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STATISTICAL ANALYSIS OF GROUNDWATER QUALITY PARAMETERS IN SELECTED SITES AT NINAVAH GOVERNORATE/ IRAQ

Abdulmuhsin S. Shihab[1], Waleed M.Sh. Al-Abidrabah[2], Ahmad Kh. Ibrahim[3]

[1]Environment & Pollution, Control Researches Centre/ Mosul Univ., Iraq
[2, 3]Department. of Environmental Engineering, Tikrit University, Iraq

ABSTRACT

Groundwater is considered one of the important water resources in the world . Due to rain shortage and the decrease of Tigris river discharges in the last years, wells excavation and groundwater use for different purposes had been increased without any planning. Therefore, it is necessary to conduct the studies about groundwater quality in Ninavah governorate and define its suitability uses. Additionally, it is very useful to define the direction of groundwater quality improvement in the area and to identify the levels of some trace elements in it. Twenty seven deep wells recently excavated were selected in the study area located south east Mosul city with an area of about 1500km^2. These wells were located in rural and urban areas of various activities: agricultural, industrial and residential. Water sample were collected each two months starting at December 2008 till June 2009. Physical tests were conducted including total dissolved solid, electrical conductivity and turbidity, as well chemical tests, which include pH, dissolved oxygen, total hardness, positive ions: calcium, magnesium, sodium, potassium, and negative ions: sulfates, nitrates, phosphate, chlorides, in addition to some of trace elements: lead, cadmium, zinc and copper using standard methods for water examination. Water quality data were statistically analyzed and the results of Pearson correlation coefficient showed many significant relationships between water quality parameters. Factor analysis extracted five factors which represented 69% of the variation in groundwater quality among the wells of the study area. Cluster analysis classified the wells into four clusters at 50% similarity.

Keywords: Groundwater, Water Quality, Ninavah Governorate, Factor Analysis.

INTRODUCTION

Groundwater resources in Iraq gets its importance as most of the sources of surface water come from outside Iraqi border. Therefore, studies must be done on the quality and distribution of this resource to determine its suitability for use and to protect it from pollution. The classification of wells according to its water quality to establish its suitable use can provide useful information to employers. Groundwater wells have different water quality, as many parameters contribute in determining its water quality type (Appelo and Postma, 1993). The quality of groundwater is not determined by the nature of the site only, since it may affected by human activities with pollutants which reach it and the variation in the hydrological cycle (Helena et al., 2000). The ground water quality data need complicated analysis to interpreted it.

Generally, the analysis of water quality results were conducted on each parameter alone to avoid the interactions, complication and for its simplicity (Lloyd, 1978). On the other hand, the use of multivariate analysis of water quality parameters all together may produce a comprehensive image on the groundwater quality of the studied area with all the interrelationships or correlations (Jackson, 1991; Meglen, 1992).

Multivariate methods has high efficiency in the analysis as it compact the raw data and give useful information for detecting the geochemical sources affecting on groundwater quality. Also this method may help in detecting the natural relationships among the quality parameters (Wenning and Erickson, 1994). Multivariate analysis of environmental issues was used successfully in the interpretation of the relationships among the variables which can be used in the management of the environmental systems (Andrade et al., 1992; Aruga et al., 1995; Vega et al., 1998; Tao, 1998; Gangopadhyay et al., 2001; Liu et al., 2003).

Many studies were conducted in Mosul city on water quality using multivariate analysis. Shihab (1993) conducted multivariate analysis on Mosul dam lake water quality data to set a sampling program for the lake. Al-Rawi and Shihab (2005) used multivariate analysis as a tool for the management of Tigris river water quality within Mosul city. Shihab and Hashim (2006) used cluster analysis to classify 66 wells in Ninavah governorate/ Iraq according to their water quality. Shihab (2007) conducted factor analysis on Tigris river water quality parameters to find the relationships among them and their variations. Additionally, Shihab and Abdul-Baqi (2011) analyzed the groundwater quality parameters of Makhmor area/ Northern Iraq using factor and cluster analysis, also they draw a classification map for groundwater quality of the area depending on the results of cluster analysis.

MATERIALS AND METHODS

Study site

The study area rests in Ninavah Governorate, Northern Iraq with an area of 1500 squared kilometers. It included the South Western part of Mosul city within the residential area to the North direction and the area lied between Tigris river from the east and Mosul-Baghdad road from the west, till Al-Qayara intersection in the South, which included many valleys, hills and agricultural area. The study area also included the zone lied to the west of Tigris river till Al-Hamdaniya township; the upper Zab in the south and Mosul-Erbil road to the north as shown in Figs (1and 2). The studied wells were selected to cover the study area within different land use and have not been studied before. The number of studied wells reach 27 deep wells with a range of (27-95) meter depth. Also some of them were newly drilled (table 1).

Table (1): Sites and depths of the studied wells

No.	Site	Depth (m)	No.	Site	Depth (m)
1	Upper Bjwania	30	15	Al-Arej/ Abid	66
2	Al-Shak	30	16	Al-Wahid Ahad M.	75
3	Lower Bjwania	35	17	Al-Akhawain M.	45
4	Snanek	32	18	Al-Mulawatha	80
5	Ain Naser	36	19	Al-Mahmod M.	46
6	Tal Teeba	58	20	Abo-Auob M.	63
7	Al-Athba Mosque	50	21	Safi M.	84
8	Al-Athba Younis	40	22	Talha M.	65
9	Al-Athba Abid	51	23	Al-Muo'min M.	45
10	Al-Jbori Station	86	24	Al-Tawajna	75
11	Al-Sajer Station	80	25	Al-Msherfa	27
12	Al-Salam/ Kamel	95	26	Al-Adla	66
13	Al-Salam/ Jasim	80	27	Ibrahim Al-Khalel	50
14	Al-Arej/ Dawood	39			

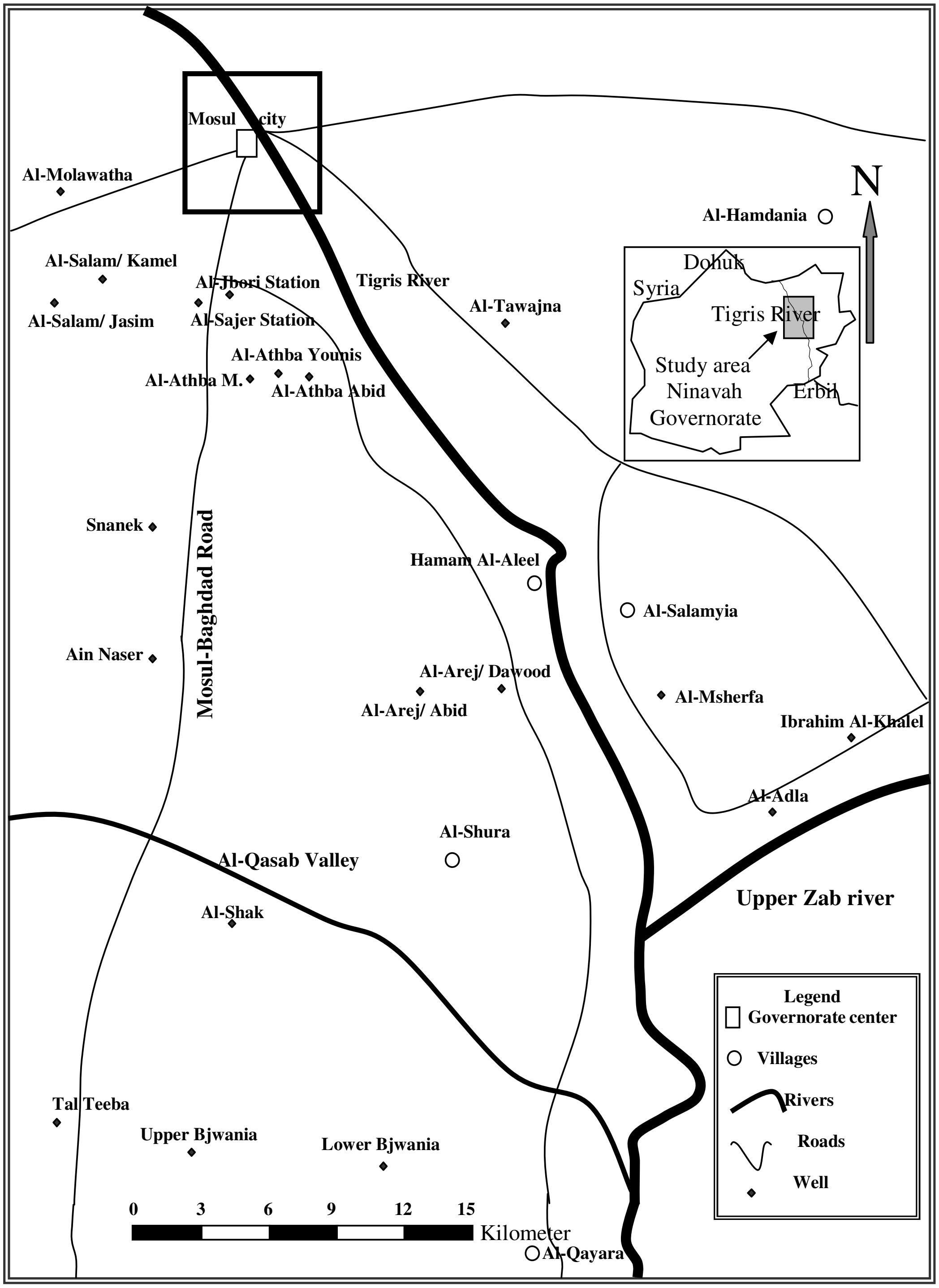

Figure 1: Map of the studied wells area (Mosul area bounded with was enlarged in the figure 2)

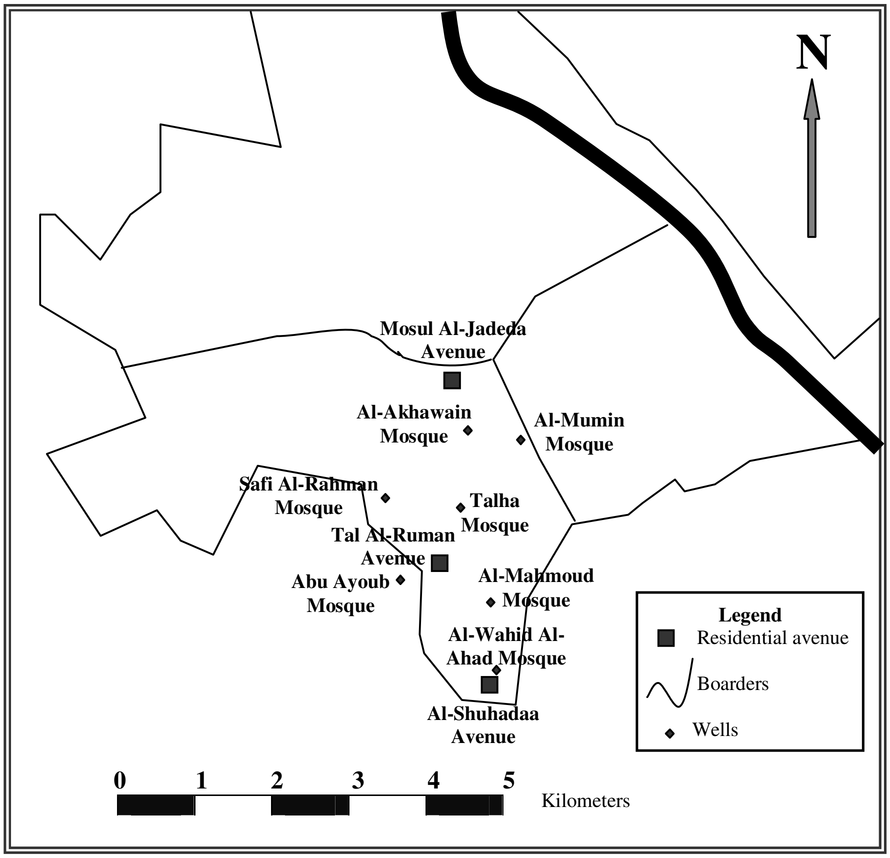

Figure 2: The part of Mosul city included in the study area with the sites of the wells

Geology of the Study Area

The structural layers of the study area consists from Al-Fatha formation for the wells Nos. 1-15 which include red and green Marl rocks with layers of thick gypsum and calcareous rocks as sedimentological cycles of lakes and delta. The geological layers of the wells Nos. 16-23 from the sequence of the upper part of Al-Fatha formation. On the other hand, the rocks of the wells No. 26 and 27 belongs to Injana formation with sequence of sandy rocks and clayey rocks layers. The wells B13 and B14 lied on terraces of the upper Zab river which consisted of thick layers of gravel sequenced by layers of coarse sand and clay (Al-Naqib and Aghwan, 1993).

Samples Collection

The samples were collected for the period Dec 2008 till Jul 2009 each two months. The pump were put on for 10 minutes then the sample was collected in plastic bottles of 2.25 liters. The samples were then transported to the laboratory and stored at 4 ^{o}C and then tested.

Methods of Analysis

The physical tests, which include total dissolved solids and electrical conductivity, and the chemical tests, which include pH, total hardness, calcium, magnesium, sodium, potassium sulfate, nitrate, and chloride, were conducted according to the standard methods (APHA, AWWA and WEF, 1986). Selected heavy metals including lead, cadmium, zinc and silver were tested by atomic absorption device type VARIAN.

The results were statically analyzed using simple Pearson correlation to find the relationships between the parameters. Factor analysis was then used to explain the outline of groundwater quality variation according to the measured parameters. Statistical analysis was also used to classify the studied wells according to their water quality using complete linkage cluster analysis depending on similarity index. The statistical results were considered significant and $p \leq 0.05$.

RESULTS AND DISCUSSION

Table (2) shows the bivariate relationships between ground water quality parameters in the study area. pH shows significant inverse correlation with each of total dissolved solids, total hardness, calcium ions, lead and copper. On the other hand, total dissolved solids shows direct significant correlation with the measured trace elements except copper. Additionally, nitrates correlation with measured trace elements did not reach the significance level. While sulfate showed significant positive relationship with cadmium and Zinc. Also, alkalinity correlated significantly with trace elements except copper directly. Lead showed positive significant relationship with cadmium, while the later showed inverse significant correlation with copper. Furthermore, electrical conductivity showed significant direct correlation with lead and cadmium.

Factor analysis extracted five factors from the measured water quality parameters to represent water quality variation in the study area (table 3). The analysis was conducted using the rotation technique depending on eigen values of 1 or more (Davis, 1973). The extracted five factors represented 69% of the variation in ground water quality withhin the studied area. The correlation of the parameters with the factors is considered significant when it exceeded the radius of the balance circle which is equal to 0.559 calculated from the square root of the division of number of factors by the number of parameters (Al-Rawi and Shihab, 2005). The first factor represents the land use of the studied area with a percentage of 16.84% from the total variance. This factor shows significant correlation with sodium, chloride and nitrate ions (table 3).

Table (2): Correlation matrix for water quality parameters of the studied wells

Par	pH	EC	TDS	TUR	TH	PO_4	DO	NO_3	SO_4	ALK	Cl	Na	K	Ca	Mg	Pb	Cd	Zn	Cu
pH	1	-0.02	-0.22*	-0.06	-0.31**	0.14	-0.06	0.21*	-0.14	-0.13	0.2*	0.23*	-0.15	-0.39**	-0.1	-0.2*	-0.14	-0.06	-0.26**
EC		1	0.94**	0.38**	0.59**	0	0.24**	0.14	0.51**	0.17	0.85**	0.82**	0.38**	0.29**	0.55**	0.4**	0.48**	0.16	-0.12
TDS			1	0.4**	0.68**	-0.06	0.26**	0.1	0.58**	0.21*	0.72**	0.73**	0.36**	0.41**	0.57**	0.42**	0.54**	0.2*	-0.02
TUR				1	0.22*	0.14	0.19*	-0.02	0.27**	0.38**	0.23*	0.39**	0.06	0.11	0.21*	0.24**	0.33**	0.43**	-0.19*
TH					1	0.23*	0.38**	-0.17	0.71**	0.29**	0.25**	0.27**	0.34**	0.74**	0.74**	0.27**	0.53**	0.1	-0.04
PO_4						1	0.09	-0.15	0.3**	0.21*	-0.11	-0.06	-0.03	0.12	0.22*	-0.02	-0.04	0.18*	-0.28**
DO							1	0.05	0.51**	0.16	0.14	0.25**	0.16	0.36**	0.25**	0.07	0.41**	0.19*	0.06
NO_3								1	-0.1	-0.27**	0.15	0.24**	-0.41**	-0.27**	-0.08	-0.04	-0.11	-0.15	-0.09
SO_4									1	0.05	0.22*	0.39**	0.2*	0.61**	0.49**	0.14	0.44**	0.33**	-0.02
ALK										1	-0.01	0.02	0.18	0.24**	0.21*	0.25**	0.27**	0.4**	-0.1
Cl											1	0.79**	0.43**	0.02	0.32**	0.25**	0.21*	-0.01	0.02
Na												1	0.2*	-0.01	0.34**	0.38**	0.41**	0.15	-0.23*
K													1	0.31**	0.27**	0.15	0.29**	-0.05	0
Ca														1	0.23*	0.23*	0.35**	0.17	0.05
Mg															1	0.24**	0.49**	-0.01	-0.12
Pb																1	0.47**	0.06	-0.27**
Cd																	1	0.29**	-0.38**
Zn																		1	0.01
Cu																			1

* Significant at $p \leq 0.05$

** Significant at $p \leq 0.001$

Table (3): The rotated weights of ground water quality parameters according to factor analysis

Parameters	Factors				
	1	2	3	4	5
Na	**0.871**	0.208	0.186	0.107	0.116
Cl	**0.844**	-0.061	0.151	0.196	-0.05
NO_3	**0.600**	-0.135	-0.044	-0.504	-0.04
Alkalinity	-0.272	**0.737**	0.068	0.165	0.016
Turbidity	0.200	**0.726**	0.177	-0.054	0.11
Zn	-0.076	**0.661**	0.407	-0.225	0.091
Pb	0.404	0.550	-0.151	0.328	-0.167
Cd	0.395	0.527	0.224	0.478	0.017
SO_4	0.190	0.144	**0.832**	0.262	0.151
DO	0.195	0.127	**0.688**	0.041	-0.025
Ca	-0.178	0.191	**0.625**	0.431	-0.215
K	0.075	-0.102	0.157	**0.794**	-0.089
Mg	0.293	0.151	0.299	0.547	0.235
PO_4	-0.283	0.135	0.285	0.031	**0.753**
pH	0.294	-0.238	-0.158	-0.35	**0.641**
Cu	-0.249	-0.318	0.326	-0.319	-0.615
Eigen value	2.695	2.434	2.217	2.131	1.553
%Variance	16.845	15.212	13.856	13.321	9.705
%Cumulative	16.845	32.057	45. 913	59.233	68.938

Factor 2 denoted 15.21% of the total variance in ground water quality within the study area. Alkalinity, turbidity and zinc was loaded on it significantly (Fig. 3). The figure also shows direct strong correlation between zinc ion and alkalinity as found in the correlation matrix (table 1). The figure exhibits weak correlation between zinc, lead and cadmium from one side versus nitrate and chloride from the other side according to the angle between the parameters vectors which is weak when it is about 90 degrees, strong when it is small and inverse when reach 180 degrees and around it.

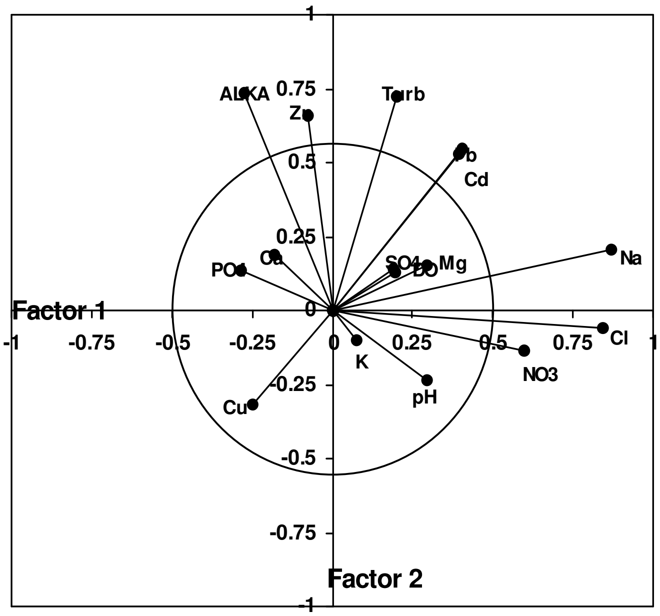

Fig. 3: The weights of factor 1 parameters versus factor 2 parameters

Factor 4 represents the geology of the studied area with 13.85% of the total variance in ground water quality (table 3). Sulfates, dissolved oxygen and calcium was loaded significantly on it. Weak correlation was observed between calcium and each of sodium and chloride, while the exhibit strong direct correlation between them. Sulfate also shows weak correlation with nitrate.

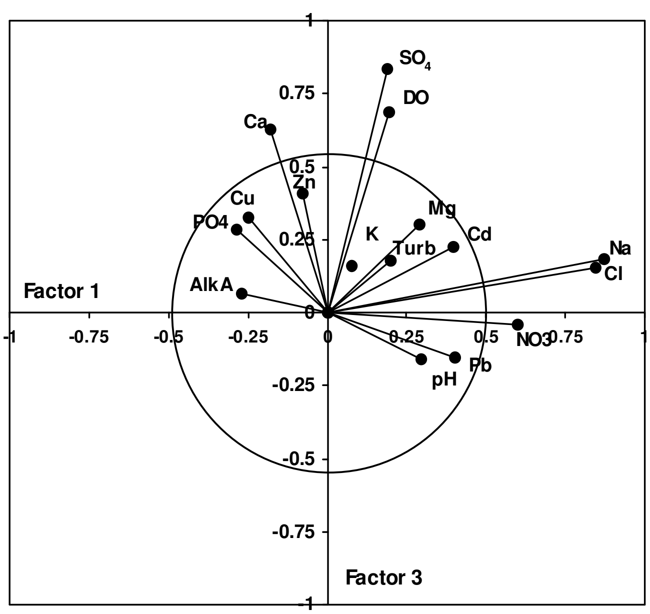

Fig. 4: The weights of factor 1 parameters versus factor 3 parameters

Factor 4 represented 13.32% of the total variance in ground water quality of the studied area (table 3). It characterized potassium ion variation significantly. When it is drawn versus factor 1 (Fig. 5), the relationships obtained: weak correlation between potassium versus sodium and chloride;

strong and inverse between copper versus lead and cadmium and weak correlation between nitrate versus cadmium, lead and magnesium.

Factor 5 represented the lowest percentage of variation in ground water quality with 9.7%, which is 60% of Factor 1 variance (table 3). Phosphate and pH was loaded significantly on it, which correlated strongly with each other (Fig. 6). The figure also denotes inverse strong correlation between pH and copper, as pH decrease, the ability of the solution to dissolve increase (Zubair et al., 2008).

In contrast, the parameters which did not loaded on any factor were lead, cadmium, magnesium and copper, since the feeding sources of the ground water did not exhibit noticeable variation in these parameters.

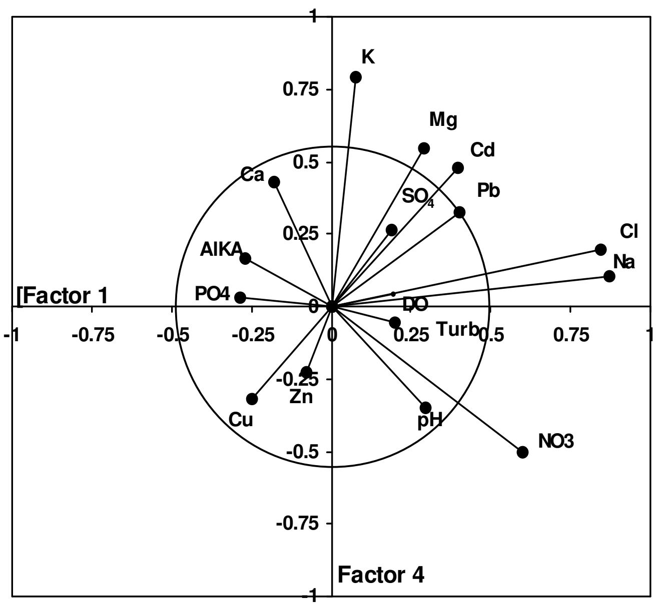

Fig. 5: The weights of factor 1 parameters versus factor 4 parameters

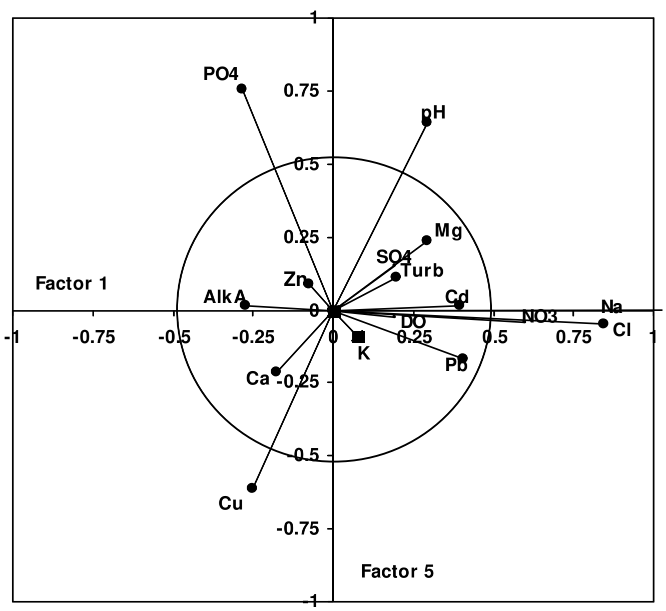

Fig. 6: The weights of factor 1 parameters versus factor 5 parameters

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Classification of the Wells

The complete linkage cluster analysis extracts five cluster depending on similarity index of 50% between ground water quality among the wells (Fig. 7). The first cluster included lower Bjwania and Tal Teba wells which represents 7.4% of the studied wells. The water quality of this cluster had the highest electrical conductivity, salt, dissolved oxygen, total hardness, magnesium, sodium, sulfate, nitrate and lead concentrations among the studied wells. The second cluster included upper Bjwania and Al-Shak wells which represents 7.4% of the studied wells. These two wells exhibited the water quality of highest calcium, phosphate, cadmium, zinc and turbidity. Additionally, lower pH was recorded in this cluster in comparison with the other clusters (tables 4, 5 and 6).

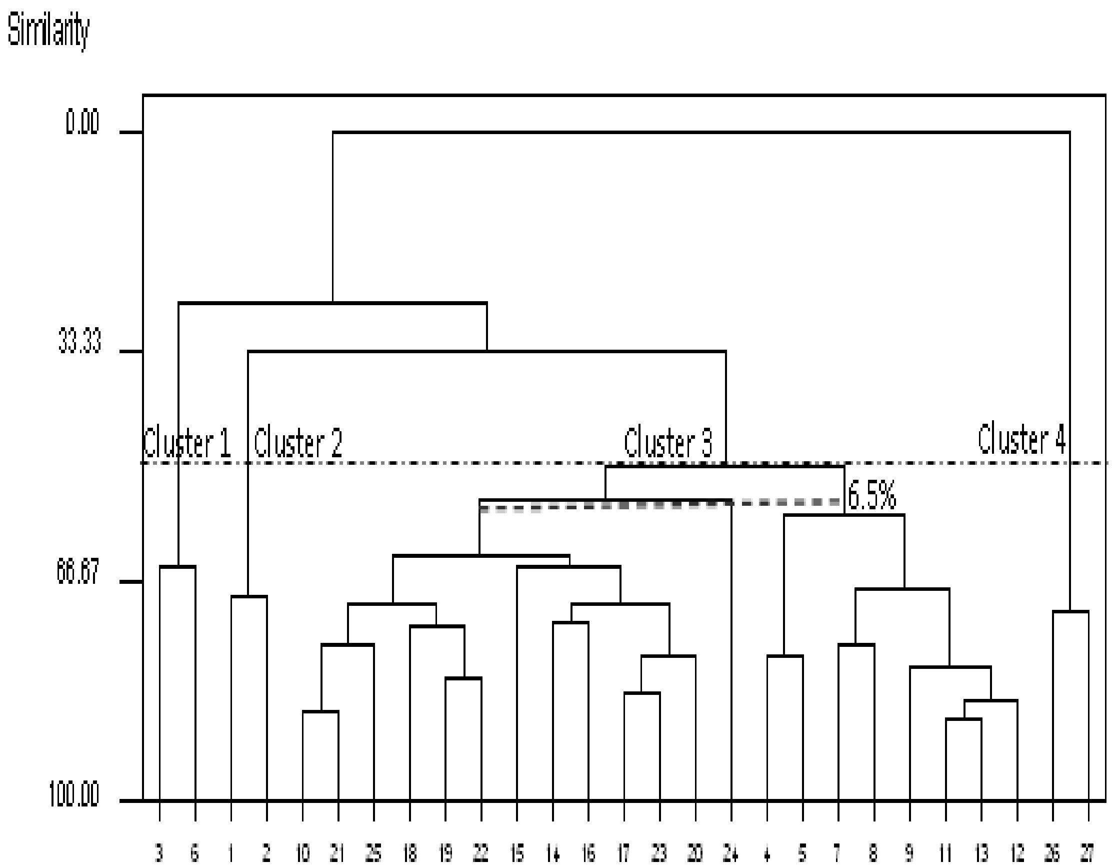

Fig. 7: Complete linkage Hierarchical cluster analysis dendrogram of water quality parameters of the studied wells (No. of wells as in table 1)

Cluster 4 contained Al-Adla and Ibrahim Al-Khaleel wells with 7.4% of the studied wells. These wells lies on the left side of Tigris river and had the highest alkalinity among the studied wells. Cluster 3 included the remaining 21 wells with 77.78%. The water quality of the wells of this cluster showed the lowest concentrations of sodium, while the concentrations of the other parameters were near the mean values.

Table (4): The characteristics of the ground water quality of the groups of wells extracted from cluster analysis

Parameters	Cluster No.	No. of wells	Mean	SD	Min.	Max.
Electrical Conductivity µmos/cm	1	2	**9684**	1862	8367	11001
	3	2	6174	1676	4989	7359
	4	21	4205	473	3122	5189
	5	2	1710	755	1175	2244
TDS (mg/l)	1	2	**6528.8**	1085.8	5761	7296.5
	3	2	4529	605	4101	4957
	4	21	3167.3	353.1	2175.5	3931.5
	5	2	933.3	430.3	629	1237.5
Turbidity Ntu	1	2	2.4	1.6	1.3	3.5
	3	2	**3.6**	0.2	3.5	3.8
	4	21	1.2	0.7	0.3	2.7
	5	2	0.8	0.7	0.4	1.3

Table (5): Trace elements concentration in the ground water quality of the groups of wells extracted from cluster analysis

Parameters	Cluster No.	No. of wells	Mean	SD	Min.	Max.
Lead	1	2	**7.50**	1.41	6.5	8.5
	2	2	7.13	0.18	7.0	7.25
	3	21	4.63	1.54	2.0	8.0
	4	2	2.63	0.18	2.5	2.75
Cadmium	1	2	4.33	0.42	4.03	4.63
	2	2	**4.55**	0.85	3.95	5.15
	3	21	2.58	0.86	1.15	4.28
	4	2	1.09	0.44	0.78	1.4
Zinc	1	2	6.88	1.59	5.75	8.0
	2	2	**39.13**	14.32	29	49.25
	3	21	8.60	4.15	2.5	19.25
	4	2	5.75	2.83	3.75	7.75
Copper	1	2	26.63	3.36	24.25	29.0
	2	2	22.38	2.65	20.5	24.25
	3	21	30.89	3.56	24.25	36.5
	4	2	25.88	3.71	23.25	28.5

This cluster can be divided into three sub-clusters at 6.5% similarity (Fig. 7). Sub-cluster 3 which included Al-Adla well showed higher mean concentration for sodium, chloride, electrical conductivity and TDS than sub-cluster 1 and 2. On the other hand, sub-cluster 2 showed higher alkalinity and lower sodium and chloride concentration than sub-cluster 1.

Table (6): The chemical characteristics of the ground water quality of the groups of wells extracted from cluster analysis

Parameters	Cluster No.	No. of wells	Mean	SD	Min.	Max.
pH	1	2	7.58	0.09	7.51	7.64
	2	2	7.5	0	7.5	7.5
	3	21	7.53	0.15	7.32	7.86
	4	2	**8.14**	0.13	8.05	8.23
Dissolved Oxygen	1	2	**2.93**	0.53	2.55	3.3
	2	2	2.84	0.41	2.55	3.13
	3	21	2.59	0.36	2.1	3.43
	4	2	2.05	0.14	1.95	2.15
Total Hardness	1	2	**2752.5**	148.49	2647.5	2857.5
	2	2	2375	60.1	2332.5	2417.5
	3	21	2173.18	255.18	1350	2465
	4	2	520	141.42	420	620
Calcium	1	2	490.22	15.21	479.46	500.97
	2	2	**513.52**	10.63	506	521.04
	3	21	484.79	64.07	356.56	617.14
	4	2	110.27	73.79	58.09	162.44
Magnesium	1	2	**329.87**	31.74	307.42	352.31
	2	2	244.48	21.77	229.08	259.87
	3	21	209.7	42.14	97.42	275.51
	4	2	84.57	40.53	55.91	113.23
Sodium	1	2	**1530**	374.77	1265	1795
	2	2	781.88	366.81	522.5	1041.25
	3	21	349.38	214.14	140	967.5
	4	2	388.13	389.79	112.5	663.75
Potassium	1	2	9.77	1.15	8.95	10.58
	2	2	8.25	2.26	6.65	9.85
	3	21	8.63	4.15	2.8	20.3
	4	2	2.63	1.27	1.73	3.53
Alkalinity	1	2	175.13	23.51	158.5	191.75
	2	2	**390.25**	1.77	389	391.5
	3	21	219.95	31.5	172.5	272.5
	4	2	102.75	13.08	93.5	112
Chlorides	1	2	**855.9**	365.38	597.53	1114.26
	2	2	212.97	229.67	50.57	375.37
	3	21	142.65	107.84	47.52	437.15
	4	2	124.74	99.12	54.65	194.83
Nitrate	1	2	**12.69**	0.08	12.63	12.75
	2	2	1.9	0.97	1.21	2.58
	3	21	4.1	4.1	0.02	11.79
	4	2	10.83	0.96	10.15	11.51
Sulfate	1	2	**1690.09**	10.68	1682.54	1697.64
	2	2	1534.16	96.92	1465.63	1602.69
	3	21	1196.6	149.6	884.14	1449.17
	4	2	361.52	21.44	346.36	376.68
Phosphate	1	2	0.04	0.01	0.03	0.04
	2	2	**0.09**	0.03	0.07	0.11
	3	21	0.05	0.02	0.03	0.12
	4	2	0.04	0.03	0.02	0.06

All parameters in mg/l except pH (unitless)

CONCLUSIONS

1. Correlation analysis showed direct significant relationships between salts and the ions: sulfate, chloride, sodium, potassium, calcium, magnesium, lead and cadmium. Weak non-significant relationship recorded between nitrate and each of cadmium, lead and zinc. Alkalinity correlated significantly with cadmium, lead and zinc,.
2. Factor analysis found that 69% of the variation in ground water quality among the studied wells corresponded to the measured parameters. Sodium, chloride and nitrate was the earliest, while phosphate and pH in the last.
3. The wells were classified into four water quality groups using cluster analysis.

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