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Groundwater quality assessment in urban area of Baghdad, Iraq, using multivariate statistical techniques

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ABSTRACT

An attempt has been made to assess the overall groundwater quality and identify major variables affecting the groundwater quality in the urban area of Baghdad, Iraq. Groundwater samples from tube wells of 66 sampling sites were analyzed for the major physicochemical variables during May 2010. From the Hill–Piper trilinear diagram, it is observed that the majority of ground water from sampling sites are Ca^{2+} -Mg^{2+} -Cl^{-} -SO_4^{2-} type and Na^{2+} -K^{+} -Cl^{-} -SO_4^{2-} type water. Multivariate statistical techniques such as factor analysis and cluster analysis were applied to identify the major factors (variables) corresponding to the different source of variation in groundwater quality of Baghdad. Factor analysis identified three major factors explaining 82.506% of the total variance in water quality; and the major variations are related to degree of mineralization of the geological components of soils, irrigation return flow, agricultural activities and mixing of wastewater. Hierarchical cluster analysis revealed three different groups of similarities between the sampling sites, reflecting different physicochemical properties and pollution levels in the groundwater quality.

Keywords: Groundwater quality, Baghdad, Multivariate statistical techniques, urban area, Factor analysis, Cluster analysis.

تقييم نوعية المياه الجوفية في المناطق الحضرية لمدينة بغداد، العراق باستخدام التحليل المتعدد المتغيرات

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الخلاصة

في هذه الدراسة، تم تقييم نوعية المياه الجوفية وتحديد المتغيرات الرئيسية التي تؤثر على نوعية المياه الجوفية في المناطق الحضرية لبغداد، العراق. علما ان عينات المياه الجوفية التي جمعت من الآبار من 66 موقع قد حُللت للمتغيرات الفيزيائية-الكيميائية الرئيسية خلال شهر أيار لسنة 2010. إستنادا الى مخطط Hill–Piper trilinear، لوحظ أن غالبية عينات المياه الجوفية من مواقع أخذ العينات هي من نوع - Ca^{2+} -Mg^{2+} -Cl^{-} -SO_4^{2-} ونوع Na^{2+} -K^{+} -Cl^{-} -SO_4^{2-}. كما تم تطبيق التحليل المتعدد المتغيرات مثل التحليل العاملي والعنقودي لتحديد العوامل الرئيسية (المتغيرات) التي تقابل مختلف مصادر تلوث المياه الجوفية في بغداد. وقد حدد التحليل العاملي Factor Analysisثلاثة عوامل رئيسية موضحا 82.506٪ من التباين الكلي في نوعية المياه؛ وارتبطت هذه الاختلافات بشكل رئيسي لدرجة التمعدن من المكونات الجيولوجية للتربة، ومياه الري الراجعة والأنشطة الزراعية واختلاط مياه الصرف الصحي. وكشف التحليل العنقودي الهرمي ثلاث مجموعات مختلفة من أوجه التشابه بين مواقع أخذ العينات، والتي تعكس مختلف الخصائص الفيزيائية-الكيميائية ومستويات التلوث في نوعية المياه الجوفية.

INTRODUCTION

Groundwater contributes about 120 million liters per day (nearly half of the total water supply) during wet season, which reaches up to 60–70% during the dry season [1]. Thus, it is an important source of potable water, in which, it is expected to be of high-quality, small seasonal variations, storage, easy exploitation, and socioeconomic development [2,3]. In general, groundwater is widely used for irrigation, industrial activities, drinking, and domestic purposes. Rapid growth of population, urbanization, industrialization, and agriculture activities increase its exploitation, reduce availability, and enhance vulnerability to contaminate the quality of water. Groundwater could be contaminated by disposal of urban and industrial wastes [4] and agricultural chemicals [5]. In urban areas, the disposal of wastewater including human excreta in a septic tank is a common practice. Also, the discharge of untreated effluent into the streams could affect the groundwater quality adversely by rising salinity and coloring matter content in wells located along the bank of these streams [6]. Many studies related to groundwater quality have been conducted in different basins [7-16].

Baghdad, the capital of Iraq, is considered to be the most populated and industrialized city in Iraq in which the urbanized, agricultural and industrial areas represent 72.69%, 25% and 2.31% of the total area respectively [17]. Despite, Tigris river at Baghdad is the main source for drinking water supply and irrigation, the river water quality has been deteriorated during the last three decades due to increase of water consumption and various urban pollutant sources [18,19]. The water quality in both surface and ground water resources was negatively affected [20]. Therefore, study the quality of other sources of water in the urban area such as groundwater is of prime importance. In other hand, several studies conducted in the area dealing mainly with Tigris river [21-24]. Groundwater is threatened with pollution from different sources such as domestic wastes, agricultural wastes, runoff from urban areas, soluble effluent and earthen septic tanks. And the groundwater chemistry, in turn, depends on a number of factors (i.e. general geology, degree of chemical weathering of various rock types and quality of recharge). In order to ensure groundwater quality, evaluation and monitoring of its quality is necessary in urban areas whilst testing of a variety of water quality characteristics and regular periodic assessment of water is a time-consuming process, toilsome and expensive. Besides, the measurement of all the groundwater quality parameters at a regular interval is not desired because this will not provide additional information on the water quality aspect.

The use of multivariate statistical techniques could simplify the process in a convenient size. The relationship between the huge numbers of variables in surface and groundwater studies is better explained using the multivariate statistical techniques such as factor and cluster analyses [25-27]. The application of these techniques help in the organize and interpretation of complex data sets to better understand the water quality and ecological status of the studied systems, remove noise from the data sets, avoid misinterpretation of environmental monitoring data, identify natural groupings in the set of data, allows the identification of possible factors/sources that influence water systems, and offers a valuable tool for reliable management of water resources as well as rapid solution to pollution problems [28-33]. In this context, this study aimed to assess the current state of water quality and identify the major factors affecting on water quality of groundwater in the urban area of Baghdad. Additionally, clustering method selects the homogeneous groups within a particular data set (i.e. the similarities or dissimilarities between the monitoring wells).This may provide a proper basis for management of groundwater schemes in the region.

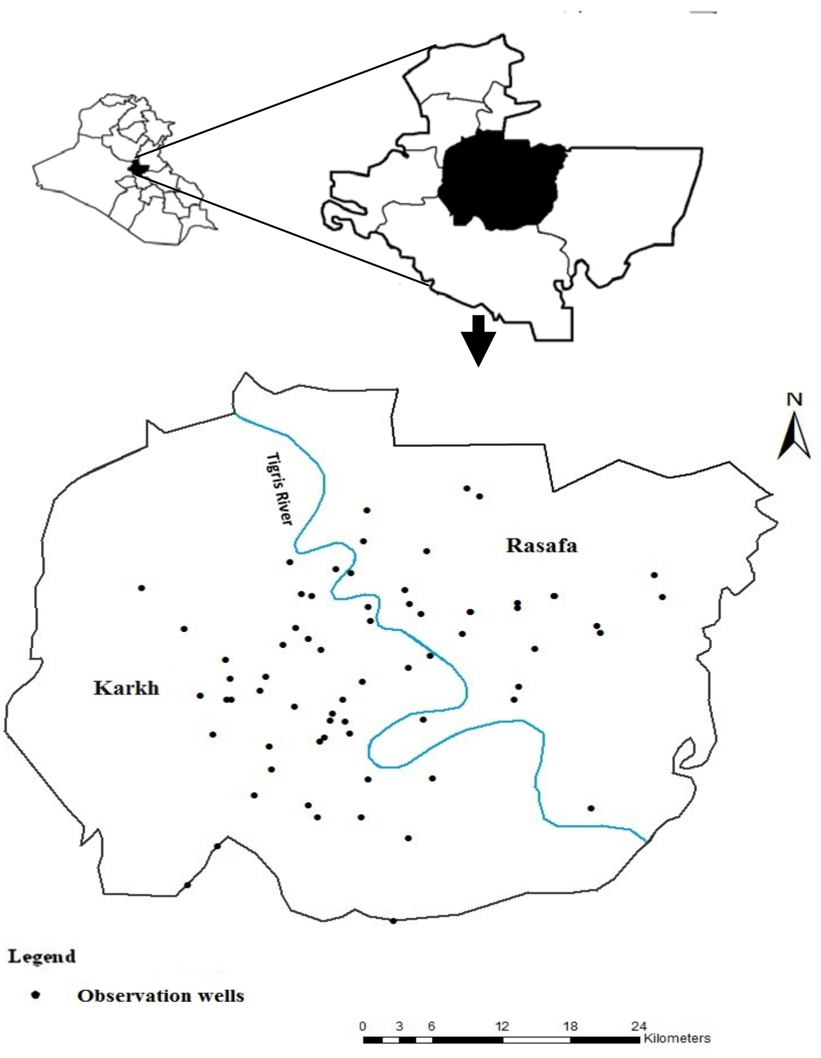
Materials and Methods:

Study area

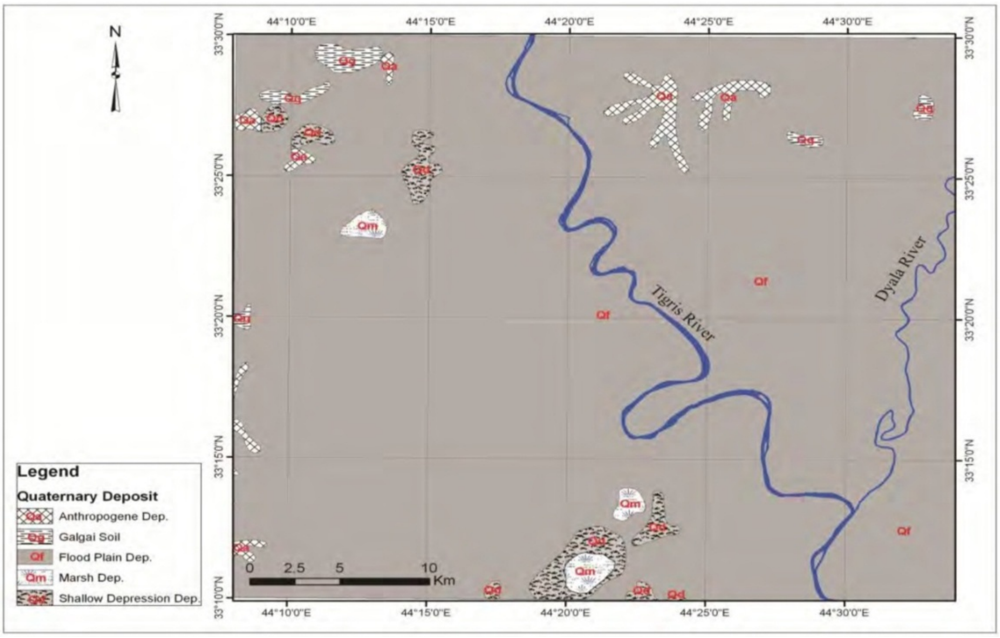
The total area of Baghdad governorate is 5159 km^2 and the population of the city is about 7 million which about 24% of Iraqi population [17]. The urban area (study region) lies between 33°10'-33°29' Nlatitudes and 44°09'- 44°33' E longitudes covering an area of about 1350 km2 and it has an average elevation of 40 m. The area is characterized by arid to semi-arid climate with dry hot summers and short cold winters and the mean annual rainfall is about 151.8 mm [34]. The average temperature in this region varies between 16.42 ºC and 35.39 ºC in summer and between 9.46 ºC and 12.49 ºC during winter, respectively for the period 1990 – 2010 [35]. The Tigris river passes through the city and divides Baghdad into two sections, Karkh to the west and Rasafa to the east and the length of the river in Baghdad stretch is about 50 km (Fig.1). The geology of the study area represents, as a whole, a flood plain which consists of quaternary deposits (see Fig. 2). Baghdad province lies within the unstable shelf of the Arabian Plate, mostly within Tigris subzone of the mesopotamian zone [36]. Most of the present structures are subsurface and they have no surface expressions. Two of these structures are anticlinal structures; the first is the East Baghdad structure and the second is the west Baghdad structure [37].

Sampling and analyses

A total of 66 samples were collected randomly from different wells of the urban area of Baghdad. Out of 66 collected samples 43 were from karkh section and 23 from Rasafa (Fig. 1). Groundwater samples were collected from different tube wells (almost 25 m in depth) during May 2010. The tube wells were continuously pumped for 10 min prior to the sampling, to ensure that groundwater to be sampled was representative of groundwater aquifer. The groundwater parameters were analyzed in laboratory of the general commission for groundwater after completion of the sampling. The analyzed parameters were pH, electrical conductivity (EC), total dissolved salts (TDS), sodium (Na), potassium(K), calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), chloride (Cl), sulphate (SO_4) and nitrate (NO_3) ions. pH and electrical conductivity values were measured immediately with corresponding portable electronic instruments. Total dissolved solids (TDS) were determined as the residue left after evaporation of the filtered sample. Calcium and magnesium were analyzed titrimetrically by complexometric titration method using (EDTA). Bicarbonate concentration was determined by acidimetric titration method using methyl orange as indicator. Chloride was determined by argentometric titration method. Sulphate and nitrate were analyzed by UV–Visible spectrophotometry. The descriptive statistics of the obtained water quality data for the present study is shown in Table 1.



Figure(1). Map of study area showing locations of observation wells in the urban area of Baghdad



Figure(2). Geological map of the urban area of Baghdad

Table (1). Descriptive statistical summary of groundwater quality data in urban area of Baghdad City, *n* = 66

No.	Variables	Minimum	Maximum	Mean	*SD*
1	EC, µS/cm	1100	29600	7179.84	5746.9
2	pH	7.20	8.7	7.8	0.378
3	TDS, mg/L	864	19064	4735.28	3672.7
4	Ca, mg/L	72	1100	407.65	252.1
5	Mg, mg/L	67	1924	542.21	449.9
6	Na, mg/L	101	6405	1386.78	1254.3
7	K, mg/L	2	60	12.94	11.8
8	Cl, mg/L	107	8724	1477.51	1616.07
9	CO_3, mg/L	0	70	7.63	15.66
10	HCO_3, mg/L	33	491	163.62	105.74
11	SO_4, mg/L	40	3110	688.18	502.77
12	NO_3, mg/L	0.1	17.5	2.36	3.36

SD: standard deviation

Data treatment and multivariateanalysis

Most multivariate statistical methods require variables to conform to the normal distribution, thus, before multivariate statistical analysis; the normality of the distribution of each variable was checked by the Shapiro–Wilk (W) test. The test demonstrated that all of water quality variables were not normally distributed. Then, the non-normal distribution variables were subjected to a transformation in which the original data were transformed in the form $x' = \log_{10}(x)$ [38,39]. After log-transformation, the data of each variable was normalized. All log-transformed variables were also z-scale standardized (the mean and variance were set to zero and

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one, respectively) in order to avoid misclassification due to the wide differences in data dimensionality [40]. The aim of standardization is to minimize the influence of difference on variance of variables and eliminates the influence of different units of measurement and renders the data dimensionless [41]. In order to account for non-normal distribution of the measured groundwater quality variables, the correlation structure between the variables was studied by using the Spearman *R* coefficient as a nonparametric measure of the correlation between the parameters [26,28,30,39].
Factor analysis (FA) was used to identify the main components of the groundwater quality and the most important variables causing difference in the groundwater quality of the urban area of Baghdad. FA includes three main stages: correlation matrix which is generated for all variables, initial set of factors are extracted using PCA method, and then the extracting factors are rotated using Varimax rotation [42]. In factor analysis, the basic concept is expressed in the following formula:

$$z_j = a_{j1} f_1 + a_{j2} f_2 + \ldots + a_{jf} f_m + e_{ij};\ j = 1,2,\ldots,p \qquad \ldots(1)$$

Where
, *z* is the measured value, *f* the factor score, *a* the factor loading, *e* the residual term accounting for errors or other sources of variation, *i* the sample number, *j* the variable number, and *m* is the total number of factors [43].

Cluster analysis (CA) was also used to classify objects with similar properties which divide a large number of objects into smaller number of homogenous groups based on the similar characteristics [44]. In this study, Hierarchical agglomerate clustering using Ward's method [28] is the most common approach, which provides similarity relationships between any one sample and the entire data set, and is typically illustrated by a dendrogram (tree diagram). Euclidean distance method was used for determining distance, which is one of the most commonly adopted measures. The geometric distance in the multidimensional space and is computed as [45]:

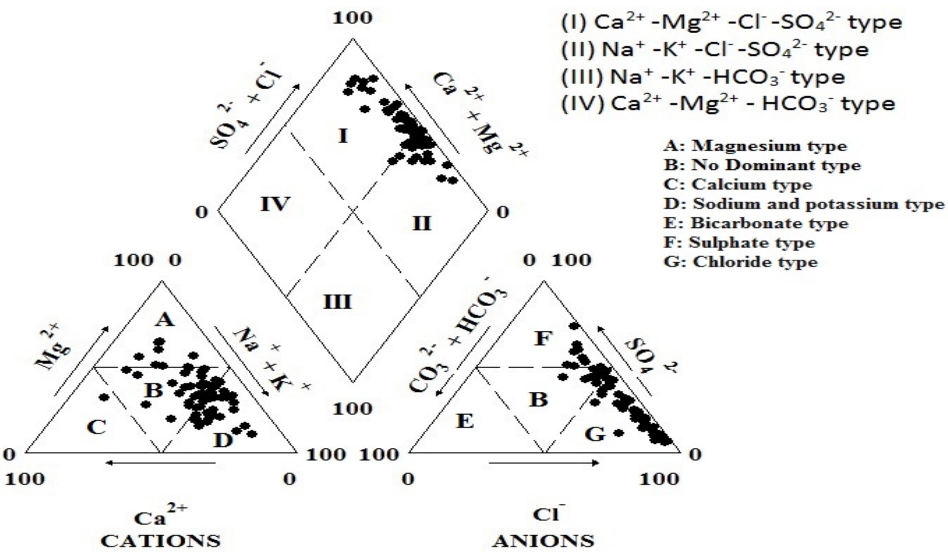
$$\text{Distance}(X,Y) = \left\{\sum i(Xi - Yi)^2\right\}^{1/2} \qquad \ldots(2)$$

All statistical data treatment, FA and CA were performed using Statisti cal Package for the Social Sciences Software - SPSS 17 for Windows.

Results and Discussion:

Classification of Groundwater

Hill (1940) [46] has developed a pattern diagram and later improved by Piper (1944, 1953) [47,48] to form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in groundwater. In order to understand the chemical characteristics of groundwater in the study region, groundwater samples were plotted in Hill–Piper trilinear with the help of GW_Chart software [49]. The diagram include two triangular diagrams at left and right for plotting the cations and anions, respectively, with a diamond-shaped field consists of two equal triangular fields. Based on Piper diagram (Fig. 3), groundwater from tube wells can be classified into two types Ca^{2+} -Mg^{2+} -Cl^- -SO_4^{2-} type and Na^{2+} -K^+ -Cl^- -SO_4^{2-}. These water types suggest the mixing of high-salinity water caused from surface contamination sources such as irrigation return flow and mixing of sewage. Nearly, 51.5% of samples fall under Ca^{2+} -Mg^{2+} -Cl^- -SO_4^{2-} type and 48.5% under Na^{2+} -K^+ -Cl^- -SO_4^{2-} type.



Figure(3). Hill–Piper trilinear diagram shows the chemical character of groundwater samples

Correlation analysis

Data in Table 2 provide the Spearmancorrelation matrix of the groundwater quality parameters. The pH has weak correlation with all variables. EC shows strong positive correlations with TDS, Mg^{2+}, $Ca2^+$, Na^+, K^+, Cl^-, HCO^{3-}, and $SO4^{2-}$; and these variables are also positively correlated with each other. NO_3 shows poor correlation with all variables and may indicate that this variable has been derived from other sources and the strong correlation between Na^+ and Cl^- (0.882) may indicate that these variables have been derived from same source. CO_3 has poor correlation with other variables in which the carbonate (CO_3) alkalinity is absent in most of the stations throughout the study and it is detectable only nearly above pH 8.0. This is approved by the findings of [50].

Table (2)Spearman correlation matrix of groundwater quality parameters (*n* = 66)

Parameter	EC	pH	TDS	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4	NO_3
EC	1.000											
pH	0.174	1.000										
TDS	0.936	0.182	1.000									
Ca	0.796	0.296 [a]	0.808	1.000								
Mg	0.781	0.217	0.856	0.735	1.000							
Na	0.904	0.135	0.956	0.678	0.726	1.000						
K	0.903	0.164	0.970	0.808	0.824	0.927	1.000					
Cl	0.863	0.188	0.922	0.735	0.773	0.882	0.896	1.000				
CO_3	0.224	0.483	0.198	0.294[a]	0.263 [a]	0.123	0.206	0.136	1.000			
HCO_3	0.743	0.184	0.790	0.662	0.715	0.749	0.782	0.645	0.287[a]	1.000		
SO_4	0.584	0.003	0.638	0.471	0.634	0.579	0.612	0.452	0.058	0.700	1.000	
NO_3	0.196	-0.291[a]	0.230	0.178	0.082	0.259 [a]	0.295 [a]	0.220	-0.432	0.088	0.167	1.00

[a] Significant value at $p<0.05$

Factor analysis

Factor analysis (varimax rotation) was performed on the normalized data sets to compare the composition structure between analyzed groundwater samples and identify the factors influencing each one. Eigenvalues are normally used to determine the number of principal components that can be retained for further study. Eigenvalues of 1.0 or greater are considered significant [26]. The result of FA is given in Table 3. From the results, first three factors have eigenvalues greater than or close to unity and explain 82.506% of the total variance in each groundwater quality data sets.

Table (3). Factor loading matrix and total variance explained after Varimax rotation

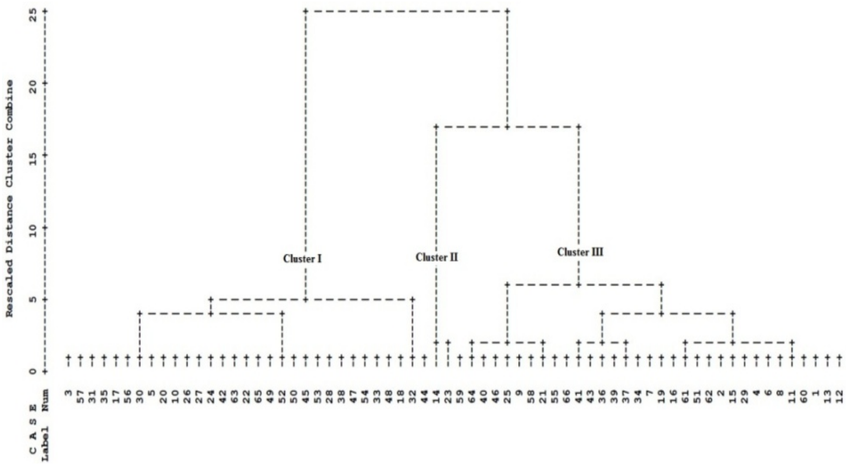
Parameters	Factor 1	Factor 2	Factor 3
EC	0.969	0.001	0.176
pH	-0.130	-0.078	-0.913
TDS	0.968	0.003	0.181
Ca	0.621	-0.009	0.297
Mg	0.803	0.224	0.439
Na	0.877	-0.140	-0.024
K	0.938	0.029	0.219
Cl	0.750	-0.121	0.259
CO_3	0.893	0.063	-0.014
HCO_3	0.844	0.375	-0.212
SO_4	0.565	0.775	0.021
NO_3	0.440	-0.743	-0.134
Eigenvalue	7.155	1.388	1.357
% Total variance	59.627	11.569	11.309
Cumulative % variance	59.627	71.196	82.506

Factor 1 (F1) explained 59.627% of the total variance which is positively contributed by EC, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, CO_3^{2-} and HCO_3^{-}. The high loading factor of EC is likely due to the active participation of dissolved ions in the groundwater quality. This factor has contribution from sources which can be linked to both the geology as well as the anthropogenic sources. F1 is related to the hydro-geochemical variables originating from mineralization of the geological components of soils and the irrigation return flow.The level of significance of the correlation coefficient (*R* values) between variables (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and HCO_3^{-}) shows strong positive correlation with each other which confirmed their coherence and logical assemblage into respective factors. The second factor (F2) explained 11.569% of the total variance which is positively contributed by SO_4^{2-} and negatively by NO_3^{-}. This factor represents the contribution of agricultural activities from agricultural areas and mixing of wastewater (cracks in pipes sewage networks). Farmers use ammonium sulfate fertilizers, and the Tigris river receives ammonium and sulphate via surface runoff and irrigation waters [51].

The F2, shows a negative correlation with NO_3, indicating that groundwater sulphate is derived from other sources. Previous studies indicated that source of non-agricultural nitrate in groundwater is due to discharge of wastewater, effluent from on-site sanitation, leachate from solid waste dump sites, and reuse of wastewater for irrigation [52,53]. In the study area, the seepage from wastewater network pipes is more pronounced due to cracks in pipes sewage networks [54]. The third factor (F3) explained 11.309% of the total variance which is negatively contributed by pH. This factor reflects the acidity–alkalinity scale in groundwater. Dissolution of cations and anions could also be regulated by this factor.

Cluster analysis

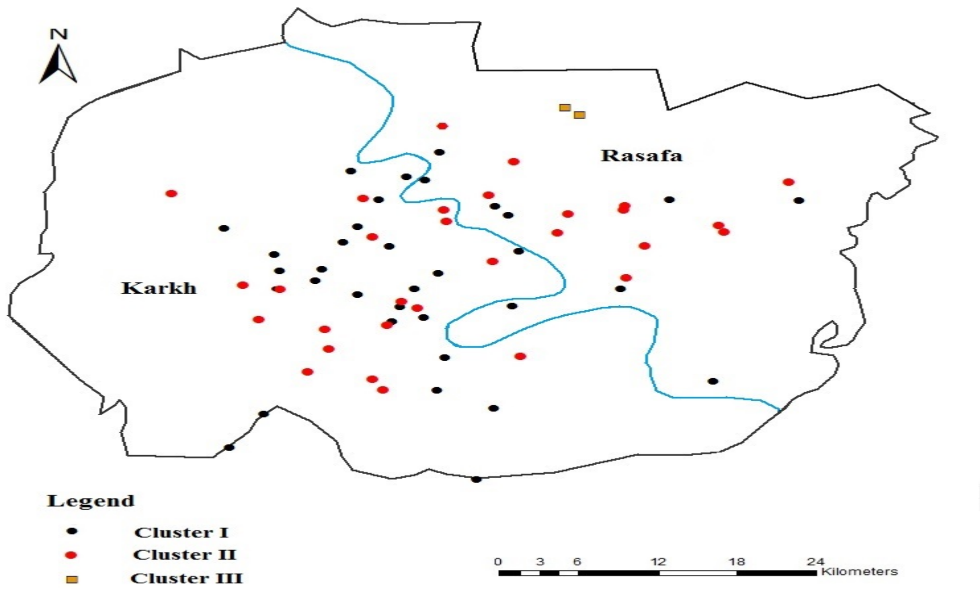
Classification of sampling site was performed by the use of cluster analysis (z-standardization of the input data, squared Euclidean distance as similarity measure and Ward's method of linkage), to detect the similarity between the monitoring sites and allowed grouping the 66 wells in three statistically significant clusters. The results of cluster analysis CA are presented in a dendrogram (Fig. 4). Dendograms in cluster analysis provides a useful graphical tool determining the number of clusters which describe underlying process that lead to spatial variation [25]. The participation of wells in the formation of cluster seems to be not systematic (i.e., it is not the condition that wells of nearby locations are fall in the same cluster) (see Fig 5). This indicates that water quality of groundwater is varied considerably and such variation is due to the direct human influence on water quality such as surface contamination sources.



Figure(4). Dendrogram showing spatial clustering of monitoring sites

Broadly, three main clusters were classified (Fig 4 and 5) based on the similar water quality characteristics. The water quality of groundwater is obviously varied between the clusters (see Table 4). Cluster I correspond to relatively less polluted sites and comprises the wells of less salinization. Cluster II corresponds to moderately pollution and comprises wells of high salinization. Cluster III were corresponded to highly polluted sites which agglomerates the wells of very high salinization (only two sites). The high values EC and TDS in Cluster III is mainly due to the anthropogenic deposit (see Fig. 2). The average values of EC in cluster I, cluster II and cluster III are 3163.2 μS/cm, 9612.4 μS/cm and 29300 μS/cm respectively. Salinity hazard is the most important water quality guideline on crop productivity as measured by EC. The primary effect of high EC water on crop productivity is the incapability of the plant to compete with ions in the soil solution for water. It is noticed that the average value of

EC in the three clusters exceed the international standard specifications for drinking and irrigation purposes. In general, the quality of groundwater in the urban area of Baghdad as a whole is of high salinity and extensive studies are required to suggest options for best management of groundwater salinity in Baghdad.



Figure(5). Classification of wells according to cluster analysis

Table (4). The average values of three identified clusters

Parameters	Cluster I	Cluster II	Cluster III
EC, µS/cm	3163.2	9612.4	29300
pH	7.68	7.89	8.02
TDS, mg/L	2055.5	6397.5	18845
Ca, mg/L	217.58	544.24	1100
Mg, mg/L	205.96	775.81	1899.5
Na, mg/L	582.80	1842.78	6324.5
K, mg/L	4.67	18.37	51.5
Cl, mg/L	464.09	2037.03	7953.5
CO_3, mg/L	1.29	11.93	35
HCO_3, mg/L	93.03	211.66	465
SO_4, mg/L	447.61	808.21	2436.5
NO_3, mg/L	2.47	2.38	0.45

Conclusion

Multivariate statistical techniques namely, factor and cluster analyses were applied in order to get better information about the groundwater quality of the urban area of Baghdad. Three latent factors were identified as responsible for the data structure, explaining 82.506% of total variance in the dataset. The first factor explained

59.627% of the total variance and mainly related to mineralization and irrigation return flow. The second factor explained 11.569% which represents the agricultural activities from agricultural areas such as fertilization and mixing of wastewater whereas, the third factor explained 11.309% of the variances and is reflects the acidity–alkalinity scale in groundwater. Three main groups were classified by cluster analysis, cluster I correspond to relatively less polluted sites and comprise the wells of less salinization. Cluster II were corresponded to highly polluted sites which agglomerates the wells of very high salinization. Cluster III corresponds to moderately pollution and comprises wells of high salinization. Based on Hill–Piper trilinear diagram, groundwater samples from wells were classified into two types Ca^{2+} -Mg^{2+} -Cl^{-} -SO_4^{2-} type (51.5% of the total samples) and Na^{2+} -K^{+} -Cl^{-} -SO_4^{2-} type water (48.5% of the total samples). It could be concluded that groundwater quality of Baghdad, as a whole suffered from salinity. Relevant authorities must begin preparing the necessary plans for the management of groundwater salinity to improve the quality of water. Multivariate methods are believed to be valuable to help water resources managers understand complex nature of groundwater quality issues and determine the priorities to improve groundwater quality.

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