Multivariate Analysis of Ground Water Quality of Makhmor Plain/ North Iraq[1]

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Abstract

The research aimed to investigate the relationships among ground water quality in Makhmor plain and to classify the wells according to their water quality. Thirty five deep wells and 28 shallow wells lies in an area of 2700 km^2 in Makhmor plain were included in the study. Ground water quality parameters were represented by pH, Ca^{2+}, Mg^{2+}, Na^{+}, Boron, K^{+}, Cl^{-}, SO_4^{2-}, CO_3^{-} + HCO_3^{-}, NO_3^{-}. Factor analysis extracted two factors from the water quality parameters of the deep wells. Factor I accounts for more than 50% of the variance among water quality. Cations including Boron, Na, Mg and K with anions including Cl^{-}, SO_4^{2-} and NO_3^{-} were loaded significantly on it. It represents the variation in the geological formation of study area, inconsistent distribution of agricultural activities and wastewater. For shallow wells, factor analysis extracts three factors. Factor I accounts for more than the 50% of the variance in the water quality. Six of water quality parameters were loaded on factor I. These parameters included pH and cations represented by boron, $Na^{+}$and Mg^{2+}in addition to Cl^{-} and SO_4^{2-} as anions. Cluster analysis had divided the deep wells into three groups with 50% similarity. Cluster I includes two wells with the worst water quality, while cluster II had the lowest concentrations of cations and anions in the area and includes 8 wells. Cluster III shows mid concentrations between I and II clusters. For shallow wells, three clusters were obtained with 37.5% similarity. Cluster I includes 7 wells with worst water quality, while cluster II exhibited the lowest concentrations of ions. These results obtained from the multivariate analysis can be very useful for the farmers and the users of ground water in this area.

[1] For the Abstract in Arabic see pages (73-74).

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Introduction

Classification of wells according to their water quality can provide useful information for the users. Complex processescontrol the distribution of water quality parameters in groundwater, which typically has a large range of chemical composition (Appelo and Postma, 1993). The ground water quality depends not only on natural factors such as the lithology of the aquifer, the quality of recharge water and the type of interaction between water and aquifer, but also on human activities, which can alter these groundwater systems either by polluting them or by changing the hydrological cycle (Helena et al., 2000). Sophisticated data analysis techniques are required to interpret groundwater quality effectively.

The univariate statistical analysis has been generally used to treat ground water quality. The simplicity of the univariate statistical analysis is obvious and likewise the fallacy of reductionism could be apparent (Ashley and Lloyd, 1978). In order to avoid this problem, multivariate analysis was used to explain the correlation amongst a large number of variables in terms of small number of factors without losing much information (Jackson, 1991; Meglen, 1992).

The intention underlying the use of multivariate analysis is to achieve great efficiency of data compression from the original data, and to gain some information useful in the interpretation of the environmental geochemical origin. This method can also help to indicate natural association between variables (Wenning and Erickson, 1994). Multivariate treatment of environmental data is widely successfully used to interpret the relationship among the variables, so that the environmental systems could be better managed (Andrade et al., 1992; Aruga et al., 1995; Vega et al., 1998; Tao, 1998; Gangopadhyay et al., 2001; Liu et al., 2003).

Shihab (1993) conducted multivariate analysis of Mosul dam lake to put a sampling program. Al-Rawi and Shihab (2003) used factor analysis as a management tool for Tigris river water quality within Mosul city. Shihab and Hashim (2006) used cluster analysis to classify 66 wells within and around Mosul city. Shihab (2007) also applied factor analysis on a stretch of Tigris river water quality south Mosul city.

Makhmor plain is an important area in Northern Iraq, well-known with agricultural activities. Irrigation with ground water in the plain had get more attention in the last years. This plain lies south east Erbil city. It is surrounded by the upper Zab river from the north, lower Zab river from the south, Tigris river from the west and Qara Chauq mountain from the east (Fig. 1). It has an area of 2700 km^2.

Many studies were conducted on the water quality of Makhmor plain. Parsons Company (1955) found that ground water of the plain has bad quality. In 1979, Ayob et al. indicate that sulfate is a principal component in the groundwater of Makhmor area due to high concentration in the soil and the rocks.

This research aimed to apply multivariate statistical analysis on groundwater quality of Makhmor plain by using factor analysis to indicate natural association between variables. Also the research tries to classify the wells of the plain using cluster analysis into groups according to their water quality.

Materials and Methods

The study included 35 deep wells and 28 shallow wells in Makhmor plain. Water quality parameters included in this study were pH, Ca^{2+}, Mg^{2+}, Na^+, Boron, K^+, Cl^-, SO_4^{2-}, CO_3^-+ HCO_3^-, NO_3^-. The tests were conducted in the laboratories of Water and Soil Company/ Ministry of Irrigation according to the Standard Methods for the examination of water and wastewater.

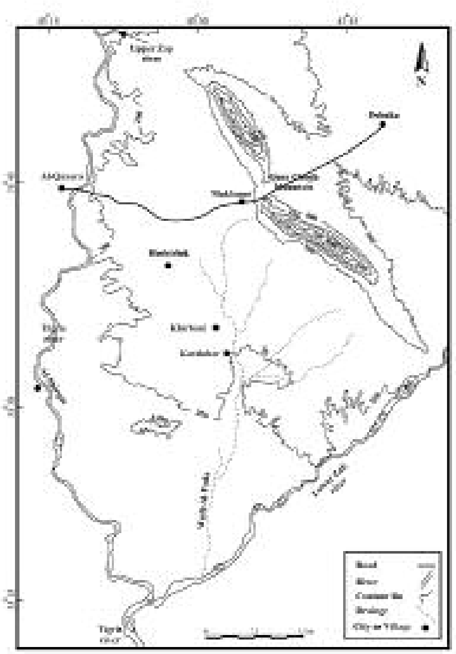

Fig.1: Location map for Makhmor plain.

Figure (1) Location map for Makhmor plain.

Statistical analysis includes descriptive statistics of water quality parameters presented by mean, standard deviation (SD), and range. Pearson correlation was conducted to find the bivariate relationships between water quality parameters. Factor analysis with varimax rotation was conducted on standardized data (Kaiser, 1958; Davis, 1973), and factor loading of the variables were obtained. Hierarchical cluster analysis was used to group each of the deep and shallow wells. Complete linkage was used depending on Pearson distance.

Results and Discussion

Table (1) shows a descriptive statistics for the water quality of the deep wells in Makhmor plain. The results showed a wide variation in anions, cations, TDS, electrical conductivity and total hardness among the deep wells. This reflects the variation in the geological formations of the study area since water is a good solvent and dissolved the substances as it moves through rocks and subsurface soil.

Table (1) Descriptive statistics for the deep wells in Makhmor area.

Symbols	Parameters	Mean	SD	Min.	Max.
pH	pH	7.86	0.23	7.5	8.35
Ca^{++}	Calcium (mg/l)	474.43	137.63	106	676
Mg^{++}	Magnesium (mg/l)	248.19	120.96	35.5	574
Na^{+}	Sodium (mg/l)	701.54	641.09	43	3160
K^{+}	Potassium (mg/l)	5.02	2.81	1.8	16.7
Cl^{-}	Chloride (mg/l)	574.25	577.99	47.2	2697
$SO_4^{=}$	Sulfate (mg/l)	2423.37	1078.1	252	5388
$CO_3^{=}$ + HCO_3^{-}	Carbonate & Bicarbonate (mg/l)	168.47	31.84	115	231.8
NO_3^{-}	Nitrate (mg/l)	236.67	196.75	21.6	892.0
Boron	Boron (mg/l)	1.10	0.68	0.04	3.34

Table (2) shows the water quality characteristics of the shallow wells within the study area. More variation in water quality was recorded among the shallow wells as indicated by their standard deviation in comparison with the deep wells. This is probably due to the higher effect of human activities and rainfall on the shallow wells as it is nearer to earth surface.

Table (3) shows the correlation coefficients between water quality parameters of the deep wells of the study area. The table shows that the parameters Ca, Mg, Na, Cl, SO_4, NO_3 and Boron were closely correlated with significance. This indicated that these parameters have similar hydrochemical characteristics in the study area. pH shows inverse relationships with the anions and cations, as pH decrease more rock dissolution occurs. Carbonate + Bicarbonate have significant positive correlation with calcium only. This can be attributed to the presence of carbonate mostly with calcium as $CaCO_3$. For shallow wells, significant positive correlations were recorded between the parameters Ca, Mg, Na, Cl, SO_4 and Boron.

Table (2) Descriptive statistics for the shallow wells in Makhmor area.

Symbols	Parameters	Mean	SD	Min.	Max.
pH	pH	7.89	0.22	7.49	8.35
Ca^{++}	Calcium (mg/l)	501.5	114.1	241	652
Mg^{++}	Magnesium (mg/l)	209.23	112.4	37.4	504
Na^{+}	Sodium (mg/l)	504.82	379.2	41	1375
K^{+}	Potassium (mg/l)	5.53	3.35	2	17.3
Cl^{-}	Chloride (mg/l)	431.96	426.1	47	1646
$SO_4^{=}$	Sulfate (mg/l)	2113.32	743.2	558	3643
$CO_3^{=}$ + HCO_3^{-}	Carbonate & Bicarbonate (mg/l)	204.06	49.99	96	302.2
NO_3^{-}	Nitrate (mg/l)	243.04	181.7	16.5	937
Boron	Boron (mg/l)	0.92	0.46	0.22	1.95

Table (3) Pearson correlation for ground water quality of deep and shallow wells of Makhmor plain.

	pH	Ca	Mg	Na	K	Cl	SO_4	CO_3	NO_3	Bo
pH	1	-0.26	-0.37*	-0.39*	0.04	-0.43*	-0.39*	0.20	-0.21	-0.41*
Ca	-0.65*	1	0.51*	0.34*	0.41*	0.37*	0.63*	-0.35*	0.44*	0.52*
Mg	-0.51*	0.56*	1	0.87*	0.33	0.87*	0.92*	-0.03	0.56*	0.92*
Na	-0.56*	0.50*	0.86*	1	0.37*	0.95*	0.90*	0.13	0.71*	0.97*
K	-0.22	0.43*	0.28	0.13	1	0.33	0.38*	0.004	0.56*	0.40*
Cl	-0.67*	0.53*	0.79*	0.93*	0.11	1	0.83*	0.12	0.61*	0.95*
SO_4	-0.53*	0.73*	0.89*	0.85*	0.32	0.72*	1	-0.10	0.70*	0.95*
CO_3	0.30	0.12	0.14	-0.14	0.37	-0.20	0.05	1	0.05	0.04
NO_3	-0.10	0.27	0.56*	0.39*	0.12	0.34	0.35	0.31	1	0.70*
Bo	-0.61*	0.62*	0.92*	0.98*	0.23	0.93*	0.90*	-0.04	0.46*	1

*** Significant correlation at $p<0.05$**
The correlation of deep wells above the diagonal and the lower for shallow wells

Factor Analysis

Table (4) shows that factor analysis extracts two factors according to eigenvalues (≥1) for the deep wells. The first factor accounts for almost half the variability in water quality, whereas the second factor assists in describing water quality information of the deep wells within 16.64%.

Cations including Boron, Na, Mg and K with anions including Cl, SO_4 and NO_3 were loaded significantly on factor I. This indicated more variation in these parameters among the deep wells than the parameters loaded on factor II. This appears that this factor reflects the variations in the geological formations of the study area, inconsistent distribution of agricultural activities and wastewater effect on some of the deep wells.

Calcium and CO_3 + HCO_3 show lesser variations among the deep wells within Makhmor area as they were loaded on factor II. This is probably due to the abundance of calcite, dolomite, gypsum and anhydrite rocks in the geological formation of the area. Additionally, carbon dioxide dissolved in surface rainwater forming carbonic acid which dissolved calcite rocks.

Table (4) Factor analysis for water quality of the deep and shallow wells of Makhmor area.

Parameters	Deep wells		Shallow wells		
	I	II	I	II	III
pH	-0.35	-0.44	**-0.62**	-0.40	0.48
Ca^{++}	0.43	**0.69**	0.57	**0.66**	-0.06
Mg^{++}	**0.89**	0.23	**0.90**	0.19	0.26
Na^{+}	**0.97**	0.02	**0.97**	0.03	-0.02
K^{+}	**0.47**	0.11	0.06	**0.87**	0.20
Cl^{-}	**0.94**	0.05	**0.93**	0.05	-0.15
$SO_4^{=}$	**0.91**	0.33	**0.85**	0.34	0.07
$CO_3^{=} + HCO_3^{-}$	0.21	**-0.88**	-0.16	0.38	**0.81**
NO_3^{-}	**0.77**	0.10	0.51	-0.08	**0.68**
Boron	**0.97**	0.17	**0.98**	0.16	0.05
Eigenvalues	5.564	1.664	5.287	1.676	1.489
% Variance	55.644	16.643	52.868	16.762	14.893
% Cumulative	55.644	72.286	52.868	69.630	84.523

Radius of equilibrium for deep well = 0.447 and for shallow wells = 0.548

Figure (2) indicates a strong relationship among the cations and anions except Ca, CO_3 + HCO_3. pH showed inverse relationship with anions and cations while CO_3 + HCO_3 has no relation as it is perpendicular to them.

For shallow wells, factor analysis extracts three factors from the water quality data of the shallow wells with eigen values of ≥1. The first factor accounts for more than the half of the variance in the water quality among the shallow wells. The other two factors assist in describing water quality variation by 16.76% for factor II and 14.89% for factor III.

Six of water quality parameters were loaded on factor I. These parameters included pH and cations represented by boron, Na and Mg in addition to Cl and SO_4 as anions. This factor represents the variation in ground water quality due to the variation in the geological formation of the study area and the inconsistent distribution of rocks rich with Mg, Cl and SO_4; while boron varied with the type of agricultural activities and type of plants.

Calcium and potassium were loaded on factor II with lesser percentage of variation among the wells. This may be due to the high stability of potassium (Davis and Dewest, 1966). As in the deep wells, calcium was loaded on the second factor due to the presence of calcium in most of the rocks of the study area.

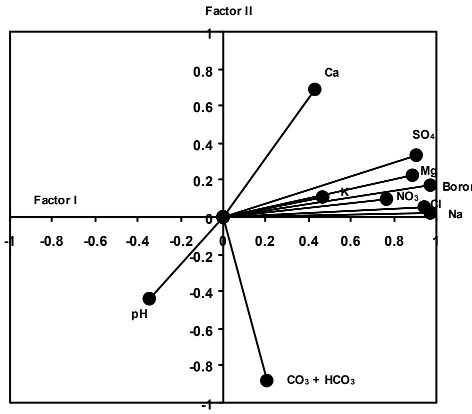

Figure (2) Parameters loaded on factor I versus factor II parameters.

Factor III was loaded with nitrate and carbonate + bicarbonate. It represents the variations in using the nitrogenous fertilizers in the area, in addition to that of wastewater.

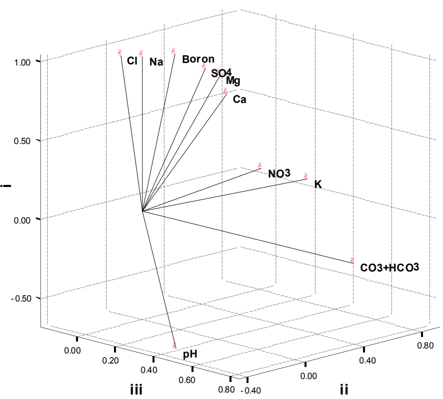

Figure (3) Factor loading for shallow wells.

Figure (3) shows strong relationships among water quality parameters of the shallow wells Cl, Na, Boron, SO_4, Mg and Ca. On the other hand, those parameters exhibited strong inverse correlation with pH as it formed about 180 degree angle with them, while those parameters exhibited weak relationship with NO_3, K and CO_3 + HCO_3 since about 90 degree angle was formed between them.

Cluster Analysis

Cluster analysis was used to combine water quality parameters into homogenous groups. It is also possible to evaluate whether water quality samples at various locations can be combined into homogenous regions.

Figure (4) shows the results of cluster analysis for water quality of the deep wells of Makhmor area. Three clusters were obtained from this analysis at 50% similarity level. Cluster I had the largest number of wells of 25 with 71.4%. It includes two sub-clusters. Cluster II includes 8 wells (No. 6, 8, 9, 24, 26, 27, 29 and 32) with 22.9% of the studied wells. It includes two sub-clusters. The smallest cluster III includes two wells only (No. 16 and 17). It represents 5.7% of the deep wells.

Table (5) shows that the water quality of the wells of cluster II recorded the lowest mean concentrations of cations, anions, TDS, TH and conductivity except for carbonate + bicarbonate, while the highest concentration of these parameters was recorded in cluster III wells. On the other hand, cluster I wells recorded intermediate mean concentrations between cluster II and III, with a lowest one for carbonate + bicarbonate. The distribution of deep wells and the clusters are shown in figure (5).

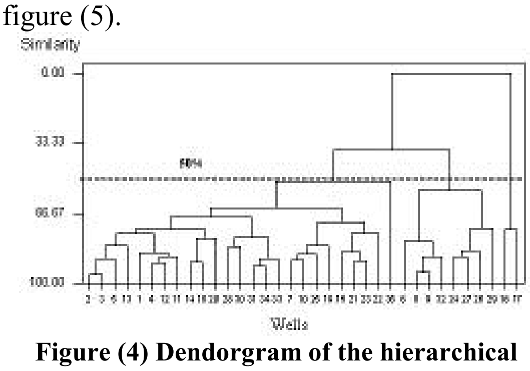

Figure (4) Dendorgram of the hierarchical cluster analysis of the groundwater quality of the deep wells in Makhmor plain using complete linkage method.

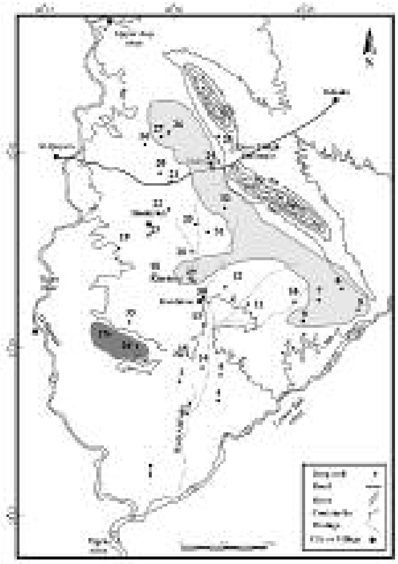

Figure (5) Deep wells in Makhmor plain with their classification.

Table (5) Water quality of the cluster of the deep wells.

Parameters	Cluster	No.	Mean	SD	Min.	Max.
pH	I	25	7.82	0.21	7.5	8.24
	II	8	8.06	0.18	7.85	8.35
	III	2	7.63	0.07	7.58	7.68
TDS	I	25	5601.96	1410.57	3015	7830
	II	8	2546.25	1548.47	500	4345
	III	2	**13302.5**	1120.76	12510	14095
EC	I	25	5764.4	1409.25	3050	7800
	II	8	2725.0	1587.9	750	4600
	III	2	**15750.0**	353.55	15500	16000
TH	I	25	2369.48	403.69	1479	3119
	II	8	1347.25	748.66	433	2302
	III	2	**3597.0**	244.66	3424	3770
Ca^{++}	I	25	512.48	80.52	370	676
	II	8	335.63	201.86	106	602
	III	2	**554.0**	14.14	544	564
Mg^{++}	I	25	264.84	82.85	106	426
	II	8	123.69	66.76	35.5	204
	III	2	**538.0**	50.91	502	574
Na^{+}	I	25	686.96	278.08	183	1198
	II	8	195.13	162.79	43	522
	III	2	**2909.5**	354.26	2659	3160
K^{+}	I	25	5.15	2.69	3.1	16.7
	II	8	3.90	2.7	1.8	10
	III	2	**7.90**	3.96	5.1	10.7
Cl^{-}	I	25	552.60	313.29	108	1094
	II	8	158.98	103.6	47.2	301
	III	2	**2506.0**	270.11	2315	2697
$SO_4^{=}$	I	25	2589.44	512.88	1490	3463
	II	8	1189.88	754.32	252	2084
	III	2	**5281.5**	150.61	5175	5388
$CO_3^{=}$ + HCO_3^{-}	I	25	155.09	25.01	115	201
	II	8	201.05	18.38	174	224.4
	III	2	**205.40**	37.34	179	231.8
NO_3^{-}	I	25	231.32	152.91	44	554
	II	8	122.56	98.21	21.6	318
	III	2	**760.00**	186.68	628	892
Boron	I	25	1.12	0.3	0.54	1.56
	II	8	0.47	0.34	0.04	0.87
	III	2	**3.28**	0.08	3.23	3.34

Shallow wells are classified into three clusters at 37.5% similarity (Figure 6). Cluster I includes seven wells (No. 1, 2, 3, 4, 9, 10 and 12), with 25%. It has two sub-clusters, with the worst water quality as it had the highest concentrations of cations, anions, TDS, TH and conductivity except potassium and carbonate + bicarbonate (table 6). Cluster II includes eight wells (No. 5, 13, 14, 15, 17, 24, 25 and 26) with 28.6%. It has the lowest concentration of cations, anions, TDS, TH and conductivity among the shallow wells.

The largest number of shallow wells was included in Cluster III (No. 6, 7, 8, 11, 16, 18-23, 27 and 28) with 13 wells which represented 46.4%. It has intermediate concentration of cations, anions, TDS, TH and conductivity between cluster I and II except for potassium and carbonate + bicarbonate which exhibited the highest concentrations (table 6).

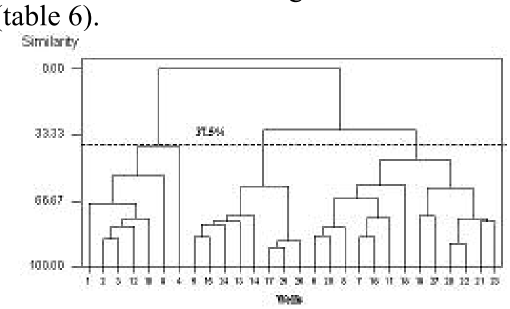

Figure (6) Dendorgram of the hierarchical cluster analysis of the groundwater quality of the shallow wells in Makhmor plain using complete linkage method.

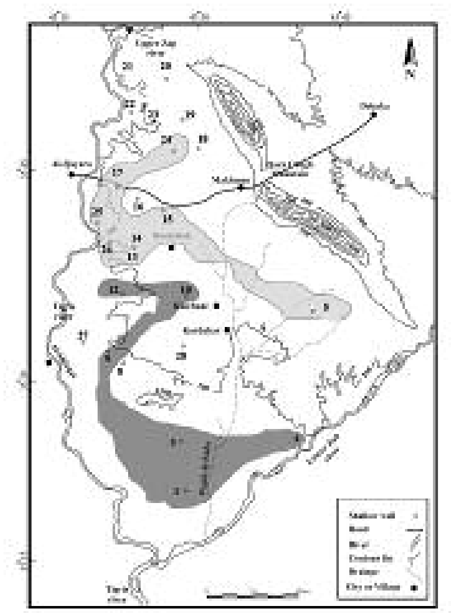

Fig.7: Shallow wells in Makhmor plain with their classification

Figure (7) Shallow wells in Makhmor plain with their classification.

Table (6) Water quality of the cluster of the shallow wells.

Parameters	Cluster	No.	Mean	SD	Min.	Max.
pH	I	7	7.62	0.1	7.49	7.75
	II	8	7.93	0.13	7.68	8.1
	III	13	**8.00**	0.19	7.79	8.35
TDS	I	7	**7792.14**	1321.15	5915	9515
	II	8	2806.38	1080.95	1300	4010
	III	13	4291.15	815.55	2730	5470
EC	I	7	**7857.14**	1146.16	6250	9600
	II	8	2808.75	981.07	1600	4050
	III	13	4392.31	897.88	3100	5950
TH	I	7	**2928.57**	381.05	2395	3492
	II	8	1437.00	457.25	846	2105
	III	13	2091.08	324.19	1293	2360
Ca^{++}	I	7	**589.71**	45.89	524	652
	II	8	417.38	128.29	241	626
	III	13	505.77	96.71	325	638
Mg^{++}	I	7	**353.86**	87.86	247	504
	II	8	95.93	49.91	37.4	207
	III	13	201.08	47.77	117	259
Na^{+}	I	7	**1052**	214.79	764	1375
	II	8	197	154.71	41	432
	III	13	399.62	191.73	225	722
K^{+}	I	7	5.77	1.31	4.2	8.3
	II	8	2.89	0.76	2	4
	III	13	**7.02**	4.13	3.3	17.3
Cl^{-}	I	7	**1059.57**	293.32	709	1646
	II	8	135.88	152.49	47	508
	III	13	276.23	193.41	86	774
$SO_4^{=}$	I	7	**2964.86**	417.47	2531	3643
	II	8	1409.25	582.26	558	2221
	III	13	2088.08	451.46	1362	2909
$CO_3^{=}$ + HCO_3^{-}	I	7	179.46	57.42	96	283
	II	8	166.85	22.69	142.8	204
	III	13	**240.22**	31.33	188.6	302.2
NO_3^{-}	I	7	**341.51**	281.5	109.6	937
	II	8	110.99	44.18	67	185
	III	13	271.27	124.15	16.5	504
Boron	I	7	**1.58**	0.25	1.23	1.95
	II	8	0.49	0.21	0.22	0.75
	III	13	0.83	0.19	0.55	1.16

Conclusions

1. Deep ground water quality of Makhmor plain has significant variation water quality.
2. Geological formation of the area was the more contributors to water quality variations, then human activities represented by fertilizers and wastewater especially in deep wells.
3. Shallow wells were more sensitive to water quality variations as it is nearer to the ground surface.
4. Valuable results can be obtained from cluster analysis in classifying the wells into groups.
5. Deep wells in Makhmor area exhibited lesser variation in calcium and carbonate ions.
6. Shallow wells exhibited lesser variation in potassium and nitrate.

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Received, 21-4-2009.