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Assessment of Water Quality Status for the Euphrates River in Iraq

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ABSTRACT

The aim of this study was to assess a spatial and temporal variations in water quality of the Euphrates River flowing through Iraqi lands, with two approaches: the use of water quality index (WQI) and a principal component analysis (PCA). In the studied section of the river the global water quality WQI was 63.09 (classified as medium – slightly polluted), this value denotes that Euphrates water requires treatment for drinking, no treatment necessary for most industries and crop uses and suitable for most fish and not recommended for sensitive one.

PCA results indicate that three factors for river water explain 92.95% of the total variance. Varifactors obtained from factor analysis for water quality variations indicate that factors responsible for water quality variations are mainly related to soil leaching and runoff process, organic pollution from municipal effluents, pH and temperature.

K**eywords**: Water Quality Index, Multivariate Analysis, Euphrates, Iraq

تقييم نوعية مياه نهر الفرات في العراق

الخلاصة

الهدف من الدراسة هو تقدير التغيرات الموقعية والزمنية لنوعية مياه نهر الفرات الجاري في الأراضي العراقية بطريقتين: الاولى باستخدام مؤشر (دليل) نوعية المياه والثانية طريقة تحليل المركب الأساسي. ومن خلال دراسة مقطع النهر كان مؤشر نوعية المياه 63.09% (يصنف متوسط الجودة –طفيف التلوث) وتلك القيمة تبين بأن مياه الفرات تحتاج الى عملية تصفية لاستخدامات الشرب، ولا تحتاج الى معالجة للمياه الصناعية التي لاتتطلب مياه نقية، وكذلك لاتحتاج الى معالجة لأغراض الري وتعتبر كبيئة مائية صالحة لأغلب انواع الأسماك ماعدا الحساسة منها.

بينت نتائج تحليل المركب الأساسي وجود ثلاثة معاملات اساسية تفسر نسبة 92.95% من التباين الكلي للبيانات. وقد ظهر من خلال تلك المعاملات وجود ثلاث مجاميع رئيسية تسبب حدوث التغيرات في نوعية المياه، الأولى ناتجة من السيح وغسل التربة، الثانية ناتجة من التلوث العضوي والناتج من تصريف المياه الثقيلة في النهر والثالثة ناتجة من التباين في درجة الحامضية ودرجة الحرارة.

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INTRODUCTION

Meeting water quality expectations for streams and rivers is required to protect drinking water resources, encourage recreational activities, and provide good environment for fish and wildlife. Traditional approaches to assessing river water quality based on the comparison of experimentally determined parameter values with existing local normative. However it does not provides a global vision on the spatial and temporal trends in the overall water quality (Debels et al., 2005) as cited by (Kannel et al., 2007).

Water quality index (WQI) is considered as a mathematical tool instrument used to transform large of water quality data into a single number, usually dimensionless, which expresses the relative magnitude of some complex phenomenon (Lohani and Todino, 1984). Since 1965 when Horton (1965) proposed the first WQI a great deal consideration has been given to the development of index methods. Indices define a unique rating curve for each parameter (Liou et al., 2003).

Numerous studies on water quality assessment at different locations have made use of WQIs such as (Lohani and Todino, 1984; Liou et al., 2003; Said et al., 2004; Avvannvavar and shrihari, 2008; Fullazzaky et al., 2010 and Susilo and Fabrinal, 2011). For effective pollution control and water resource management, it is required to identify the pollution source and their quantitave contributions. Multivariate statistic analysis provides an alternative approach to understand the water quality of the study region and identify the pollution source apportionments, principal component analysis (PCA) is one of the main techniques of multivariate analysis approach, the main advantages of this technique is the ability in analyzing large complicated data, which have many variables and experimental unit (Akbal et al., 2011).

In recent years the PCA have been applied to a variety of environmental applications, including groundwater monitoring wells, and hydrographs, examination of spatial and temporal patterns of surface water quality, identification of chemical species related to hydrological conditions, and assessment of environmental quality indicators (Kazi et al., 2009; Shirodkar et al., 2009) as cited by (Akbal et al., 2011).

The aim of this study is to determine temporal and spatial variations in surface water quality for the Euphrates River in Iraq during a six years monitoring period (2005-2010). A generalized pattern for water quality assessment is attempted to develop by linking the two mature methodologies above WQI and PCA. Rating curves are used in data processing. PCA is proposed for categorizing the employed parameters in accordance with common features.

STUDY AREA

The Euphrates River is one of two major rivers flowing through Iraq. It originates in Turkey, runs through Syria entering Iraq from the western border and discharge in Shat Al-Arab. The water of the river is used for drinking, irrigation, recreation and fishing. A total of seven sampling stations for water quality monitoring were selected along a specified section of the river as shown in Figure (1). The details of sampling stations are presented in Table (1).

WATER QUALITY DATA

The water quality data were retrieved from (Ministry of Water Resources – Environmental Studies Center). The data set in this study comprised of 11 parameters, continuously monitored in twelve months for six years period from (2005 – 2010). These parameters are water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca), chlorides (Cl), sulfates (SO_4), five days biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and fecal coliforms (Ecoli). These parameters were chosen as they have verified weight factors for different ranges of the parameters to calculate water quality index (WQI) in various literatures: (Kannel et al., 2007 and Diaz et al., 2007).

Water Quality Index (WQI)

Water Quality indices are calculated in two steps: the raw analytical results for the selected water quality parameters, having different units of measurements are transformed into unit-less sub-index values. This can be done by transforming each parameter into (0 to 100) scale using sub-index curves (Cude, 2000; Pesce and Wunderlin, 2000) as cited by (Kannel et al., 2007). Applying a suitable weighting factors that reflects the importance of each parameter as an indicator of the water quality. These sub indices are then averaged to give a water index value (Kannel et al., 2007).

The equation for the water quality index is (Kannel et al., 2007):

$$WQI=\frac{\sum_{i=1}^{n} C_i * P_i}{\sum P_i} \qquad \ldots\ldots (1)$$

Where:

n is the total number of parameters.

C_i is sub-index of parameter (i),

a number from (0 to 100) having 100 as highest water quality.

P_i is the relative weight assigned to each parameter.

P_i value range from (1 to 4) with 4 assigned to a parameter that has the most important impact on environment and value of 1 assigned to the parameter that has a smaller impact (Kannel et. al, 2007).

P_i values for each parameter are presented in Table (2).

Rating sub-index curves for the employed parameters were drawn by using GRAPHER ver.1.09 software based on the ratings proposed by (Liou et al., 2003; Kannel et al., 2007; Diaz et al., 2007) as shown in Figure (2).

A general water classification system adopted her is presented by (Kannel et al., 2007), according to which WQI in the range (0-25) is very bad, (26-50) is bad, (51-70) is medium, (71-90) is good and (91-100) is excellent. While more detailed classification will be considered to classify the validity of water quality for different uses (Diaz et al. , 2007), as shown in Figure (3).

All calculations were performed with Microsoft Excel 2007. WQI scores in this paper are based on annual averages. The quality map was plotted with SURFER ver. 8.0 software using ordinary kriging without drift interpolation which allows to get a 3D plot (Keckler, 1996) as cited by (Diaz et al., 2007).

Principal Component Analysis (PCA)

This analysis was applied to assess the significance of parameters that explain the patterns of the monitoring stations (Diaz et al., 2007). The PCA was applied on the basis of the data set of the mean annual values of the 11 water quality parameters. PCA technique extracts the eigenvalues and eigenvectors from the covariance matrix of original variables. The PCs are the uncorrelated variables with eigenvectors (loading or weighting), thus the PCs are the weighted linear combinations of the original variables (Akbal et al., 2011).

It is a powerful technique for pattern recognition that attempts to explain variance of a large set of inter-correlated variables and transforming into a smaller set of independent variables (principal components) (Andrade et al., 2008) as cited by (Akbal et al., 2011).

The correlation matrix consisting of 11 water quality parameters for the WQI was used for PCA; all assessments were carried out with STATISTICA 99 edition software and varimax rotation.

RESULTS AND DISCUSSION

Water Quality Index (WQI)

The mean, standard deviation and range (minimum and maximum) values of WQI score for each monitoring station in the whole period studied are provided in Table (3).

WQI scores indicate water quality throughout the period of the study and along the studied section of the river was less than 81 on a scale of (0-100). Mean WQI along the river section ranged from 55.65 to 74.94 (monitoring station S6 and S1) respectively, with a global average of 63.09 ± 9.47 during the study period. Station S6 in year 2008 had the lowest WQI score and station S1 in year 2007 is the highest.

The spatial and temporal variations of WQI scores are shown in Figures (4) and (5). Mean WQI scores were lower than 65 during the period of study except the years 2005 and 2007, Figure (5).

WQI values were higher at the monitoring stations upstream, at station S3 there is a significant water quality drop of 15 units compared with station S1. Such a deterioration of the river water quality proceeds as the river moves downstream. This associated with the city sewage discharge and the extensive agricultural activities and increasing population, both point and non point sources leads to river pollution. While at station S7 a slight increase of the water quality about 6 units appears this is due to the low human population and activities in the area between the two stations.

Figure (6) shows the water quality map based on a 3D Surfer plot. During the whole study period, the five sites (S3, S4, S5 and S6) downstream of the river show the lowest water quality scores especially through the last two years.

The WQI analysis enabled to classify the river water quality as medium (WQI=63.09 units) and a further classification according to Figure (3) , indicates that Euphrates river requires extensive treatment for public water supply system, no treatment necessary for normal industry and crop uses and is suitable for most fish.

Principal Component Analysis (PCA)

The Results correlation matrix of the PCA for the data set is shown in Table (4), where some clear hydro-chemical relationships can be readily inferred, BOD is negatively related with COD, TDS, TH and SO_4. Ecoli is positively related with Ca, CL and negatively related with COD, temperature and pH. Parameters that are related with mineralization have high interdependence among them.

According to the eigenvalue – one criterion (Kowalkowski et al., 2006) as cited by (Diaz et al., 2007), only three first eigenvalues was taken into account (eigenvalues >1); the reminder principal (PC) components were eliminated. Following the above criterion those components loadings higher than 0.6 may be taken into consideration for the interpretation of the PC analysis (Diaz et al., 2007) as shown in Table (5).

Factor 1 explains 56.44% of the total variance and is associated with strong loadings of TDS, TH Ca, CL, SO_4 and EC. This factor represents soil leaching processes and active participation of dissolved ions in the river water quality.

Factor 2 explains 23.84% of total variance in the data set and consists of strong loadings of BOD, Ecoli, COD, and Ca. This factor represents influences from wastewater disposal activities.

Factor 3 Accounts for 12.68% of the total variance and indicates a strong negative loadings of temperature and pH. This factor represents physicochemical sources of variability.

The three factors for river water explain 92.95% of the total variance as shown in Table (5).

CONCLUSIONS

All of these physico-chemical biological parameters have shown temporal and spatial variations. As a case study, WQI was used to evaluate the spatial and temporal changes in the water quality. It was found that the WQI was 74.94 units (classified as good) at the upstream monitoring station and 61 units (classified as medium) at the downstream station. The variation of WQI showed that there was a significant decrease in water quality for the studied period with deterioration of water quality from 67.81 to 62.95 during six years. The maximum water quality decrease was found at station S6. The global WQI was 63.09, which means (extensive treatment required for use in the public water supply system, no treatment necessary for most industries and crop uses and not recommended for sensitive fish).

PCA permitted the identification of indicator parameters affecting water quality in the different monitoring stations. Varifactors obtained from factor analysis indicate that the parameters responsible for water quality variations are mainly related to soil leaching and runoff process, domestic effluents and waste disposal areas.

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Table (1) The Sampling Site Locations

Sampling Location	Governorate	Location No.	Distance (km)	Latitude	Longitude
Saqlawiyah	Al-Anbar	S1	0	33° 23.774' N	43° 39.603' E
Hindiyah	Babel	S2	93.3	32° 43.697' N	44° 16.154' E
Shenafiyah	Al-Qadissiyah	S3	132.5	31° 34.793' N	44° 38.748' E
Semawa	Al-Mothanna	S4	68.6	31° 18.819' N	45° 18.853' E
Nasiriyah	Thi-Qaar	S5	96	31° 02.492' N	46° 15.264' E
Madina	Basrah	S6	97.4	30° 57.678' N	47° 16.288' E
Qurna	Basrah	S7	15	30° 7.125' N	47° 10.5' E

Table (2) Parameters Used in WQI Calculation and Relative Weights (Kannel et al., 2007).

Parameter	BOD	Ecoli /100ml	COD	TDS	TH	Ca	CL	SO4	EC	Temp.	pH
Units	(mg/L)	no	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	µS/cm	C°	pH unit
Relative Wight (Pi)	4	3	4	3	2	1	1	2	2	1	1

Table (3) WQI Scores of The Monitoring Stations Monitoring Station.

Year	S1	S2	S3	S4	S5	S6	S7	Mean	SD	Min	Max
2005	66.69	78.31	66.59	63.35	66.14	67.89	65.71	67.81	4.83	63.35	78.31
2006	77.08	61.9	62.07	60.26	54.65	55.8	65.38	62.45	7.45	54.65	77.08
2007	80.8	80.73	66.77	64.42	60.54	53.16	58.86	66.47	10.67	53.16	80.8
2008	77.96	77.17	56.77	57.33	58.55	48.88	49.96	60.95	11.94	48.88	77.96
2009	71.22	72.86	51.02	51.12	49.42	50.33	59.31	57.90	10.21	49.42	72.86
2010	75.86	75.79	56.2	55.44	52.81	57.81	66.75	62.95	9.81	52.81	75.86
Mean	74.94	74.46	59.90	58.65	57.02	55.65	61.00	Global mean		63.09	
SD	5.11	6.69	6.31	5.03	5.98	6.85	6.38	Global SD		9.47	
Min	66.69	61.9	51.02	51.12	49.42	48.88	49.96	Absolute Min		48.88	
Max	80.8	80.73	66.77	64.42	66.14	67.89	66.75	Absolute Max		80.8	

Table (4) Correlation Matrix of Water Quality Parameters

	BOD	Ecoli	COD	TDS	TH	Ca	CL	SO4	EC	Temp.	pH
BOD	1.000										
Ecoli	0.009	1.000									
COD	-0.418	-0.553	1.000								
TDS	-0.451	0.310	0.055	1.000							
TH	-0.509	0.348	0.098	0.994	1.000						
Ca	0.098	0.753	-0.725	0.612	0.585	1.000					
CL	-0.378	0.424	-0.134	0.981	0.970	0.748	1.000				
SO4	-0.619	0.160	0.250	0.961	0.967	0.407	0.901	1.000			
EC	-0.301	0.314	-0.041	0.979	0.960	0.684	0.981	0.891	1.000		
Temp.	0.229	-0.617	0.381	-0.607	-0.614	-0.762	-0.704	-0.429	-0.679	1.000	
pH	0.278	-0.458	0.188	0.009	-0.042	-0.229	-0.070	0.106	-0.028	0.714	1.000

Table (5) Factor Loadings (Varimax Normalized) of Water Quality Parameters.

Parameter	Factor 1	Factor 2	Factor 3
BOD	-0.466	0.615	-0.466
Ecoli	0.246	0.649	0.491
COD	0.099	-0.914	-0.117
TDS	0.995	0.051	0.077
TH	0.995	0.007	0.142
Ca	0.995	0.796	0.214
CL	0.995	0.222	0.139
SO4	0.995	-0.189	0.024
EC	0.995	0.174	0.069
Temp.	-0.527	-0.411	-0.692
pH	0.096	-0.104	-0.973
Eigenvalue	6.208	2.622	1.394
% Total Variance	56.44	23.84	12.68
% Cumlulative Variance	56.44	80.27	92.95

Figure (1) Monitoring Stations

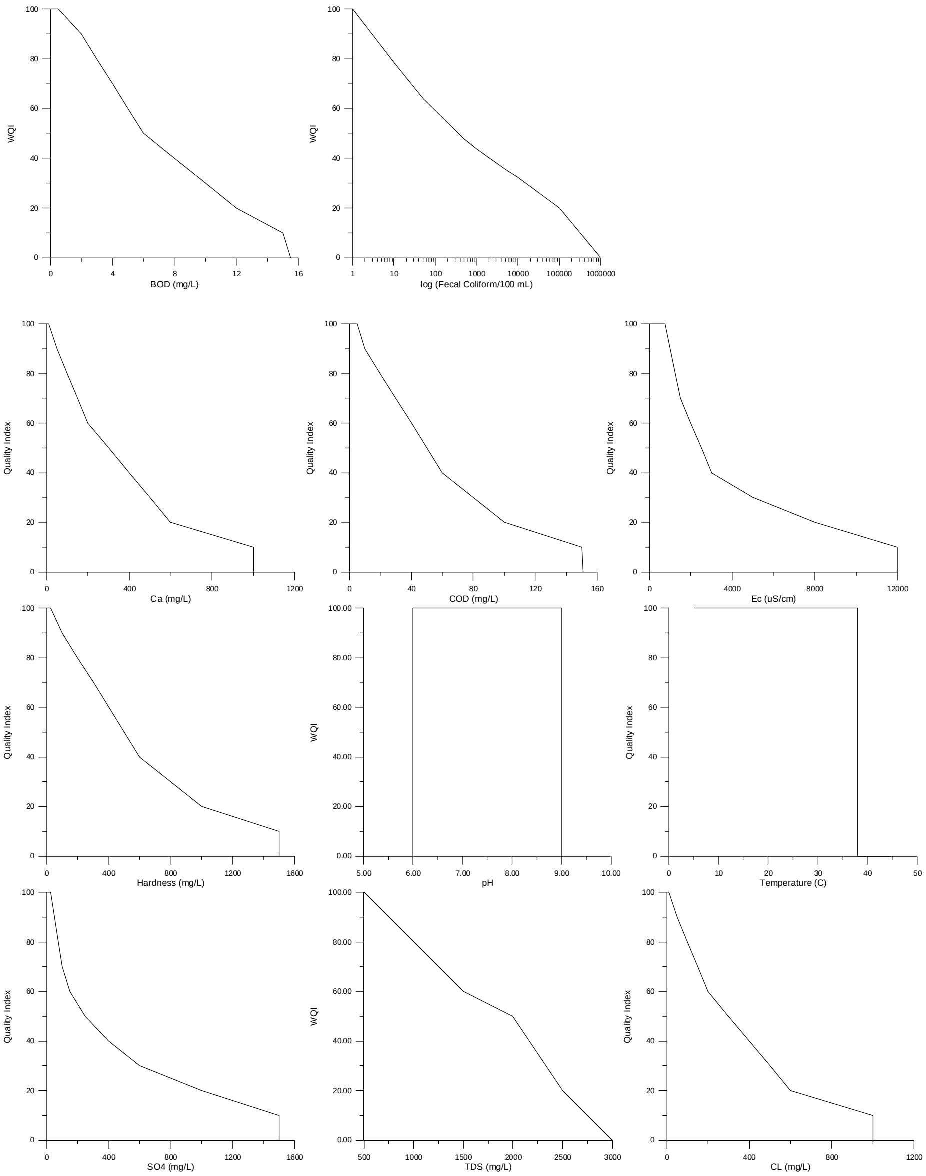

Figure (2) the Assigned Rating Curves for the Studied Parameters

Level of Pollution (100=Best)	**Water Uses**				
	Public Water	**Recreation**	**Fish**	**Agricultural**	**Industrial**
100	Purification not Necessary	Acceptable for All Water Sports	Acceptable for All Fish	Purification not Necessary	Purification not Necessary
90	Minor Purification Required			Minor Purification for Crops Requiring High Quality Water	Minor Purification for Industries Requiring High Quality Water
80	Necessary Treatment Becoming more Extensive				
70		Becoming Polluted Still Bacteria Count	Marginal for Sensitive Fish	No Treatment Necessary for Most Crops	No Treatment Necessary for Normal Industry
60			Doubtful for Sensitive Fish		
50	Doubtful	Doubtful for Water Contact	Hardy Fish Only	Extensive Treatment for Most Crops	Extensive Treatment for Most Industry
40	Not Acceptable		Coarse Fish Only		
30		Obvious Pollution Appearing	Not Acceptable	Use Only for Very Hardy Crops	Rough Industrial Use Only
20		Obvious Pollution Not Acceptable		Not Acceptable	Not Acceptable
10					
0					

Figure (3) General Rating Scale for Water Quality (Diaz et al., 2007)

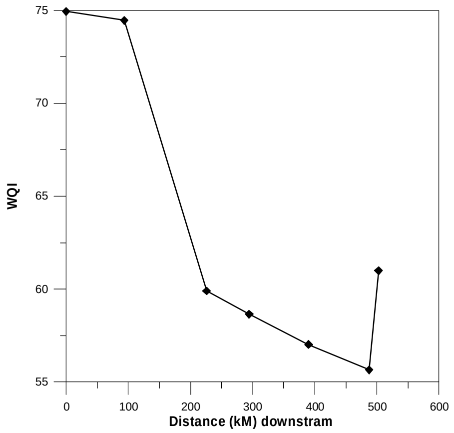

Figure (4) Spatial Variation of Mean WQI Scores for the (7) Monitoring Stations

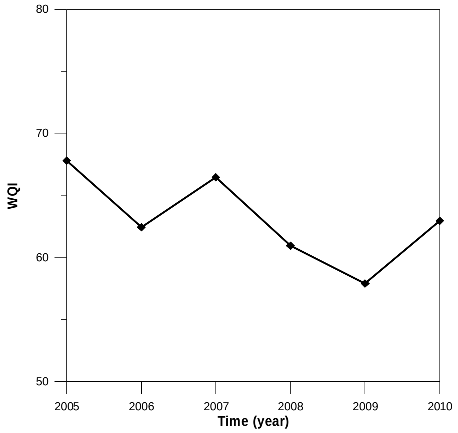

Figure (5) Temporal Variation of Mean WQI Scores for the (7) Monitoring Stations

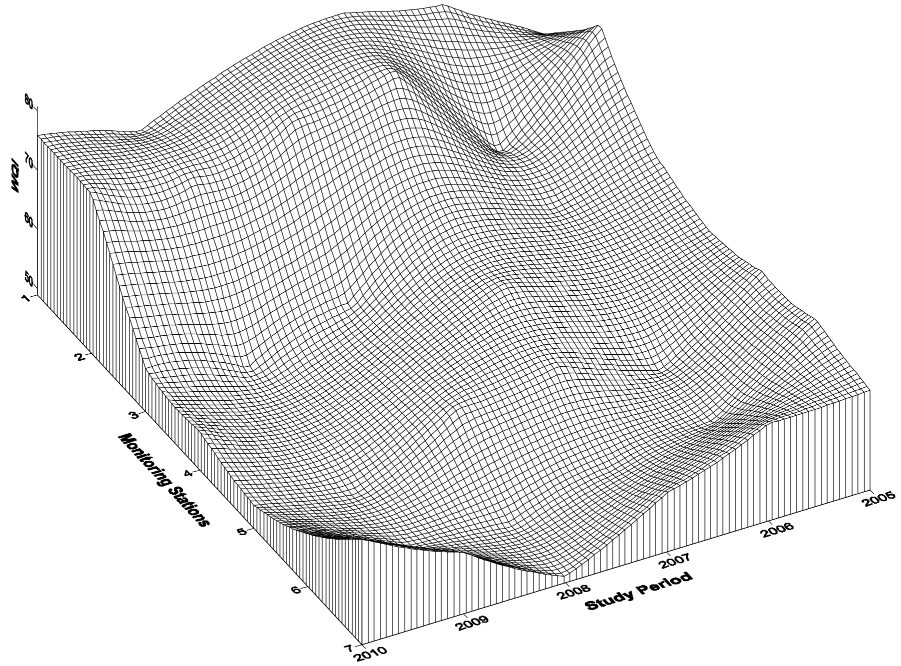

Figure (6) 3D Plot of Annual WQI Scores for Each Monitoring Station