Application of Multivariate Statistical Techniques in the surface water quality Assessment of Tigris River at Baghdad stretch, Iraq

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Abstract

Multivariate statistical techniques namely factor analysis and cluster analysis were applied to evaluate spatial variations, and to interpret measured water quality data set in Tigris river at Baghdad. The water quality was monitored at seven different sites, along the water line, over a period of one year (2011) using 14 water quality parameters. When factor analysis was applied, three factors were identified, which were responsible from the 86.750% of the total variance of the water quality in the Tigris river. The first factor called the anthropogenic factor explained 49.829% of the total variance and the second factor called the erosion and rainfall factor explained 24.967% of the total variance. While, the third factor called the pH factor explained 11.954% of the total variance. Hierarchical cluster analysis was used to classify seven stations with similar properties and results distinguished three groups of stations. Results revealed that, water quality in Tigris river was strongly affected from anthropologic influences. Thus, these methods are believed to be valuable to help water resources managers understand complex nature of water quality issues and determine the priorities to improve water quality.

Keywords: Multivariate statistical techniques, water quality assessment, Tigris River, Factor analysis, Cluster analysis.

الخلاصة

في هذه الدراسة تم أستخدام التحليل المتعدد المتغيرات عن طريق تطبيق التحليل العاملي (طريقة المركبات الأساسية) والتحليل العنقودي لمعرفة التغيرات المكانية وأعطاء تفسير لبيانات نوعية المياه المقاسة على نهر دجلة في بغداد. تم رصد نوعية المياه عن طريق سبعة مواقع مختلفة على طول النهر لفترة سنة واحدة (٢٠١١) بأستخدام ١٤ عنصرا من متغيرات نوعية المياه. عند تطبيق التحليل العاملي، حددت ثلاثة عوامل، وهي مسؤولة عن ٨٦,٧٥% من التباين الكلي لنوعية المياه لنهر دجلة. وقد سمي العامل الاول (بشري المصدر) والذي يفسر ٤٩,٨٢٩% من التباين الكلي والعامل الثاني يسمى عامل التعرية وهطول الامطار حيث يفسر ٢٤,٩٦٧% من التباين الكلي، اما العامل الثالث وهو عامل الاس الهيدروجيني يفسر ١١,٩٥٤% من التباين الكلي. كما تم استخدام التحليل العنقودي الهرمي لتصنيف السبع محطات مع خصائصها المماثلة وأظهرت النتائج ثلاث مجموعات من المحطات. كشفت نتائج الدراسة ان نوعية مياه نهر دجلة تتأثر بشدة بالعوامل البشرية. وبالتالي ممكن ان تكون هذه الطرق/الاساليب ذات قيمة لمساعدة العاملين في الموارد المائية في فهم الطبيعة المعقدة للقضايا وتحديد الأولويات لتحسين نوعية المياه.

الكلمات المفتاحية: الأساليب الإحصائية متعدد المتغيرات، وتقييم نوعية المياه، ونهر دجلة، التحليل العاملي، وتحليل الكتلة

Introduction

The quality of water is identified in terms of its physical, chemical and biological parameters (Sargaonkar & Deshpande, 2003). The anthropological influences (i.e., urban, industrial and agricultural activities) as well as the natural processes (i.e., changes in precipitation amounts, erosion and weathering of crustal materials) degrade surface water quality and impair its use for drinking, industrial, agricultural, recreational and other purposes (Carpenter et al. 1998). Increasing exploitation of water resources in catchment is responsible for much of the pollution load (Singh et al. 2005). On the other hand, rivers and streams play a major role in assimilation or carrying off the municipal and industrial wastewater and run-off from agricultural land. The municipal and industrial wastewater discharge constitutes the constant polluting source, whereas the surface run-off is a seasonal phenomenon, largely affected by climate in the basin. (Vega et al. 1998; Singh et al. 2004).

The particular problem in the case of water quality monitoring is the complexity associated with analyzing the large number of measured variables and high variability due to anthropogenic and natural influences (Saffran, 2001; Simeonov et al. 2002).

The application of different multivariate statistical techniques, such as cluster analysis (CA) and factor analysis (FA), helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied systems, 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 (Wunderlin et al. 2001; Reghunath et al. 2002; Simeonova et al. 2003; Shrestha and Kazama 2007).

Factor and cluster analyses have been used successfully in hydrochemistry for many years. Surface water quality assessment and environmental research employing these techniques are well described in the literature. (Sojka et al. 2008) have assessed different physico-chemical parameters of the Mała Wełna waters in Western Poland by using Factor, cluster and discriminant analyses, they identified different water quality indicators suitable for characterizing its temporal and spatial variability. (Arzu, et al. 2009) presented the necessity and usefulness of multivariate statistical assessment of large and complex databases in order to get better information about the quality of surface water. (Zhang et al. 2009) were applied different Multivariate statistical techniques to assessing the water quality in Xiangjiang watershed, china for twelve parameters at 34 different profiles. They stated that these methods are valuable to understand complex nature of water quality issues. (Palma, et al. 2010) were applied Multivariate statistical techniques to evaluate spatial/temporal variations, and to interpret water quality data set obtained at Alqueva reservoir, their results emphasized the need for the implementation of some remediation processes in order to improve the water quality at the Alqueva reservoir, by reducing pollutant inputs to the reservoir, such as pesticides, and by the implementation of wastewater treatment processes.

All of them allow deriving hidden information from the data set about the possible influences of the environment on water quality and offer greater possibilities to managers in terms of aiding the decision-making process.

Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable (Yu et al. 2003). Observations that are highly correlated (either positively or negatively) are likely influenced by the same factors, while those that are relatively uncorrelated are likely influenced by different factors.

There are three stages in factor analysis (Gupta et al. 2005):

1. For all the variables a correlation matrix is generated.
2. Initial set of factors are extracted. The factors are extracted based on the fundamental theorem of factor analysis, which says, that every observed value can be written as a linear combination of hypothetical factors. There are a number of different extraction methods, including centroid, maximum likelihood, principal component, and principal axis extraction.
3. To maximize the relationship between some of the factors and variables, the factors are rotated. By rotating it is attempted to find a factor solution that is equal to that obtained in the initial extraction but which has the simplest interpretation.

The best rotation method is widely believed to be Varimax. After a Varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables.

The term cluster analysis encompasses a number of different algorithms and methods for grouping objects of similar kind into respective categories. In other words cluster analysis is a group of multivariate techniques whose primary purpose is to assemble objects based on the characteristics they possess. Cluster analysis classifies objects so that each object can be similar to the others in the cluster with respect to a predetermined selection criterion. Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set, and is typically illustrated by a dendrogram (tree diagram) (Singh et al. 2004; Shrestha and Kazama 2007). Euclidean distance method was used for determining distance. This is probably the most commonly chosen type of distance. It simply is the geometric distance in the multidimensional space and is computed as (Singh et al. 2008):

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

In this study, the data sets observed during 2011 in Tigris River for the Baghdad stretch in Iraq, are analyzed with FA and CA analyses. Statistical calculations were performed using the “Statistical Package for the Social Sciences Software - SPSS 17 for Windows”. This study aimed at extract information about: (1) identify the main components of the water quality and the most important variables causing difference in the water quality of Tigris River for the Baghdad stretch in Iraq, (2) the similarities or dissimilarities between the monitoring sites, (3) the influence of the possible sources (natural or/and anthropogenic) on the water quality parameters. The results of these analyses may provide a crude guideline for officials to identify and prevent the pollution sources in the Tigris River, Baghdad stretch, especially, there are few scientific studies on this river.

Materials and methods

Study area

The Tigris River is one of the largest rivers of the Middle East stretching for over 1,900 km, of which 1415 km are within Iraq, with a catchment area of 235000 km^2, sharing with Euphrates River as the main sources for man use, especially for drinking water since they pass the major cities in the country (Rzoska 1980).

The Tigris River originates in the Toros mountains of southeastern Turkey; it passes through Turkey, Syria, and Iraq. There are many tributaries flow into the river; these include Botmanse, Kessora, A1-Khabur, the Greater and Lesser Zabs, and A1-Adhaim and Diyala Rivers (Mutlak et al. 1980) Tigris River is the main source of drinking water for Baghdad, the capital of Iraq. Baghdad stretch of the Tigris River extends from Al-Tarmiyahm in the north to Al-Zafaraniah in the south and is located in the Mesopotamian alluvial plain between latitudes 33°14'-33°25' N and longitudes 44°31'- 44°17' E, 30.5 to 34.85 m.a.s.l (Fig. 1). The River divides the city into a right (Karkh) and left (Risafa) sections with a flow direction from north to south. The area is characterized by arid to semi-arid climate with dry hot summers and cold winters; the mean annual rainfall is about 151.8 mm (Al-Adili 1998).

Baghdad, with its six million people, is considered to be the most populated and industrialized city in Iraq. The majority of its municipal and industrial wastes are discharged directly into the river without adequate treatment.

Sampling and analyses

Seven sampling stations were selected on Tigris River namely Al-Tarmiyahm (S1), Al-Muthana bridge (S2), Al-Adhamiyah bridge (S3), Midecal City bridge (S4), Al-Jadriyah Bridge (S5), Al-Rashed (S6) and Al-Zafarania (S7). Figure 1 shows the sampling stations along the Tigris river. The data for seven water quality monitoring stations, consisting of 14 water quality parameters, were monitored over 1 year.

Water samples were collected in polypropylene bottles at monthly intervals from sampling sites between January 2011 and December 2011. Grab sampling procedure was adopted for the analysis of various water quality parameters as recommended by standard methods (APHA, 1998). The polypropylene bottles were used for water quality parameter analysis. Water samples for BOD estimation were collected in BOD bottles (non-reactive borosilicate glass bottles of 300 ml capacity). Analysis of water samples was started as soon as possible after collection to avoid unpredictable changes. Microbiological samples were taken in sterile dark glass bottles. The bottles were kept at +4°C and analyzed within approximately 24 h. The analysis of the samples was done at chemical laboratory of water resource techniques department, institute of technology. Certain analyses were carried out in the Research Directorate for Environment and Water Technology, Ministry of Science and Technology. Table 1 shows the water quality parameters, alongside some of the abbreviations and units used in this study.

The selected parameters included water pH, electrical conductivity (EC), total hardness (TH), biochemical oxygen demand (BOD), fecal coliform (FC) total alkalinity (TA), turbidity (TBR), nitrate nitrogen (NO_3-N), chloride (Cl^-), sulfate (SO_4), magnesium (Mg), calcium (Ca), total dissolved solids (TDS), and iron (Fe).

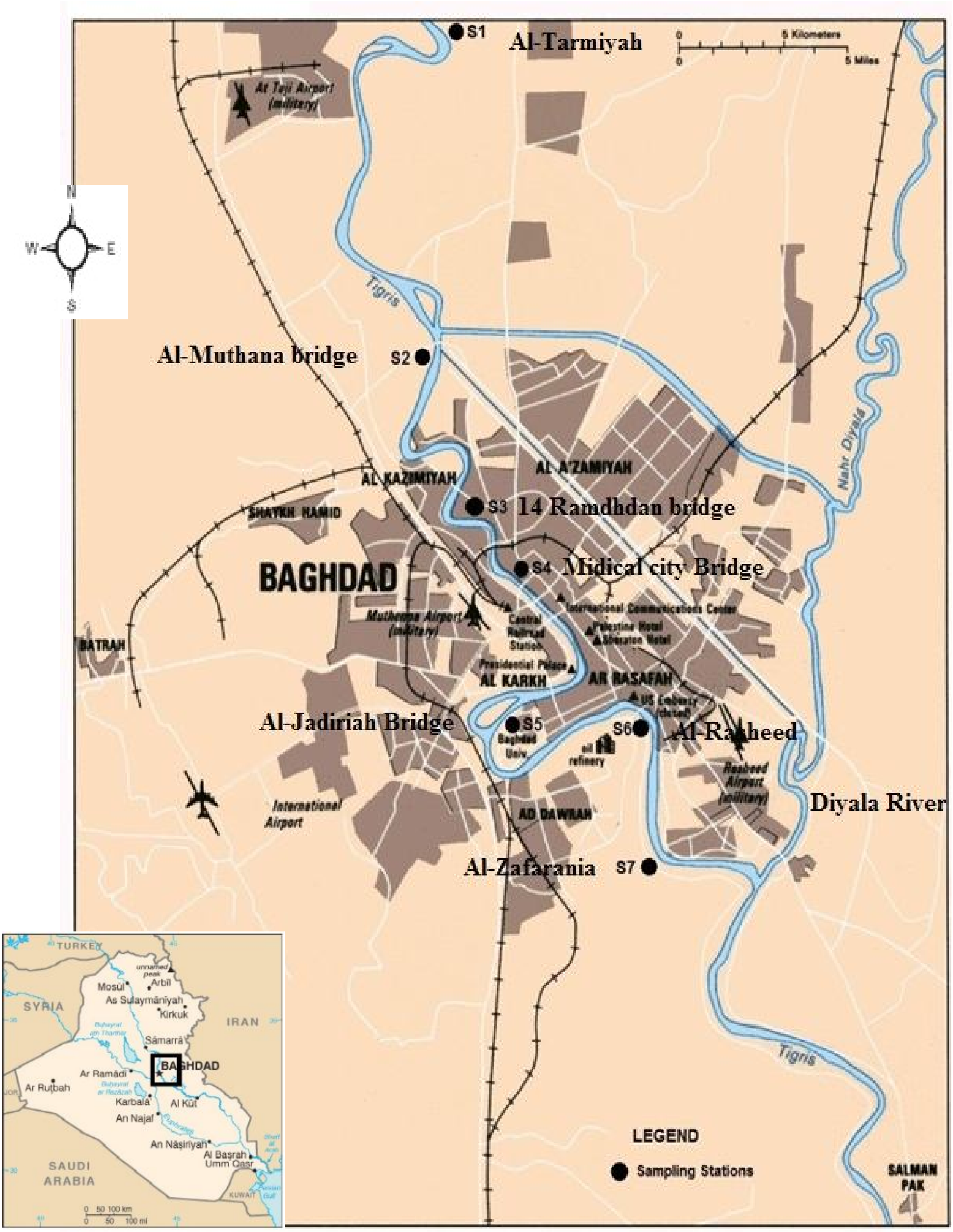

Figure 1 study area and monitoring sites (modified from http://iraqmap.org/)

Table 1: Analytical method, Abbreviation, units for water quality parameters

Parameter	Abbreviation	Units	Instruments / technique used
pH	pH	-	Digital pH meter
nitrate nitrogen NO_3-N,	NO_3^-	mg/L	MAS**
Total Hardness	TH	mg/L	EDTA Titrimetric method
Turbidity	TBR	NTU	Digital Turbidity Meter
Fecal coliform	FC	CFU/100 ml	Membrane filtration technique
Biochemical oxygen demand	BOD	mg/L	Winkler's method, incubation for 5 days at 20°C
Calcium	Ca	mg/L	Titrimetric method
Magnesium	Mg	mg/L	Titrimetric method
Total dissolved solids	TDS	mg/L	Temperature controlled oven
Total Alkalinity	TA	mg/L	Titration method
Electrical conductivity	EC	µs/cm	Measured by conductivity meter
Chloride	Cl^-	mg/L	Silver nitrate method
Sulphate	SO_4^{2-}	mg/L	UV. visible spectrophotometer
Fe	-	mg/L	Detection by FAAS*

*FAAS: Flame atomic absorption spectrophotometr
** MAS: Molecular absorption spectrometry

Results and discussion

Water quality monitoring was conducted at 7 stations in the study area along one year (Jan2011 to Dec 2011). Monitoring stations are seen at Figure 1. The selected parameters for the estimation of surface water quality characteristics were: pH, electrical conductivity (EC), total hardness (TH), biochemical oxygen demand (BOD_5), fecal coliform (FC) total alkalinity (TA), turbidity (TBR), nitrate nitrogen (NO3-N), chloride (Cl^-), sulfate (SO4), magnesium (Mg), calcium (Ca), total dissolved solids (TDS), and iron (Fe). The measured water quality results of Tigris River for one year are summarized in Table 2.

Factor analysis

Factor analysis was applied to fourteen water quality parameters from the 7 surface water quality monitoring stations situated in the Tigris river within Baghdad stretch during one year 2011 using SPSS 17 (Panda et al. 2006; Shrestha & Kazama 2007). The correlation matrix of variables was generated and factors extracted by the Centroid method, rotated by Varimax rotation (Ahmed et al. 2005).

An Eigenvalue gives a measure of the significance for the factor, which with highest Eigenvalue is the most significant. Eigenvalues of 1.0 or greater are considered significant (Kim and Mueller 1978). Therefore, from the results of the FA, the first three eigenvalues were found to be bigger than 1 and the fourth eigenvalue was found to be slightly less than 1. The screen plot of the factor analysis is shown in Fig. 2.

Table 2: The summary of the observed water quality of Tigris river over one year. (n=12)

Parameters		Sampling locations						
		Al-Tarmiyah	*Al-Muthana bridge*	*14 Ramdhdan bridge*	*Midical city Bridge*	*Al-Jadiriah Bridge*	*Al-Rasheed*	*Al-Zafarania*
pH	Min	6.7	7.3	6.9	6.6	6.6	6.7	6.9
	Max	8.1	8.1	8.0	7.9	7.9	7.8	8.0
	Mean	7.3	7.8	7.4	7.7	7.5	7.2	7.6
TBR	Min	17	22	20	23	23	35	25
	Max	114	118	82	132	110	140	110
	Mean	39	43	29	52	53	60	83
T.A	Min	118	118	111	131	109	120	130
	Max	144	147	145	170	141	169	136
	Mean	139	140	132	161	132	155	154
T.H	Min	182	220	200	244	230	220	250
	Max	372	356	340	395	352	300	330
	Mean	234	254	267	291	302	257	297
EC	Min	393	416	402	666	720	594	610
	Max	546	840	747	1132	1112	890	1019
	Mean	447	520	512	894	869	684	842
TDS	Min	190	256	243	351	349	395	410
	Max	372	540	516	1012	955	520	575
	Mean	278	360	362	766	733	432	505
Cl	Min	26	32	30	77	68	42	90
	Max	56	67	61	158	160	80	213
	Mean	38	43	40.5	102	123	74	185
Ca	Min	47	60	67	67	72	69	87
	Max	72	74	103	111	105	109	116
	Mean	54	64	83	77	93	82	94
Mg	Min	19	20	20	23	33	52	36
	Max	54	62	50	73	70	64	68
	Mean	27	29	26	35	43	58	51
SO4	Min	51	70	105	144	120	168	185
	Max	102	202	249	275	222	253	220
	Mean	69	94	168	174	182	193	190
Fe	Min	0.093	0.13	0.07	0.15	0.11	0.9	0.65
	Max	0.49	1.73	1.10	3.8	2.9	2.3	1.72
	Mean	0.12	0.82	0.81	0.9	1.33	1.05	1.13
NO3	Min	0.15	0.3	0.54	0.81	0.91	1.1	1.3
	Max	3.2	3.7	3.3	3.5	3.9	3.3	2.6
	Mean	1.7	1.5	1.9	2.9	2.9	2.2	2.05
BOD	Min	0.8	1	0.9	2.3	2.1	1.9	2.0
	Max	2.5	1.5	2.1	7.4	6.5	5.1	6.3
	Mean	1.5	1.3	1.4	4.2	4.6	3.4	4.2
FC	Min	200	200	210	260	263	200	210
	Max	1000	1400	1500	1400	1320	1350	1400
	Mean	421	590	620	730	1020	920	663

[*] All values in mg/l except pH, EC (µs/cm), FC (CFU/100 ml) and TBR (NTU)

According to the Fig. 2 and a subsequent interpretation of the factor loadings, the first three components were extracted and the other components have been eliminated. This means that majority of the total variance of the original data has been explained by the first three factors. Then, it was used factor rotation (Varimax) to obtain readily interpretable factor loadings (Johnson and Wichern 2002). Table 3 shows the proportion of total variance explained by the first three factors for both rotated and non-rotated factor loadings.

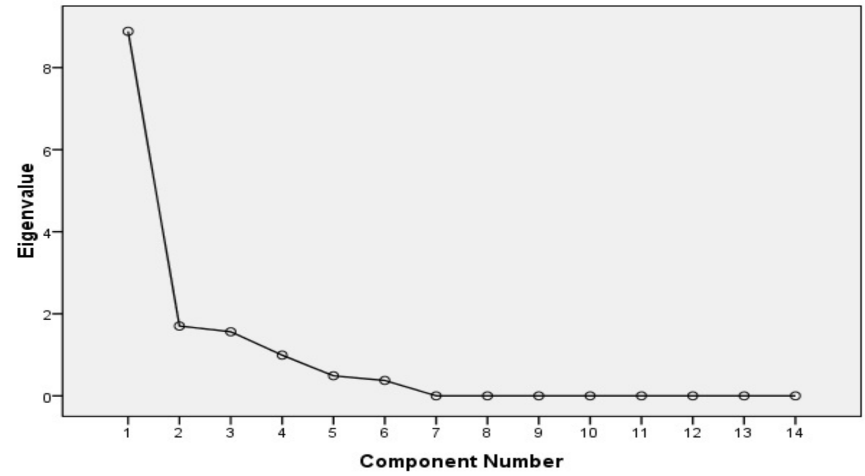

Figure 2 Scree plot of eigenvalues versus components for the observed water quality

It is clear that 49.829%, 24.967% and 11.954% of the total variance of the observed water quality data are explained by the first, second and the third components, respectively. While the first three components explain about 86.75% of the total variance, the remaining 11 components only explain 13.25%. The factor loadings for the first three components from the factor analysis of the observed water quality data are given in Table 4. And the factor loadings were classified as ‘strong’, ‘moderate’ and ‘weak’, corresponding to absolute loading values of >0.75, 0.75–0.50 and 0.50–0.30, respectively (Liu et al. 2003).

Table 3 Total variance explained before and after Varimax rotation

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.882	63.445	63.445	8.882	63.445	63.445	6.976	49.829	49.829
2	1.702	12.154	75.599	1.702	12.154	75.599	3.495	24.967	74.796
3	1.561	11.151	86.750	1.561	11.151	86.750	1.674	11.954	86.750
4	0.992	7.086	93.836						
5	0.488	3.484	97.320						
6	0.375	2.680	100.000						
7	6.308E-16	4.506E-15	100.000						
8	2.785E-16	1.989E-15	100.000						
9	2.045E-16	1.461E-15	100.000						
10	6.190E-17	4.422E-16	100.000						
11	-7.033E-17	-5.024E-16	100.000						
12	-1.197E-16	-8.548E-16	100.000						
13	-2.089E-16	-1.492E-15	100.000						
14	-3.859E-16	-2.756E-15	100.000						

Extraction Method: Principal Component Analysis.

The first factor (F1) explained 49.829% of the total variance and was strong positive loading EC, TDS, Ca, SO_4, TH, Fe, FC, NO_3 and BOD; moderate positive loading Mg and Cl. The contribution to different sources can be from the anthropogenic stresses like urban, industrial activities which carry domestic and industrial wastewater of the city. Based on the presence of different constituents in the factors extracted, the latter can be associated with different sources. The first factor (F1) has contribution from sources which can be linked to point source pollution from domestic and industrial waste and nonpoint source pollution from agricultural activities. The domestic and industrial wastes contain heavy metals and their signature is evident from the higher loadings of Fe in the Factor 1. This factor also invariably indicated that the TDS in the river was mostly contributed by the TH. The association of EC was known for obvious reasons. F1 has strong positive loading with FC (0.885), which represents microorganisms, F1 may involve an urban origin, where waste disposal from populated areas increases fecal contents in the affected waters (Arzu et al. 2008). The contribution to Factor 1 is from anthropogenic influences. This factor assigned as the anthropogenic factor.

Table 4 Factor loadings (Varimax rotation) rotated component matrix

Parameters	Component		
	F1	F2	F3
pH	0.070	0.089	0.895
TRB	0.306	0.919	-0.011
TA	0.022	0.820	0.138
TH	0.856	0.283	0.349
EC	0.802	0.504	0.282
TDS	0.837	0.167	0.425
Cl	0.560	0.708	0.186
Ca	0.846	0.293	-0.159
Mg	0.459	0.718	-0.477
SO4	0.818	0.361	-0.240
Fe	0.862	0.260	-0.034
NO3	0.859	0.090	0.184
BOD	0.791	0.539	0.100
FC	0.885	0.088	-0.285

Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser Normalization, a Rotation converged in four iterations

The second factor F2 explained 24.967% of the total variance and was strong positive loading TBR and TA; moderate positive loading Mg, Cl and BOD. This factor is linked with the agricultural activities, municipal wastewater, erosion effect which occurs during cultivation of soil and heavy rainfall from upland areas (Mutlak et al. 1980). The third factor (F3), explaining the lowest variance (11.954%), has strong positive loadings on pH.

From the factor analysis results it can be concluded that, three factors representing three different processes are: anthropogenic factor, erosion and rainfall factor and pH factor.

Cluster analysis

In this study sampling site classification was performed by the use of cluster analysis (z-transformation of the input data, squared Euclidean distance as similarity measure and Ward's method of linkage). The results of cluster analysis CA are presented in a dendrogram (Fig. 3). Dendograms in cluster analysis provides a useful graphical tool determining the number of clusters which describe underlying process that lead to spatial variation (Boyacioglu, & Boyacioglu 2007).

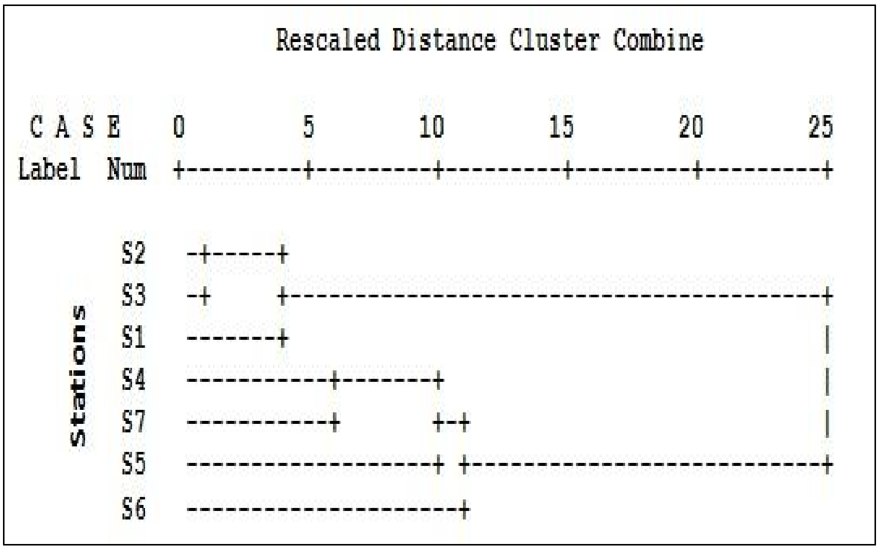

Figure 3 Dendogram showing clustering of monitoring sites of Tigris River (The axis shown at the top indicates the relative similarity of different cluster groups. Lesser distance corresponds to greater similarity between samples)

Since we used hierarchical agglomerative cluster analysis, the number of clusters was decided by water environment quality, which is mainly effected by types of land use and industrial structure. Based on the results of cluster analysis and locations of the monitoring sites, it can be concluded that three major groups were formed by treating all data by clustering:

Cluster 1 (Stations 1 – 2 – 3)

Sites mainly located at the entrance of the river to Baghdad city. Cluster I showing reach that has least concentrations of almost all the variables including the total dissolved solids. S1, S2 and S3 are located upstream of sewage and domestic wastes mixing zones and so no contamination was observed.

Cluster 1I (Stations 4 – 5 – 7)

In this cluster, stations (4 and 5) mainly located at the middle of the river and were grouped under Cluster II. These stations located downstream of sewage mixing zones from medical city. In addition, Station 7 which located in south of Baghdad city, showed the similar water environment quality characteristics with these stations.

Cluster 1II (Station 6)

This cluster consists one station mainly located near Al-Rasheed water treatment plant. Most of the city's factories (Al-Dora oil refinery, oil vegetables factory,tanning factory and cement factory) and agricultural areas located downstream of this station. Therefore, this station received pollutants mostly from non-point source pollution and industrial effluents.

Obviously, the station 7 (cluster II) is much less polluted than station 6 (cluster III), the inclusion of the sampling location suggests the self-purification and assimilative capacity of the river are strong.

Conclusions

In this study, different multivariable statistical methods were successfully applied to assess the quality of Tigris river at Baghdad stretch. The results are useful for river water quality management. The conclusion drawn of this study as follows:

1. Factor analysis results revealed that 14 quality variables can be grouped under three factors namely: anthropogenic factor, erosion and rainfall factor and pH factor.
2. Hierarchical cluster analysis grouped 7 sampling sites into three clusters of similar water quality characteristics. Based on obtained information, it is possible to design an optimal sampling strategy, which could reduce the number of sampling stations and associate costs. It is concluded that stations can be grouped under three clusters.

- Cluster I included sites (Al-Tarmiyahm, Al-Muthana Bridge and Al-Adhamiyah Bridge) which showing least concentrations of all the variables including and are located upstream of sewage and domestic wastes mixing zones. Cluster I represent less polluted sites.
- Cluster II represents sites (Midecal City bridge, Al-Jadriyah Bridge and Al-Zafarania). This cluster considered as moderately polluted zone.
- While the cluster III represents one station (Al-Rashed) located downstream of Baghdad factories and agricultural areas which is corresponded to highly polluted site.

3. With serious situation of Tigris river water pollution at populated city like Baghdad, the management of water quality of the different zones is becoming more important. According to the sources of pollution, different measures should be adopted, in order to control the total quantity of the pollutants and achieve the water quality standard of Tigris river. It could be helpful to managers and government agencies in water quality management.
4. As a result, multivariate statistical methods including factor and cluster analyses can be used to understand complex nature of water quality issues and determine priorities to improve water quality. These methods are believed to assist decision makers assessing water quality and determining priorities in pollution prevention efforts.

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