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A correlation study of the ground water quality in the Manali Petroleum Industrial Region in Tamil Nadu, India

S. Arul Antony [1], M. Balakrishnan* [2], S. Gunasekaran[3] and R.K. Natarajan[4]
[1]S. Arul Antony, Department of Chemistry, Presidency College, Chennai - 600 005, India.
[2]M. Balakrishnan*, Department of Physics, Presidency College, Chennai - 600 005.
[3]S. Gunasekaran, Department of Physics, Pachaiyappa's College, Chennai – 600 030.
[4]R.K. Natarajan, Dept. of Science & Humanities, Dhanalakshmi College of Engg., Chennai -601 301
mbkarunmathi_ro@yahoo.co.in*

Abstract: The increased prominence of the petroleum industry in Manali at North Chennai has given rise to a concomitant upsurge of ecological disturbances together with groundwater pollution. Ten representative groundwater samples were collected from various parts of the industrial region in the monsoon, winter and summer seasons during 2006-2007 and those water samples were analysed by standard analytic methods. As many as twenty water quality parameters were taken into account in the correlation analysis. Some parameters were found within and some parameters beyond the permissible limit. Correlation coefficients (r) between different pairs of parameters were computed. Significant positive correlation was found to exist between the pairs of parameters; turbidity-alkalinity, turbidity-iron, EC-Na, TDS-EC, TDS-TH, EC-TH, TH-K and COD-BOD. It is also observed that, some of the parameters were found to have weak correlation and some parameters have negative correlation.

Keywords: Manali, petroleum industry, groundwater quality, correlation coefficients.

Introduction

Groundwater is one of earth's most vital renewable and widely distributed resources as well as an important source of water supply throughout the world. Its use in irrigation, industries and domestic usage continues to increase where perennial surface water sources are absent. The quality of groundwater is more significant as the case of quantity for all purposes (Mariappan *et al.,* 2005). The pollution of groundwater is of major concern, firstly because of increasing utilization for human needs and secondly because of the ill effects of the increased industrial activity (Jain *et al.,* 2006). Improper waste disposal and unscientific anthropogenic practices over the decades have adversely affected the surface and groundwater quality (Dash *et al.,* 2006).

Industries consume large quantities of water, consequently depleting the available resources and at the same time produce wastewater containing organic chemicals and toxic heavy metals depending upon the various chemicals used in the industries (Vaishnav *et al.,* 2007). Even after aerobic or anaerobic treatment, disposal of the industrial wastes and effluents contain toxic substances to be leached and seep into the soil and affect groundwater course (Madhusudana *et al.,* 2001; Jain *et al.,* 2004). Storing liquid petroleum products above ground or underground presents a potential threat to public health and the environment. Gasoline, diesel and fuel oil can move rapidly through surface layers and into ground water. A few quarts of gasoline in the ground water may be enough to severely pollute drinking water (Harris *et al.,* 2001). Therefore, regular monitoring of groundwater pollution in an industrial area assumes paramount importance to maintain environmental safety.

Water quality is dependent on several parameters. There exist strong correlations among different parameters and a combined effect of their inter-relatedness indicates the water quality. In general, groundwater quality in the industrial areas is determined by measuring the concentration of some physico-chemical parameters and comparing them with drinking water standards. The number of such parameters necessary to fully specify the quality of water, however, is quite large. In a developing country like India, it may be too expensive or even unfeasible to determine all of them due to lack of laboratory facilities or trained manpower. On the other hand, the task of monitoring the quality of water is facilitated if one can find some correlations among these numerous parameters. When such correlations do exist, measuring a few important parameters and then predicting others using these correlations would give an indication of the quality of water (Punam *et al.,* 2003).

Karthikeyan *et al.,* (2003) and Jain *et al.,* (2006) have reported the correlation between alkalinity and fluoride in groundwater. Similar type of correlation studies among groundwater quality parameters have also been reported (Nagarajan *et al.,* 1993; Kalvin *et al.,* 1996; Rajasekaran *et al.,* 2004). 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 coefficients of the quality parameters not only helps to assess the overall water quality

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Table 1. List of groundwater sample sites

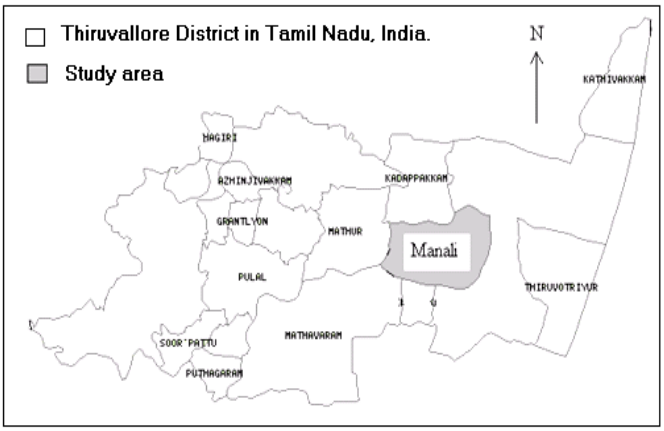
Sample	Site	Source
S1	No. 3, Wikad village Manali (Near Indian Oil Tanking), Chennai -103	Bore well
S2	No. 62, Wikad village Manali (Near Indian Oil Tanking), Chennai -103	Bore well
S3	Indian Oil Tanking, Manali , Chennai - 103	Bore well
S4	No. 35/2, New Manali , Chennai - 103	Open well
S5	10, First Cross Road, Manali, Chennai-103	Bore well
S6	Chennai Petroleum Corporation Ltd.,Manali, Chennai - 103	Open well
S7	Chennai Petroleum Corporation Ltd., Manali, Chennai - 103	Bore well
S8	Madras Oil Corporation Ltd., Manali, Chennai - 103	Bore well
S9	Indian Oil Corporation Ltd., Manali, Chennai - 103	Open well
S10	Indian Oil Corporation Ltd., Manali, Chennai - 103	Bore well

but also provide necessary cue for implementation of rapid water quality management programmes (Dash *et al.,* 2006). Hence, the present investigation makes an attempt to evaluate the groundwater quality in the study area considering twenty one important water quality parameters in the correlation analysis.

Study area

The study area Manali is a part of North Chennai in Tamil Nadu, India. The location of the study area is shown in the Fig. 1. Groundwater is the main source of potable water and used for drinking and other domestic purposes in the study area. Many petroleum oil industries and fertilizer manufacturing industries are situated in this region.

Fig. 1 Study area location



The Manali Refinery has a capacity of 9.5 MMTPA and is one of the most complex refineries in India with Fuel, Lube, Wax and Petrochemical feed stocks production facilities. Contamination of air, soils and groundwater by the release of fuels, oils and halogenated solvents has posed serious environmental problems in this region.

Materials and Methods

Sample collection and analysis

Representative groundwater samples were collected in the study area to assess its quality for drinking purpose. Ten groundwater samples were collected following standard procedures from open wells and bore wells in various parts of the industrial region in the monsoon (September-2006), winter (December-2006) and summer (March-2007) seasons during 2006- 2007. The location of the sample sites were given in Table 1. The samples were analysed for physico-chemical characteristics by standard analytic methods (APHA, 1995). All the groundwater samples were found to be colourless and odourless. The temperature of the groundwater samples ranged between 28 °C and 30 °C during the sampling periods. The tolerance (permissible) and excessive limits of drinking water quality parameters are given in Table 2. The various analytical results are listed in Tables 3-5.

Statistical analysis

Average values of all the water quality parameters were obtained with 95% confidence level (CL). The statistical evaluation from physico-chemical data of the groundwater samples in the rainy, winter and summer seasons were summarized in Tables 6-8 respectively. Correlation indicates the relationship between two variables such that a change in one variable causes a corresponding change in the other variable. It gives a rough but fairly useful indication of water quality and also facilitates a rapid monitoring of the status of water pollution. A pair of parameters having correlation coefficient r up to 0.5 do not have any significant correlation between them, $r \geq \pm 0.5$ bears significant linear correlation between them and $r \geq \pm 0.8$ indicates very strong linear correlation between them (Jeyaraj *et al.,* 2002). The correlation coefficient for different environmentally important water quality parameters are calculated using equation (1)

$$r = \frac{n\sum xy - \sum x \sum y}{\left[\left\{n\sum x^2 - \left(\sum x\right)^2\right\}\left\{n\sum y^2 - \left(\sum y\right)^2\right\}\right]^{1/2}} \quad (1)$$

(Saxena *et al.,* 2004).

Where, x and y are any two variables and n is the number of samples. In the present

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Table 2. Tolerance and excess limits of drinking water quality parameters

Parameter	Tolerance limit	Excessive limit
Colour (Pt-Scale)	5	25
Turbidity (NTU)	5	25
pH	7.5	6.5 if pH < 7.5 8.5 if pH > 7.5
DO @ 30 °C (mg/L)	10	3
Chloride (mg/L)	250	1000
Nitrate (mg/L)	45	100
Sulphate (mg/L)	200	400
TH (mg/L)	200	600
TDS (mg/L)	500	1500
F.Coli. (MPN/100ml)	1	100
BOD_5 (mg/L)	0	30
Iron (mg/L)	0.3	1.0
Zinc (mg/L)	5.0	15.0
Fluoride (mg/L)	1.0	2.0
Copper (mg/L)	0.05	1.5
Arsenic (mg/L)	0.05	0.05
Cadmium (mg/L)	0.05	0.05
Chromium (mg/L)	0.05	0.05
Mercury (mg/L)	0.001	0.001
Lead (mg/L)	0.10	0.10

investigation n =10. The numerical values of correlation coefficient (r) of the physico-chemical parameters of all the groundwater samples for the three seasons were listed in Tables 9a -11b.

Results and discussion

The analytical results from the Tables 3-5 show that most of the samples have low pH (less than 7) and are found to be acidic in nature. The descriptive statistics obtained for various physico-chemical parameters of groundwater revealed that the pH values of the samples were in the range of 6.07 to 7.27 (Tables 6-8). The TDS value varied between 1236 mg/L and 6908 mg/L and most of the samples exceed the tolerance as well as the excessive limits of WHO and BIS standards (WHO, 2003; BIS, 1991). The values of the EC, chloride, total hardness and sulphate were found to be higher than the permissible limits and varied in the range of 2331-10990 µS/cm, 427-2871 mg/L, 529-1801 mg/L and 82-912 mg/L respectively. Alkalinity was found to be in the range of 191-1360 mg/L. The samples S1-S3 were found to have nitrate values more than 45 mg/L. Higher concentration of nitrate in water causes Methaemoglobinaemia, an infant disease up to 6 months of child (Agarwal *et al.,* 1991).

The concentrations of iron and chromium were found in the range of 0.37-15.69 mg/L and 0.14-2.15 mg/L respectively. Lead had concentrations up to 0.361 mg/L. These elements were found in excess higher than the permissible limits of BIS and WHO standards. The concentrations of dissolved oxygen were well below the desirable limit, which is an indication of organic pollution (Vaishnav *et al.,* 2007). The concentrations of turbidity, fluoride, COD and BOD were well within the permissible limits in all the samples. The values of Ca, Na, K and Mg were also found to be higher than the tolerance limits in most of the samples. The presence of elevated amounts of chemical contaminants and toxic trace elements discussed above render the groundwater chemically unpotable.

In the rainy season, the average values of pH, TDS, turbidity and TH with 95% CL were found in the range of 6.503 ± 0.1601, 2811.5 ± 1136.5 mg/L, 2.489 ± 3.80 NTU and 1122.2 ± 246.05 mg/L respectively. The average values of DO, calcium and magnesium were in the range 2.66 ± 1.35 mg/L, 243.9 ± 76.94mg/L and 124.6 ± 23.58 mg/L respectively. Fluoride and lead had the average values in the range 0.9 ± 0.26 and 0.1008 ± 0.079 respectively. In the winter season, the average values of alkalinity and sulphate were found in the range of 504.5±272.9 and 434.8±196.68 respectively. In the summer season, the average values of chloride and nitrate were found in the range of 1219.9±460.15 and 23.8±8.66 respectively.

From the correlation coefficients (r) of the physico-chemical parameters, it is observed that strong positive correlations exist between the pairs, turbidity-iron (0.923), EC-Na (0.909), TDS-EC (0.99) and COD-BOD (0.969) (Tables 9a-11b). There exist very strong correlations between EC and the parameters TDS (0.999), alkalinity (0.95), sulphate (0.859), chloride (0.970), nitrate (0.857), TH (0.8180), Na (0.909) and K (0.875). This result is in confirmation with the previous studies (Mahajan *et al.,* 2005; Sunitha *et al.,* 2005). Since EC correlates with most of the parameters, the quality of groundwater can be predicted with sufficient accuracy just by the measurement of EC alone. This provides a means for easier and faster monitoring of water quality in a location (Kalyanaraman *et al.,* 2005).

Table 3. Analytical results of groundwater samples (September - 2006)

Parameters	Units	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Turbidity	NTU	17.31	2.554	0.2	3.095	0.3	0.122	0.12	0.44	0.196	0.56
EC	µS/cm	10990	10250	5990	4570	3304	3480	4326	4868	3128	2429
TDS	mg/L	5875	5437	3183	2366	1759	1846	2298	2421	1642	1288
pH		6.25	6.82	6.81	6.47	6.55	6.63	6.35	6.64	6.19	6.32
Alkalinity	mg/L	1015	872	321	286	237	225	240	281	315	266
Sulphate	mg/L	548	621	296	428	361	247	285	379	166	86
Chloride	mg/L	2372	1948	993	1061	836	692	1038	982	427	524
Nitrate	mg/L	51	42	23	16	13	27	31	36	17	11
TH	mg/L	1801	1568	1022	602	1072	1193	1105	1022	1032	805
DO	mg/L	1.0	0.9	3.7	0.1	4.2	6.1	2.3	1.6	4.4	2.3
COD	mg/L	4.62	5.17	4.95	6.70	3.34	8.02	4.10	3.22	7.65	3.89
BOD	mg/L	1.34	1.82	1.61	2.52	1.21	3.12	1.48	1.10	2.83	1.71
Ca	mg/L	451	384	205	129	253	318	174	149	214	162
Mg	mg/L	164	148	124	68	107	97	163	158	121	96
Na	mg/L	1511	1776	795	594	943	273	787	710	408	262
K	mg/L	216	162	38	32	50	26	89	40	79	28
F	mg/L	1.48	1.21	0.74	0.23	0.82	1.08	1.05	0.42	0.86	1.11
Fe	mg/L	4.31	0.84	1.26	0.58	0.72	1.13	0.86	1.47	0.51	0.63
Cr	mg/L	1.03	0.95	0.52	0.46	0.28	0.39	0.15	0.16	1.64	0.48
Pb	mg/L	0.050	0.021	0.048	0.140	0.070	0.018	0.361	0.174	#0	0.025
Hg	mg/L	0.012	0.14	0.037	0.097	0.080	0.060	0.046	0	0.013	0.160

(#0 - the concentration of the element is below the detectable limit)

Table 4. Analytical results of groundwater samples (December - 2006)

Turbidity	NTU	16.5	10.7	0.7	9.1	8.4	0.6	1.1	0.4	0.2	0.5
EC	µS/cm	9797	9459	5555	4326	8779	3306	4196	4478	3253	2331
TDS	mg/L	6908	6736	3988	3192	6370	1753	2229	2237	1707	1236
Alkalinity	mg/L	592	1360	472	348	988	213	232	258	327	255
Sulphate	mg/L	541	529	411	912	843	234	276	348	172	82
Chloride	mg/L	2871	1931	1307	574	622	657	1006	903	444	503
Nitrate	mg/L	18	46	61	28	25	25	30	33	17	10
TH	mg/L	1760	780	1040	800	1331	1133	1071	940	1073	772
DO	mg/L	5.6	6.8	2.7	2.3	3.2	5.8	2.2	1.4	4.6	2.2
COD	mg/L	3.84	5.61	4.25	7.05	2.35	8.17	3.66	3.28	7.18	4.52
BOD	mg/L	1.27	1.68	1.41	2.80	1.10	3.26	1.17	1.05	2.69	1.86
Ca	mg/L	416	176	248	196	276	302	168	137	222	155
Mg	mg/L	173	82	101	74	156	92	158	145	125	92
Na	mg/L	1425	1675	750	560	890	258	742	670	385	247
K	mg/L	200	150	40	30	46	24	82	37	73	26
F	mg/L	1.16	1.09	0.98	0.89	1.36	1.02	1.01	0.38	0.89	1.06
Fe	mg/L	15.69	1.31	0.37	0.78	6.47	1.07	0.83	1.35	0.53	0.60
Cr	mg/L	1.3	2.15	0.57	1.16	0.22	0.37	0.14	0.14	1.70	0.46
Pb	mg/L	0.115	#0	0.048	0.24	0.13	0.017	0.350	0.160	0.013	0.024
Hg	mg/L	0	0.017	0.003	0.117	0.081	0.057	0.046	0	0.013	0.153

The pairs of parameters like turbidity-alkalinity(0.808), TDS - TH (0.825), EC-TH (0.818) and TH-K (0.883) show significant positive correlations among them. Some of the pairs of parameters like pH-sulphate, TDS-pH, Cl-Mg, nitrate-sulphate etc., have weak positive correlation and some other pairs of parameters like TDS-DO, pH-Cr, BOD-Na, Pb-Ca etc. have

Table 5. Analytical results of groundwater samples (March – 2007)

Parameters	Units	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Turbidity	NTU	11.3	1.9	0.1	2.4	0.2	0.3	0.1	0.3	0.6	0.4
EC	µS/cm	10620	9942	5810	4432	3204	3375	4196	4721	3034	2356
TDS	mg/L	5728	5301	3103	2306	1715	1799	2240	2360	1600	1255
pH		6.43	7.02	7.05	6.67	6.75	6.84	6.55	6.87	6.37	6.51
Alkalinity	mg/L	862	741	272	243	201	191	204	238	267	226
Sulphate	mg/L	695	788	375	543	458	313	361	481	210	109
Chloride	mg/L	2527	2140	1141	1220	961	795	1193	1129	491	602
Nitrate	mg/L	46	38	20	14	11	24	28	32	15	10
TH	mg/L	1584	1379	899.36	529	943	1049	972	899	908	708
DO	mg/L	0.9	0.8	3.5	0.3	4. 3	5.8	2.2	1.5	4.2	2.2
COD	mg/L	4.85	5.42	5.19	7.03	3.50	8.42	4.30	3.38	8.032	4.08
BOD	mg/L	1.43	1.94	1.72	2.64	1.29	3.33	1.58	1.17	3.02	1.82
Ca	mg/L	392	334	178	112	220	276	151	129	186	140
Mg	mg/L	144	130	109	59	94	85	143	139	106	84
Na	mg/L	1692	1989	890	665	1056	305	881	795	456	293
K	mg/L	252	189	44	37	58	30	104	46	92	32
F	mg/L	1.56	1.28	0.78	0.24	0.86	1.14	1.11	0.44	0.91	1.17
Fe	mg/L	4.05	0.79	1.18	0.55	0.68	1.06	0.88	1.38	0.49	0.59
Cr	mg/L	1.06	0.97	0.53	0.47	0.29	0.47	0.15	0.16	1.69	0.49
Pb	mg/L	0.048	0.020	0.046	0.134	0.067	0.017	0.346	0.167	#0	0.024
Hg	mg/L	.0123	0.144	0.038	0.099	0.082	0.061	0.047	0	0.013	0.170

negative correlation. The parameters COD and DO were found to be correlated negatively with most of the other parameters. Negative correlation between a pair of parameters is due to the increase of one parameter while the other decreases. As an example, pure water has higher concentration of DO (10 mg/L) but low TDS (less than 500 mg/L).

It is possible to develop equation of best fit for the data input of electrical conductivity and other parameters by the systematic calculation and interpretation of the correlation coefficients. These equations could be effectively used for the prediction of water quality by making observation on electrical conductivity alone or any one of the other parameters. This enables the monitoring of water quality an easy and quick method (Ibrahim *et al.,* 2006). The correlation study and correlation coefficient values can help in selecting treatments to minimize contaminants in groundwater (Achuthan *et al.,* 2005).

Conclusion

In the present study, the statistical parameters like minimum, maximum, mean, standard deviation and coefficient of correlation of the groundwater characteristics have been evaluated. The correlation analysis of various physico-chemical parameters of groundwater samples revealed that electrical conductivity has more or less correlated with all other parameters and can be used for the estimation of unknown values. This proves to be a rapid method of water quality monitoring.

The significance of the analysis is that in addition to finding correlation among the parameters, it provides a fairly accurate idea about the quality of the groundwater. The statistical data obtained in the present study indicate that the groundwater quality in the study area is poor as it is polluted with high amount of TDS, TH, chloride, alkalinity, iron, chromium and lead. Most of the parameters were either more than permissible limit or excessive limit. Therefore, the groundwater in the study area is not potable. To maintain quality of groundwater, the continuous monitoring of physicochemical parameters should be done. On the basis of the present study, it is recommended that the groundwater in the study area should be suitably treated before it is used for drinking and other domestic purposes.

References

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Table 6. Statistical values of the groundwater samples in the rainy season (September-2006)

Parameters	Units	Min	Max	Average	SD	SE	95 % CL
Turbidity	NTU	0.12	17.31	2.4897	5.3172	1.6814	2.489 ± 3.80
EC	µS/cm	2429	10990	5333.5	2967.7	938.48	5333.5 ± 2120
TDS	mg/L	1288	5875	2811.5	1590.2	502.87	2811.5 ± 1136
pH		6.19	6.82	6.503	0.2241	0.0708	6.503 ± 0.1601
Alkalinity	mg/L	225	1015	405.8	287.14	90.801	405.8 ± 205.21
Sulphate	mg/L	86	621	341.7	163.403	51.672	341.7 ± 116.78
Chloride	mg/L	427	2372	1087.3	613.467	193.99	1087.3 ± 438.4
Nitrate	mg/L	11	51	26.7	13.2753	4.1980	26.7 ± 9.48
TH	mg/L	602	1801	1122.2	344.283	108.87	1122.2 ± 246.0
DO	mg/L	0.1	6.1	2.66	1.8886	0.5973	2.66 ± 1.35
COD	mg/L	3.22	8.02	5.166	1.72882	0.5467	5.166 ± 1.24
BOD	mg/L	1.1	3.12	1.874	0.70424	0.2227	1.874±0.50331
Ca	mg/L	129	451	243.9	107.652	34.043	243.9 ± 76.94
Mg	mg/L	68	164	124.6	32.9923	10.433	124.6 ± 23.58
Na	mg/L	262	1776	805.9	499.974	158.106	805.9 ± 357.32
K	mg/L	26	216	76	64.4032	20.366	76 ± 46.03
F	mg/L	0.23	1.48	0.9	0.37184	0.1176	0.9 ± 0.26
Fe	mg/L	0.51	4.31	1.231	1.1257	0.3559	1.231 ± 0.80
Cr	mg/L	0.15	1.64	0.606	0.46805	0.1480	0.606 ± 0.33
Pb	mg/L	0.018	0.361	0.10078	0.11174	0.0353	0.1008 ± 0.079
Hg	mg/L	0	0.16	0.0645	0.05457	0.01726	0.0645 ± 0.039

Table 7. Statistical values of the groundwater samples in the winter season (December-2006)

Parameters	Units	Min	Max	Average	SD	SE	95%CL
Turbidity	NTU	0.20	16.50	4.82	5.872	1.857	4.82±4.19
EC	µS/cm	2331	9797	5548	2766.8	874.948	5548±1977
TDS	mg/L	1236	6908	3635.6	2237.9	707.699	3635.6±1599
pH		6.07	7.27	6.43	0.367	0.116	6.4292±0.262
Alkalinity	mg/L	213	1360	504.5	381.897	120.766	504.5±272.9
Sulphate	mg/L	82.0	912	434.8	275.211	87.029	434.8±196.68
Chloride	mg/L	444	2871	1081.8	774.764	245.002	1081.8±553.70
Nitrate	mg/L	10.0	61.0	29.30	14.863	4.700	29.3±10.62
TH	mg/L	772	1760	1070	300.334	94.974	1070±214.64
DO	mg/L	1.40	6.80	3.68	1.869	0.591	3.68±1.33
COD	mg/L	2.35	8.17	4.99	1.923	0.608	4.991±1.374
BOD	mg/L	1.05	3.26	1.83	0.804	0.254	1.829±0.574
Ca	mg/L	137.0	416	229.6	84.638	26.765	229.6±60.48
Mg	mg/L	74.0	173	119.8	36.036	11.396	119.8±25.75
Na	mg/L	247	1675	760.2	471.484	149.096	760.2±336.9
K	mg/L	24.0	200	70.80	59.314	18.757	70.8±42.39
F	mg/L	0.38	1.36	0.98	0.253	0.080	0.984±0.180
Fe	mg/L	0.37	15.69	2.90	4.838	1.530	2.9±3.457
Cr	mg/L	0.14	2.15	0.82	0.712	0.225	0.821±0.509
Pb	mg/L	0.00	0.35	0.11	0.1149	0.03634	0.1097±0.082
Hg	mg/L	0.00	0.15	0.05	0.05351	0.01692	0.0487±0.038

Table 8. Statistical values of the groundwater samples in the summer season (March-2007)

Parameters	Units	Min	Max	Average	SD	SE	95% CL
Turbidity	NTU	0.10	11.30	1.76	3.446	1.090	1.76±2.462
EC	µS/cm	2356	10620	5169	2870.29	907.667	5169±2051.3
TDS	mg/L	1255	5728	2740.7	1550.71	490.378	2740.7±1108.2
pH		6.37	7.05	6.71	0.240	0.076	6.706±0.172
Alkalinity	mg/L	191	862	344.50	244.009	77.162	344.5±174.4
Sulphate	mg/L	109	788	433.30	207.458	65.604	433.3±148.26
Chloride	mg/L	491	2527	1219.90	643.857	203.606	1219.9±460.15
Nitrate	mg/L	10.0	46.0	23.80	12.118	3.832	23.8±8.66
TH	mg/L	529.0	1584	987.04	302.829	95.763	987.04±216.42
DO	mg/L	0.30	5.80	2.38	1.807	0.571	2.377±1.291
COD	mg/L	3.38	8.42	5.42	1.816	0.574	5.420±1.298
BOD	mg/L	1.17	3.33	1.99	0.747	0.236	1.994±0.534
Ca	mg/L	112.0	392.0	211.80	93.731	29.640	211.8±66.98
Mg	mg/L	59.00	144	109.30	29.166	9.223	109.3±20.844
Na	mg/L	293.0	1989	902.20	560.138	177.131	902.2±400.31
K	mg/L	30.0	252	88.40	75.328	23.821	88.4±53.83
F	mg/L	0.24	1.56	0.95	0.394	0.124	0.949±0.281
Fe	mg/L	0.49	4.05	1.17	1.054	0.333	1.165±0.753
Cr	mg/L	0.15	1.69	0.63	0.480	0.152	0.628±0.342
Pb	mg/L	0.00	0.35	0.09	0.106	0.033	0.087±0.075
Hg	mg/L	0.00	0.17	0.07	0.057	0.018	0.066±0.041

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Table 9a. Correlation coefficient(r) for different parameters of GW samples (September -2006)

	Turb	EC	TDS	pH	Alk	Sulp	Chlo	Nitrate	TH	DO	COD
Turb	1.000	0.739	0.745	-0.345	0.808	0.559	0.808	0.654	0.668	-0.447	-0.074
EC		1.000	0.999	0.223	0.950	0.859	0.970	0.857	0.818	-0.532	-0.125
TDS			1.000	0.213	0.953	0.851	0.970	0.850	0.825	-0.518	-0.118
pH				1.000	0.005	0.376	0.130	0.143	0.054	0.054	-0.100
Alk					1.000	0.757	0.927	0.787	0.849	-0.494	-0.074
Sulp						1.000	0.886	0.720	0.614	-0.587	-0.156
Chlo							1.000	0.851	0.796	-0.599	-0.215
Nitrate								1.000	0.846	-0.383	-0.144
TH									1.000	-0.077	-0.085
DO										1.000	0.374
COD											1.000

Table 9b. Correlation coefficient(r) for different parameters of GW samples (September -2006)

	BOD	Ca	Mg	Na	K	F	Fe	Cr	Pb	Hg
Turbidity	-0.231	0.677	0.355	0.567	0.793	0.486	0.923	0.335	-0.140	-0.231
EC	-0.308	0.760	0.572	0.909	0.875	0.462	0.693	0.317	-0.130	-0.073
TDS	-0.301	0.773	0.566	0.910	0.882	0.484	0.695	0.325	-0.139	-0.064
pH	-0.121	0.073	-0.002	0.283	-0.193	-0.228	-0.213	-0.376	-0.118	0.186
Alkalinity	-0.231	0.831	0.510	0.858	0.938	0.606	0.706	0.490	-0.284	0.016
Sulphate	-0.310	0.591	0.394	0.895	0.684	0.117	0.470	0.071	0.033	-0.021
Chloride	-0.383	0.742	0.553	0.907	0.881	0.460	0.742	0.185	-0.001	-0.050
Nitrate	-0.307	0.687	0.790	0.731	0.795	0.473	0.741	0.137	0.128	-0.347
TH	-0.240	0.932	0.695	0.772	0.883	0.777	0.719	0.363	-0.200	-0.213
DO	0.418	0.019	-0.231	-0.513	-0.426	0.134	-0.262	0.027	-0.311	-0.214
COD	0.969	0.122	-0.454	-0.329	-0.105	-0.042	-0.179	0.498	-0.382	-0.072
BOD	1.000	-0.015	-0.579	-0.482	-0.268	-0.085	-0.346	0.393	-0.366	0.083
Ca		1.000	0.387	0.692	0.801	0.773	0.659	0.421	-0.436	-0.038
Mg			1.000	0.592	0.656	0.439	0.521	0.088	0.359	-0.474
Na				1.000	0.839	0.413	0.496	0.211	-0.024	0.038
K					1.000	0.675	0.700	0.506	-0.073	-0.129
F						1.000	0.491	0.338	-0.251	0.130
Fe							1.000	0.178	-0.080	-0.451
Cr								1.000	-0.579	-0.134
Pb									1.000	-0.228
Hg										1.000

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Table 10a. Correlation coefficient(r) for different parameters of GW samples (December -2006)

	Turb	EC	TDS	pH	Alk	Sulp	Chlo	Nitrate	TH	DO	COD
Turb	1.000	0.839	0.858	0.216	0.618	0.685	0.719	-0.059	0.494	0.465	-0.161
EC		1.000	0.990	0.284	0.838	0.591	0.758	0.271	0.524	0.490	-0.429
TDS			1.000	0.346	0.850	0.652	0.725	0.290	0.488	0.477	-0.389
pH				1.000	0.175	0.195	0.458	0.683	0.132	0.229	0.140
Alk					1.000	0.498	0.443	0.343	0.067	0.530	-0.236
Sulp						1.000	0.166	0.210	0.171	-0.010	-0.174
Chlo							1.000	0.230	0.557	0.512	-0.268
Nitrate								1.000	-0.234	0.007	-0.118
TH									1.000	0.311	-0.313
DO										1.000	0.439
COD											1.000

Table 10b. Correlation coefficient(r) for different parameters of GW samples (December -2006)

	BOD	Ca	Mg	Na	K	F	Fe	Cr	Pb	Hg
Turbidity	-0.197	0.559	0.194	0.776	0.742	0.462	0.772	0.496	0.065	-0.090
EC	-0.503	0.499	0.348	0.922	0.740	0.476	0.694	0.376	-0.061	-0.395
TDS	-0.449	0.508	0.261	0.896	0.695	0.533	0.671	0.400	-0.081	-0.316
pH	0.020	0.351	-0.244	0.323	0.254	0.091	0.098	0.383	-0.238	-0.447
Alkalinity	-0.316	0.124	-0.040	0.804	0.511	0.497	0.263	0.515	-0.289	-0.187
Sulphate	-0.126	0.233	0.014	0.433	0.123	0.282	0.332	0.143	0.330	0.108
Chloride	-0.422	0.553	0.329	0.844	0.902	0.219	0.725	0.412	-0.062	-0.552
Nitrate	-0.263	-0.153	-0.252	0.372	-0.004	-0.134	-0.293	0.064	-0.033	-0.482
TH	-0.275	0.890	0.753	0.324	0.539	0.399	0.889	-0.065	0.066	-0.397
DO	0.326	0.531	-0.130	0.496	0.625	0.433	0.335	0.674	-0.564	-0.347
COD	0.964	0.025	-0.671	-0.361	-0.171	-0.103	-0.384	0.444	-0.345	0.121
BOD	1.000	0.061	-0.645	-0.518	-0.327	-0.028	-0.362	0.288	-0.319	0.305
Ca		1.000	0.370	0.283	0.484	0.518	0.811	0.123	-0.191	-0.276
Mg			1.000	0.250	0.393	0.067	0.636	-0.317	0.409	-0.411
Na				1.000	0.843	0.293	0.542	0.512	-0.004	-0.486
K					1.000	0.305	0.703	0.606	-0.048	-0.508
F						1.000	0.409	0.146	-0.153	0.287
Fe							1.000	0.123	0.043	-0.247
Cr								1.000	-0.415	-0.256
Pb									1.000	0.113
Hg										1.000

Table 11a. Correlation coefficient(r) for different parameters of GW samples (March -2007)

	Turb	EC	TDS	pH	Alk	Sulp	Chlo	Nitrate	TH	DO	COD
Turb	1.000	0.735	0.742	-0.373	0.811	0.560	0.782	0.648	0.661	-0.437	-0.032
EC		1.000	0.999	0.204	0.949	0.860	0.968	0.857	0.817	-0.522	-0.125
TDS			1.000	0.191	0.953	0.851	0.968	0.850	0.825	-0.509	-0.118
pH				1.000	-0.024	0.353	0.135	0.122	0.031	0.038	-0.112
Alk					1.000	0.757	0.914	0.791	0.849	-0.488	-0.074
Sulp						1.000	0.897	0.715	0.613	-0.639	-0.157
Chlo							1.000	0.850	0.781	-0.620	-0.225
Nitrate								1.000	0.847	-0.348	-0.143
TH									1.000	-0.097	-0.085
DO										1.000	0.561
COD											1.000

Table 11b. Correlation coefficient(r) for different parameters of GW samples (March -2007)

	BOD	Ca	Mg	Na	K	F	Fe	Cr	Pb	Hg
Turbidity	-0.191	0.678	0.332	0.560	0.795	0.474	0.908	0.364	-0.156	-0.227
EC	-0.307	0.760	0.572	0.910	0.874	0.461	0.690	0.305	-0.130	-0.079
TDS	-0.300	0.773	0.565	0.910	0.882	0.484	0.694	0.314	-0.139	-0.071
pH	-0.131	0.041	0.006	0.256	-0.220	-0.253	-0.221	-0.394	-0.097	0.147
Alkalinity	-0.229	0.831	0.509	0.858	0.937	0.606	0.704	0.480	-0.283	0.014
Sulphate	-0.315	0.591	0.393	0.895	0.683	0.116	0.469	0.059	0.033	-0.036
Chloride	-0.394	0.725	0.551	0.912	0.867	0.435	0.725	0.147	0.022	-0.052
Nitrate	-0.300	0.688	0.790	0.730	0.800	0.485	0.742	0.141	0.130	-0.336
TH	-0.231	0.932	0.695	0.772	0.883	0.777	0.720	0.368	-0.200	-0.217
DO	0.605	-0.014	-0.220	-0.591	-0.431	0.136	-0.251	0.134	-0.300	-0.246
COD	0.969	0.122	-0.456	-0.330	-0.104	-0.038	-0.182	0.529	-0.383	-0.083
BOD	1.000	-0.006	-0.572	-0.482	-0.263	-0.069	-0.347	0.430	-0.371	0.070
Ca		1.000	0.387	0.693	0.801	0.771	0.655	0.435	-0.436	-0.045
Mg			1.000	0.592	0.654	0.439	0.531	0.072	0.357	-0.471
Na				1.000	0.839	0.413	0.497	0.192	-0.023	0.028
K					1.000	0.676	0.703	0.495	-0.072	-0.133
F						1.000	0.493	0.350	-0.250	0.136
Fe							1.000	0.174	-0.061	-0.451
Cr								1.000	-0.593	-0.139
Pb									1.000	-0.231
Hg										1.000

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