788	0.114	-0.445	0.610
BOD	1.000	-0.249	0.702	0.715	-0.094	0.375	0.583	-0.093	-0.426	0.216
DO		1.000	-0.494	-0.485	0.027	0.165	-0.380	-0.756	-0.182	-0.700
Na			1.000	1.000	0.448	0.608	0.606	0.549	-0.124	0.584
K				1.000	0.439	0.605	0.614	0.530	-0.120	0.576
Cl					1.000	0.266	-0.286	0.415	0.095	-0.091
F						1.000	0.513	0.221	-0.375	0.443
Fe							1.000	0.274	0.158	0.697
Cr ⁶⁺								1.000	0.246	0.757
SO ₄									1.000	0.070
NO ₃										1.000

Sodium and potassium contents were found in the range 36.75-209.50 and 8-49.25 mg/L with the average values range $102.71 \pm (63.1334)$ and $23.46 \pm (14.8717)$, respectively. Chloride and fluoride

level were observed in the range 100.83-296.53 and 0.57-1.71 mg/L with the average values in the range $200.82 \pm (74.1414)$ and $1.14 \pm (0.4157)$, respectively. Iron and hexavalent chromium contents

Table 8. Correlation coefficient (*r*) for different parameters in the ground waters of rural areas around Angul - Talcher industrial zone, Orissa in summer season (2001 - 03)

	pH	SS	TDS	Turb	EC	TH	Ca	Mg	Alk	COD
pH	1.000	0.620	0.554	0.495	0.535	0.433	-0.054	0.592	0.647	0.391
SS		1.000	0.152	0.942	0.105	0.585	0.737	0.417	0.535	0.015
TDS			1.000	-0.028	0.992	0.561	-0.207	0.749	0.720	-0.307
Turb				1.000	-0.048	0.637	0.756	0.420	0.487	-0.015
EC					1.000	0.584	-0.247	0.790	0.752	-0.310
TH						1.000	0.439	0.912	0.863	-0.418
Ca							1.000	0.109	0.218	-0.305
Mg								1.000	0.963	-0.247
Alk									1.000	-0.168
COD										1.000
BOD										
DO										
Na										
K										
Cl										
F										
Fe										
Cr ⁶⁺										
SO ₄										
NO ₃										

Table 8. (continue)

	BOD	DO	Na	K	Cl	F	Fe	Cr ⁶⁺	SO ₄	NO ₃
pH	-0.154	0.029	0.793	0.792	0.698	0.653	-0.538	0.642	0.173	0.234
SS	-0.042	0.183	0.197	0.197	0.281	0.386	-0.418	0.580	0.308	0.102
TDS	-0.778	0.174	0.649	0.649	0.794	0.536	-0.263	0.719	0.162	0.512
Turb	0.035	0.014	0.160	0.162	0.105	0.407	-0.254	0.570	0.206	0.233
EC	-0.757	0.083	0.657	0.658	0.746	0.561	-0.192	0.740	0.173	0.596
TH	-0.541	0.042	0.407	0.411	0.341	0.748	-0.165	0.901	0.059	0.819
Ca	0.067	0.290	-0.448	-0.447	-0.259	0.034	-0.155	0.216	0.210	0.003
Mg	-0.524	-0.086	0.598	0.602	0.460	0.822	-0.166	0.927	0.142	0.886
Alk	-0.388	-0.072	0.496	0.499	0.403	0.762	-0.212	0.902	0.319	0.787
COD	0.711	0.063	0.142	0.138	-0.120	0.196	-0.495	-0.374	-0.249	-0.358
BOD	1.000	-0.202	-0.453	-0.485	-0.723	-0.267	0.006	-0.604	0.044	-0.428
DO		1.000	-0.150	-0.155	0.193	0.219	-0.806	-0.174	-0.519	-0.331
Na			1.000	1.000	0.833	0.607	-0.244	0.644	-0.071	0.414
K				1.000	0.831	0.608	-0.239	0.648	-0.069	0.420
Cl					1.000	0.378	-0.354	0.591	0.041	0.143
F						1.000	-0.574	0.650	-0.332	0.678
Fe							1.000	-0.056	0.453	0.179
Cr ⁶⁺								1.000	0.324	0.764
SO ₄									1.000	0.048
NO ₃										1.000

were found in the range 0.13-0.37 and 0.01-0.02 mg/L with the average in the range $0.22 \pm (0.0757)$ and $0.01 \pm (0.0047)$, respectively. Nitrate and

sulphate concentration varied in the range 7.32-26.96 and 6.18-68.90 mg/L with the average values in the range $17.98 \pm (6.1145)$ and $32.75 \pm (22.86)$

Table 9. Linear correlation and regression equation ($Y=aX+b$) for some pairs of strongly correlated parameters and their predicted values in the rainy, winter and summer season (2001 - 03)

Sseason	Parameter	a	b	r	Regression equation	Predicted value	Observed value	% Deviation
Rainy	TDS, EC	1.396	352.15	0.992	$EC = 1.396 (TDS) + 352.15$	2982.21	2966.75	-0.52
	TH, Mg	0.178	-18.011	0.973	$Mg = 0.178 (TH) - 18.011$	8.87	9.35	0.52
	Na, K	0.230	-0.265	1.000	$K = 0.23 (Na) - 0.265$	48.27	48	-0.55
Winter	TDS, EC	1.611	79.70	0.988	$EC = 1.611 (TDS) + 79.70$	2441.43	2490	1.95
	Mg, TH	5.138	124.82	0.984	$TH = 5.138 (Mg) + 124.82$	477.98	456	-4.82
	Na, K	0.235	-0.719	1.000	$K = 0.235 (Na) - 0.719$	42.29	41.5	-1.89
Summer	TDS, EC	1.600	99.587	0.992	$EC = 1.6 (TDS) + 99.587$	2918.79	2992	2.45
	TH, Mg	0.193	-20.031	0.912	$Mg = 0.193 (TH) - 20.031$	48.29	44.45	-8.64
	Na, K	0.245	-1.233	1.000	$K = 0.254 (Na) - 1.233$	73.86	74	0.19

87), respectively.

In the summer season, however, pH values were in the range 7.45-7.83 and average values with 95 % CI were in the range $7.65 \pm (0.1205)$. Suspended solids and turbidity were found in the range 1-6.25 mg/L and 0.68-2.2 NTU and average values in the range $2.32 \pm (1.7132)$ and $1.08 \pm (0.4725)$, respectively. Total dissolved solids were detected in the range 636.5-1762 mg/L with an average range of $1121.82 \pm (352.2434)$. Electrical conductivity varied in the range 1186.75-2992 μ mho/cm with average values in the range $1894.43 \pm (567.8857)$. Total hardness were observed in the range 164-354 mg/L with average values in the range $268.07 \pm (66.1671)$. Calcium and magnesium contents were found in the range 45.90-68.55 and 9.28-55.03 mg/L with the average values varying in the range $56.35 \pm (7.3056)$ and $31.62 \pm (13.9756)$, respectively. Alkalinity was detected in the range 58-404 mg/L with the average range of $252.57 \pm (115.7857)$. COD and BOD were found in the range 2.4-3.5 and 0.83-1.43 mg/L with the average range $3.02 \pm (0.3688)$ and $1.14 \pm (0.2059)$, respectively. Dissolved oxygen were found in the range 1.7-2.4 mg/L with the average in the range $2.06 \pm (0.2725)$. Sodium and potassium contents were found in the range 42.75-306.5 and 9.5-7.4 mg/L with the average values in the range $120.71 \pm (86.6721)$ and $28.36 \pm (21.2462)$, respectively. Chloride and fluoride level were observed in the range 110.8-388.3 and 0.62-1.50 mg/L with the average values in the range $229.45 \pm (94.60)$ and $1.02 \pm (0.3483)$, respectively. Iron and hexavalent chromium contents were found in the range 0.2-0.32 and 0.01-0.03 mg/L with the average values in the range $0.24 \pm (0.0408)$ and $0.02 \pm (0.0074)$, respectively. Nitrate and sulphate concentration varied in the ra-

range 6.42-28.12 and 9.83-58.33 mg/L with the average values in the range $18.19 \pm (6.1168)$ and $35.28 \pm (15.2449)$, respectively.

A critical study of tables 3, 4 and 5 reveals that 8 parameters, namely pH, Turb, COD, BOD, DO, Cr^{6+} , NO_3 , and SO_4 were found within desirable limit (BIS, 2003; ICMR, 1975; WHO, 1984) for drinking waters for all the sampling station in the entire study period. On the other hand the parameters : TDS, EC, Na and K were found significant and above the desirable limit in the samples throughout the study period. 14 % of samples were found with higher Fe, 43 % with higher TH, Mg, Cl, F and 71 % with higher Alk above the desirable limit in all the seasons. 29 % of the samples showed marginally higher Ca content in rainy seasons only. Suspended solids (SS) were found above desirable limit in 14 % of samples in winter and summer and in the 71 % samples in the rainy season. It is observed that high TDS contents led to high EC and Mg-hardness was more significant than Ca-hardness. It is also revealed that most of the parameters were found to have maximum concentration in the rainy and minimum in summer. This may be due to percolation of contaminated water into the ground waters in the rainy season.

The numerical values of correlation coefficient(r) for 20 physico-chemical parameters analysed in rainy, winter and summer season are tabulated in tables 6, 7 and 8, respectively. In the rainy season, the significant positively correlated values were observed between pH and TH (0.852), Ca (0.917), Alk (0.889); SS and Turb (0.845); TDS and EC (0.992), TH (0.878), Mg (0.872); EC and TH (0.872), Mg (0.813), Cl (0.803); TH and Ca (0.835), Mg (0.973), Alk (0.846); COD and BOD (0.801); Na and K (1.0),

Cl (0.823); K and Cl (0.824). However, some weak correlations were also observed between Mg and BOD (0.006); pH and BOD (0.016) which showed that BOD concentration did not depend upon Mg and pH values. The parameters COD and DO were found to be negatively correlated with most of the parameters.

In winter, significant positive correlations were found between pH and Ca (0.897), TDS and EC (0.988), Mg (0.826), Alk (0.879), Na (0.889), K (0.887); EC and Mg (0.838), Alk (0.906); TH and Ca (0.847), Mg (0.984), Alk (0.870) NO₃ (0.811); Mg and Alk (0.886); COD and BOD (0.832); Na and K (1.0). Some weak correlations were found between Turb and SO₄ (0.009); SS and TDS (-0.003), TH (0.012). SO₄ and DO were found to have negative correlations with most of the parameters. In summer, a number of pairs of parameters were found to have significant positive correlations. Some of these are : SS and Turb (0.942), TDS and EC (0.992); TH and Mg (0.912), Alk (0.863), Cr⁶⁺ (0.901), NO₃ (0.819); Mg and Alk (0.963), F (0.822), Cr⁶⁺ (0.927), NO₃ (0.886); Na and K (1.0), Cl (0.833); K and Cl (0.831); Alk and Cr⁶⁺ (0.902). Fe, COD and BOD were negatively correlated with the parameters. The linear regression analysis were carried out in a few pairs of significantly correlated parameters observed in different seasons. The results of the analysis are summarised in table 9, representing the value of correlation coefficient (r); empirical parameters 'a' and 'b', best fit linear regression equations, observed and predicted values of some significantly correlated parameters.

CONCLUSION

In present study, the correlation and regression of 20 physico-chemical parameters of ground waters revealed that all the parameters were more or less correlated with one another. The statistical analysis facilitated the evaluation of some parameters without experimental determination. The significance of the analysis is that in addition to finding correlation among various parameters, it provides a fairly accurate idea about the quality of the ground water. On the basis of the findings of present study, it is recommended that the tubewell water in the study area should be treated before it is used for drinking purpose.

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