Application of Water Quality Index and Water Suitability for Drinking of the Euphrates River within Al-Anbar Province, Iraq

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ABSTRACT

In this study water quality was indicated in terms of Water Quality Index that was determined through summarizing multiple parameters of water test results. This index offers a useful representation of the overall quality of water for public or any intended use as well as indicating pollution, which are useful in water quality management and decision making. The application of Water Quality Index (WQI) with ten physicochemical water quality parameters was performed to evaluate the quality of Euphrates River water for drinking usage. This was done by subjecting the water samples collected from seven stations within Al-Anbar province during the period 2004-2010 to comprehensive physicochemical analysis. The ten physicochemical parameters included: pH value, Alkalinity (ALK), Orthophosphate (PO_4^{-3}), Nitrate (NO_3^-), Sulphate (SO_4^{-2}), Chloride (Cl^-), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), and Total Dissolved Solids (TDS). The average annual overall WQI was found to be 107.59 through the study period. The high WQI obtained is a result of the high concentrations of Orthophosphate and Magnesium which can be attributed to the various human activities taking place along the river banks. From this analysis the quality of the Euphrates River is classified as "very poor quality" ranging poor water at the river upstream near station (E1) and unsuitable for drinking at the river downstream near station (E7) with an annual minimum WQI of 89.34 in 2008 and maximum 112.44 in 2009. The present study demonstrated the application of WQI in estimating and understanding the water quality of Euphrates River. WQI appears to be promising in water quality management and a valuable tool in categorizing pollution sources in surface waters.

KEYWORDS: Water quality index, Euphrates River, Drinking water quality, Physicochemical parameters, Total hardness, Total dissolved solids, and orthophosphate.

تقييم مؤشر نوعيةِ الماءِ وملائمةِ ماءِ نهرِ الفرات للشربِ ضمن محافظة الانبار،العراق

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الخلاصة

في هذه الدراسة تم تقييم نوعية المياه من خلال مؤشر نوعية الماء والذي يحسب من عدة مواصفات للماء. ويعتبر هذا المؤشر اداة فعالة لمعرفة نوعية الماء للأستخدامات المختلفة، تحديد التلوث، ادارة نوعية المياه واتخاذ القرارات الصائبة في هذه الانشطة. تم استخدام هذا المؤشر لمعرفة مدى صلاحية مياه نهر الفرات للشرب. ولتحديد المؤشر تم الاعتماد على عشر عناصر لمواصفة ماء النهر المقاسة في المحطات المحددة في محافظة الانبار للفترة 2004-2010. العناصر المقاسة هي درجة الحامضية، القاعدية، الاورثوفوسفات، النترات، الكبريتات، الكلوريد، العسرة الكلية، الكالسيوم، المغنسيوم، المواد الصلبة الكلية. ان المعدل السنوي الكلي لمؤشر نوعية الماء كان 107,59. وهذه القيمة العالية لهذا المؤشر كان بسبب تراكيز عناصر المغنيسيوم والاورثوفوسفيت والتي تعزى الى الفعاليات البشرية على ضفاف النهر. من هذا التحليل تعتبرنوعية مياه نهر الفرات "رديئة جدا" وتحتاج الى معالجة حيث تتدرج من صنف "ردي جدا" في مقدمة النهر وقرب المحطة (1) الى مياه غير ملائمة للشرب في مؤخرة النهروقرب المحطة (7) ، اما التغاير السنوي لمؤشر نوعية بحده الادنى 89,34 بعام 2008 وبحده الاعلى 112,44 بعام 2009. هذه الدراسة تمثل تطبيق لمؤشر نوعية المياه في تخمين وفهم نوعية ماء نهر الفرات ،ويمكن اعتبار مؤشرنوعية الماء اداة فعالة في ادارة نوعية المياه وكذلك للتعرف على مصادر التلوث في المياه السطحية.

الكلمات الرئيسية: مؤشر نوعية المياه، نهر الفرات، نوعية مياه الشرب، العناصر الفيزوكيميائية، العسرة الكلية، التوصيلية الكهربائية، المواد الذائبة الكلية، الاورثوفوسفيت.

1. INTRODUCTION

Rivers are the most important natural resource for human development but they are being polluted by indiscriminate disposal of sewage, industrial waste and plethora of human activities, which affects its physicochemical and microbiological quality. This may cause the deterioration of river water quality and makes it necessary to monitor water quality to evaluate the problem and its cause (Mishra et al., 2009).Water quality can be defined as a conventional ensemble of physical, chemical, biological and bacteriological features that are expressed as values, which expresses the possibility of its anthropoid usage. It is imperative to prevent and control river pollution and to have reliable information on the quality of water for effective management (Koklu and Topal, 2010).

Many efforts have been directed toward making qualitative and quantitative decisions based on monitoring water quality. A comprehensive river water quality monitoring program is becoming a necessity in order to safeguard public health and to protect valuable fresh water resources. Monitoring programs of a river play a significant role in water quality control since it is necessary to know the contamination degree so as not to fail in the attempt to regulate its impact. However, the quality is difficult to evaluate from a large number of samples, each containing concentrations for many parameters (Almeida et al. 2007).

The concept of water quality index (WQI) is based on the comparison of the water quality parameters with respective regulatory standards and gives a single value to the water quality of a source; this translates the list of constituents and their concentrations present in a sample (Khan et al. 2003).

WQI is a mathematical instrument used to transform large quantities of water quality data into a single number, which provides a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water body (Bordalo et al. 2006). It serves the purpose to improve understanding water quality issues, by integrating complex data and generating a score that describes water quality status and evaluate water quality trends.

WQI also permits the assessment of changes in water quality, to identify water trends, and to classify the purpose of various water uses. The water quality index is a good indication of telling whether or not the water being tested is healthy (Cude 2001).

Water quality index is one of the most effective tools expressing water quality that offers a simple, stable, reproducible unit of measure and communicate information of water quality and becomes an important parameter for the assessment and management of surface water (Atulegwu and Njoku, 2004).

WQI identifies and compares water quality conditions over time which can be used in a variety of ways as an environmental indicator; evaluate the effectiveness of water quality management activities; improves comprehension of general water quality issues and Illustrates the need for and effectiveness of protective practices. The objective of the present study is to assess the present water quality, through analysis of some selected water quality parameters of Euphrates River in order to appreciate the impacts of unregulated waste discharge on the quality of the river as well as to compare and discuss its suitability for human consumption based on computed water quality index values.

2. Materials and Methods

2.1 Study Area Description

Euphrates River is the longest river in the Middle East. It originates in the eastern highlands of Turkey, between Lake Van and the Black Sea. It travels a distance of 2,700 kilometers before flowing into the Arab Gulf. About 40 percent of the river lies within Turkey, while the rest is divided among the two downstream riparian countries, 25 percent in Syria and 35 percent in Iraq. The stream flow variations naturally prevent utilization of the river's full water potential. Unfortunately, the seasonal distribution of the availability of water does not coincide with the irrigation requirements of the basin. In an average year, the river reaches its peak flow in April and May as the winter mountain precipitation melts. The typical low water season occurs from July to December, reaching its lowest value in August and September when water is most needed to irrigate the region's winter crops. The average monthly hydrograph of the Euphrates shows a variation between 33 percent and 275 percent of the annual average, evidence of the extent of its seasonal fluctuations (Iraqi Ministries of Environment, 2006).The Euphrates River is a major river of Iraq having a drainage area and entering in the western side of Iraq. Within Al-Anbar province it runs for a distance of about 337 km in the Mesopotamian alluvial plain. This area is characterized by arid to semi-arid climate with dry hot summers and cold winters. The water of the river is used for irrigation and drinking water after it has been purified.

2.2 Data collection and analysis

In order to give a comprehensive idea of the overall water quality and to determine the water quality index of the river, water samples were collected from seven stations along the Euphrates River near the borders at Al-Qaim City to the Bridge Fallujah. These stations were selected to carry out the present study a long 337 km stretch of Euphrates River situated in Al-Anbar city. The locations of these stations are described in **Table 1** and shown **in Fig. 1**.

The data used in this paper were provided by Ministry Of Environment-Water Quality Monitoring and Evaluating Department–Technical Directorate, which cover the study period from January 2004 to December 2010 which represent the monthly average values for ten water parameters. These ten parameters are; pH value, Total Alkalinity (TA), Orthophosphate (PO_4^{-3}), Nitrate (NO_3^-), Sulphate (SO_4^{-2}), Chloride (Cl^-), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), and Total Dissolved Solids (TDS).

2.3 Calculations of the WQI

The water quality index was calculated using the assigned weighted arithmetic index method. The ten important physicochemical parameters were used with respect to their suitability for human consumption and availability of data from each station. These parameters were compared with the permissible values for drinking water quality recommended by the World Health Organization (WHO) based on the formula to calculate WQI proposed by Tiwari and Mishra (1985):

$$w_i = \frac{K}{S_i} \qquad (1)$$

Where:

w_i: Unit weight factor;

K: Proportional constant;

S_i: Standard permissible value of i^{th} parameter.

The unit weight (w_i) for all the ten chosen parameters with standard values one given in **Table 2**. The quality rating scale (q_i) is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value and is determined as follows:

$$q_i = \frac{(V_i - V_{10})}{(S_i - V_{10})} \times 100 \qquad (2)$$

Where:

q_i: Quality rating scale for the i^{th} water quality parameter;

V_i: Estimated permissible value of the i^{th} parameter;

V_{10}: Ideal value of the i^{th} parameter in pure water;

All the ideal values (V_{10} =0) are taken as zero for drinking water except for pH=7.0.

$$Overall\ WQI = \sum_{i=1}^{i=n} w_i \times q_i \qquad (3)$$

Based on the calculated WQI, the classification of water quality types is shown in **Table 3**.

3. Results and Discussion

3.1 Water Quality

This study involves the determination of physical and chemical parameters of surface water at different stations along the Euphrates River (study area). The descriptive statistics analyses for the collected water quality parameters are shown in **Table 4**. In order to reach a better view on the causes of deterioration in water quality the results are compared with the permissible values of various impurities in drinking water recommended by the World Health Organization (WHO, 2004). In present study the mean concentration value of physic-chemical parameters as below:

1. pH value was 7.71 within the allowable limits for surface water indicating that the water samples are almost neutral to sub-alkaline in nature, and the pH value in the river increased along the downstream.

2. Total alkalinity value concentration was 171.9 mg/L indicating slightly higher than the permissible level for drinking water recommended 100 mg/L, and the maximum value of alkalinity in the river at station 3.
3. Orthophosphate value concentration was 0.22 mg/L less than the tolerable limits 1 mg/L, and the maximum value is at station 3.
4. Nitrate value 3.85 mg/L indicating that the nitrate concentration do not cause eutrophication in surface waters that still complies with the WHO recommendations 50 mg/L, and the maximum value of nitrate in the river at station 1.
5. Sulphate concentration was 223.86 mg/ L which is within the tolerable limits of 250 mg/L, and the maximum value of sulphate is at station 4. This may be due to the using of fertilizer in the region.
6. Chloride value concentration was 138.34 mg/L which is found to be within the permissible levels of 250 mg/L and the maximum value of chloride was located at station 2 which could be from a non-point pollution source.
7. Total hardness value concentration was 331.71 mg/L and often higher than the permissible level recommended by the WHO for drinking water 100 mg/L, and the maximum value of total hardness in the river is at station 2. Hardness in water may cause clogging troubles in pipelines, formation of scales in boilers leading to wastage of fuel and the danger of overheating of boilers (Egereonu and Nwachukwu, 2005).
8. The mean concentrations of calcium and magnesium were 92.24 and 34.33 mg/L which are within the recommended permissible limit of 100 mg/L and 30 mg/L respectively. The maximum value of calcium and magnesium in the river were at station 7 and 2 respectively.
9. Total dissolved solids value was 606.29 mg/L which is higher than the maximum permissible limit in drinking water 500 mg/L, and the maximum value of TDS was at station 2.

The most observed physicochemical parameters values were often lower than the permissible level for pH value, Total Alkalinity, Orthophosphate, Nitrate, Sulphate, Chloride, and Calcium while the Total Hardness, Magnesium, and Total Dissolved Solids were higher than the permissible levels recommended by the WHO for drinking water. **Fig. 2** shows the variation of the different water quality parameters along the selected stations on the Euphrates River. The results from the data analysis show that, the water is certainly unfit for drinking purposes (without treatment), but for various other usage purposes, it could be considered quite acceptable.

3.2 Water Quality Index (WQI)

In this study, the water quality index (WQI) along the Euphrates River within Al-Anbar province has been calculated using the assigned weighted arithmetic index method by ten parameters of raw water that were studied in respect to their suitability for human consumption compared with the standards of drinking water quality recommended by the World Health Organization (WHO, 2004). **Table 3** shows the classification of water quality based on WQI value and distribution of the water samples according to their respective quality group. Based on the WQI value, water is categorized into five groups ranging from excellent water to water Unfit and unsuitable for drinking.

The computed overall WQI value of all the samples and stations along Euphrates River was 107.59 which implies that the water is generally " Unfit and unsuitable for drinking " as shown in **Table 5**. The computed monthly overall WQI along Euphrates River for all samples and stations was 125.97, which implies that the water is generally " Unfit and unsuitable for drinking " as shown in **Table 6**. The monthly WQI variation ranged lower value 91.98 at January and higher value 170.28 at November along Euphrates River , and classify from very poor water quality to Unfit and unsuitable for drinking as shown in **Fig. 3** .

The annual river water quality index variation along Euphrates River ranged 74.95 "poor quality" at 2008 and 112.44 " Unfit and unsuitable for drinking" at 2009 as shown in Fig. 4, and the annual river water quality index variation along Euphrates River ranged 90.71 "very poor quality" at the upstream near station (E1) and 100.5" Unfit and unsuitable for drinking" at the downstream station (E7) which reflect the effects of pollution as shown in **Table 7 and Fig. 5**. The result obtained from this study indicates that the overall WQI of Euphrates River water is not within the permissible limits for drinking water (100) for the entire samples taken, thereby signifying contamination. The high value of WQI obtained is as a result of the high concentrations of phosphate and magnesium in the water and can be attributed to the various human activities taking place at the river bank. Shaymaa and Ayad, in 2012, performed WQI on the Euphrates River to evaluate its anthropoid usage such as potable, and agricultural water usages, and the results showed that WQI of Euphrates River ranged from "Good" to "Very Poor" quality for drinking and irrigation usage.

3.3 Correlation matrix

From correlation coefficient values between monthly water quality index

(MWQI) and water quality parameters, it is evident that phosphate and magnesium were the most affecting factors for the computed MWQI values of Euphrates River in the study period as shown in **Table 8**.

4. CONCLUSIONS

The use of the water quality index in the determination of the water quality for any river corresponds to the present tendencies within the field of water resources management; thus, it is attempted at a more important scale to assign chemical and ecological importance to the classical parameters related to the physical and chemical quality. The advantages of using this method were numerous, as it includes more variables in only one number; brings to the same measuring unit more parameters related to water quality; offers the possibility to compare in temporal and spatial terms the quality of more water bodies or that of a single one; and offers an image of the water usage degree in various fields/purposes.

Application of WQI in this study has been found very useful in the assessment of the overall water quality. Along seven stations on the Euphrates River within Al-Anbar province during the study period revealed that the water quality is not suitable for drinking purposes. The results indicated that the water quality of Euphrates River is generally "very poor" and it ranged poor water at the upstream and unsuitable for drinking at the downstream which reflected the effect of pollution due to domestic and industrial effluents.

5. Acknowledgements

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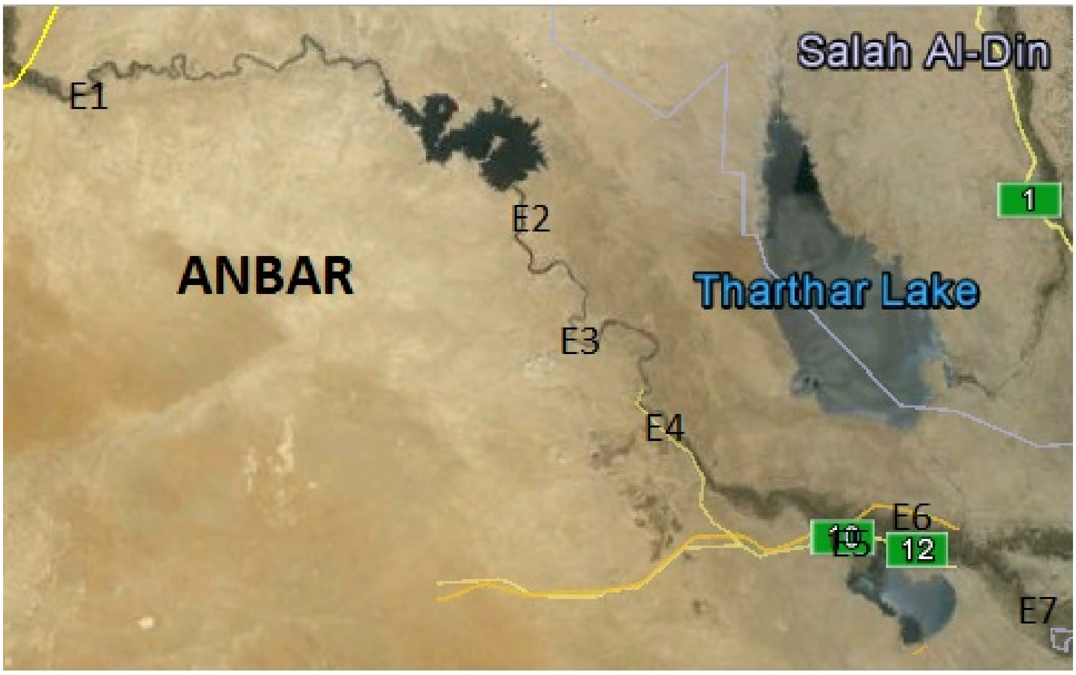

Fig. 1 Stations location for water quality monitoring along the Euphrates River within Al-Anbar province.

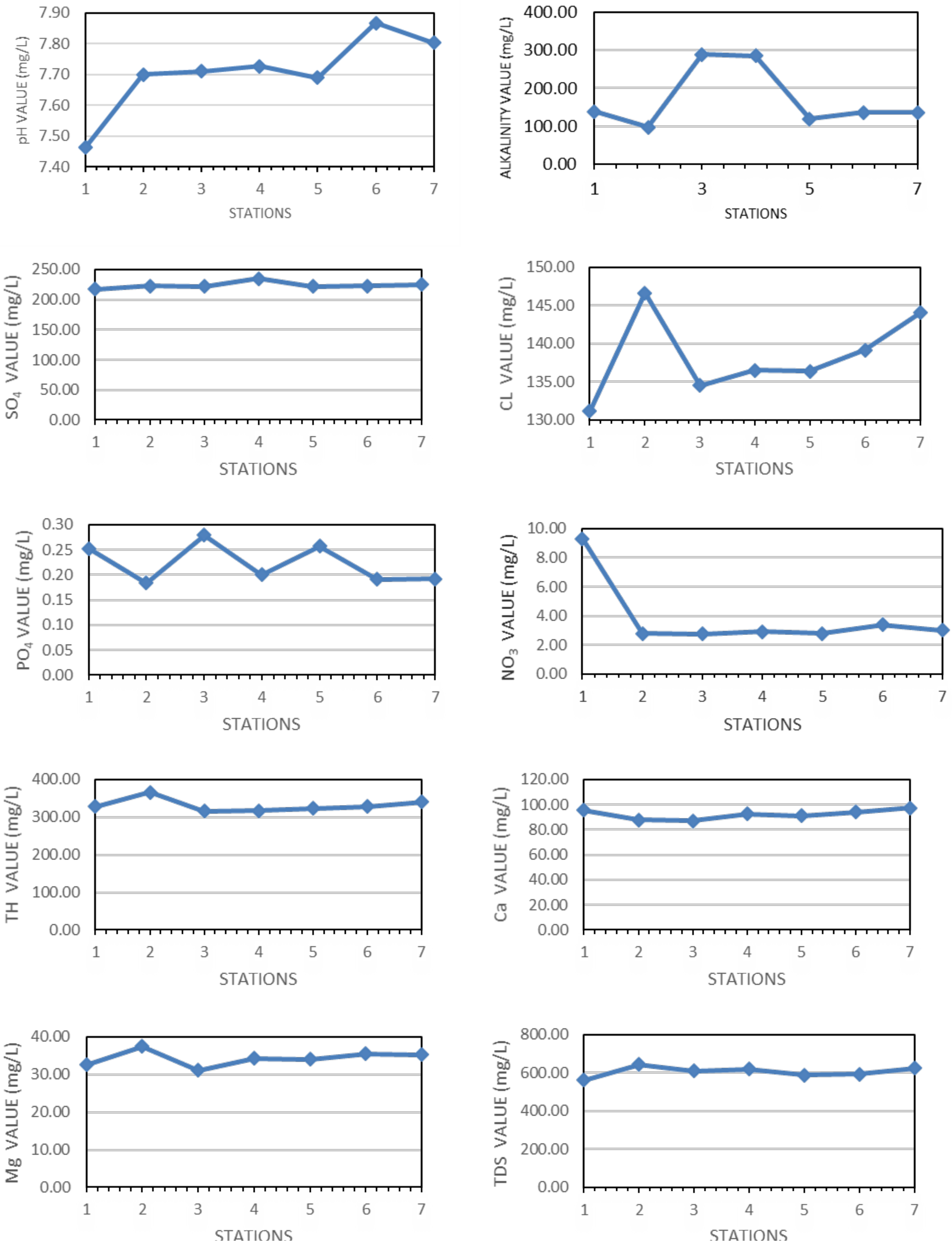

Fig 2. Variation of average water quality parameters at different stations along Euphrates River during the study period.

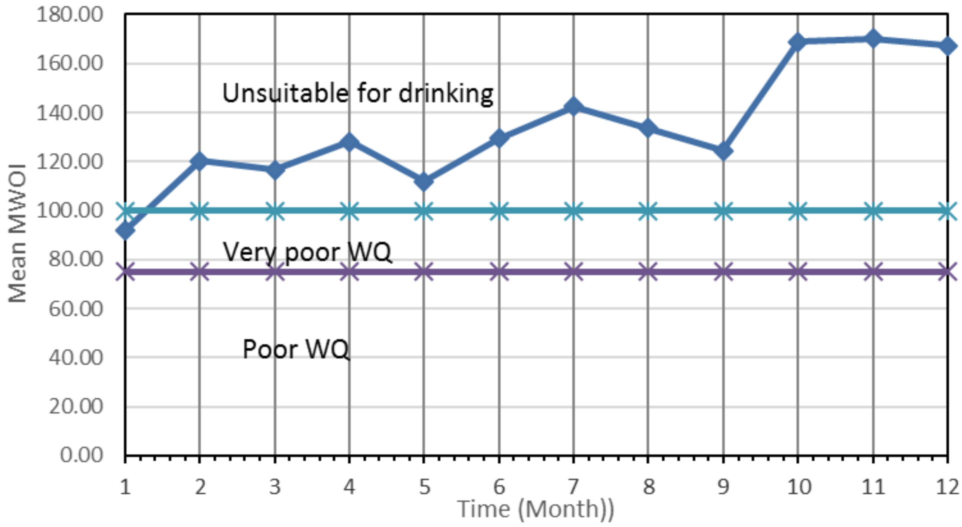

Fig. 3 Variation of monthly mean values of WQI in Euphrates River within Al-Anbar province during 2004-2010.

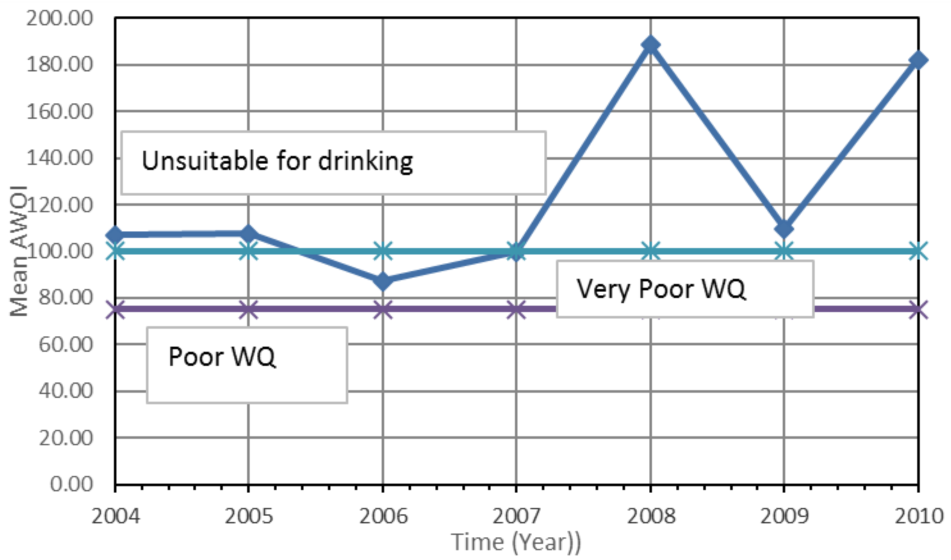

Fig. 4 Variation of annual mean values of WQI in Euphrates River within Al-Anbar province during 2004-2010.

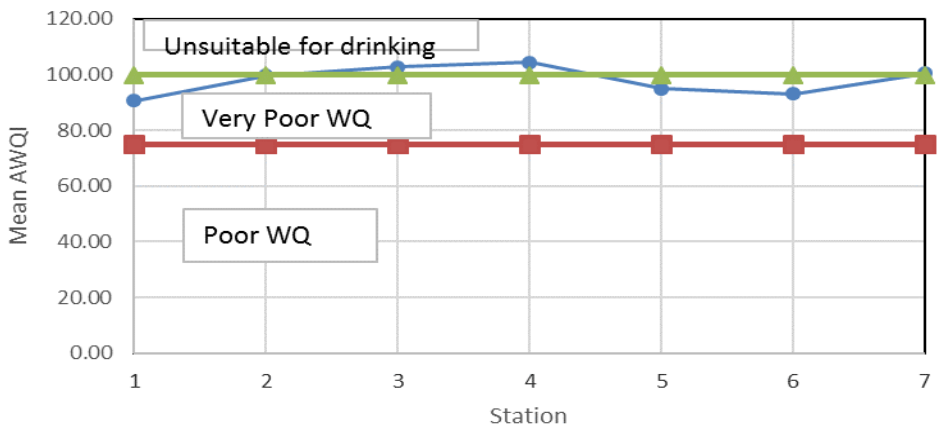

Fig. 5 Variation of annual mean values of WQI at the stations along Euphrates River within Al-Anbar province during 2004-2010.

Table 1 Description of the monitoring stations along the Euphrates River within Al-Anbar province.

Station	Location	Coordinates		Distance between stations (km)	Accumulated Distance (km)
		East	North		
E1	Al-Qaim City- near a bridge in Ramadi	42 º 27′8″	34 º 25′15″		0
E2	Haditha city /bridge Haditha Alaim	39 º 77′22″	23 º 42′08″	116.729	116.729
E3	Baghdadi city /near drinking water treatment project	42 º 13′40.1″	33 º 52.6′8.3″	40.05	156.779
E4	South of the city of Hit	43 º 0.2′8.12″	33 º 22.9′6.3″	69.66	226.439
E5	North of the city of Ramadi	42 º 50′30.9″	33 º 38′06.0″	51.927	278.366
E6	South of the city of Ramadi/bridge Al-Sediqa	43 º 30′14.4″	33 º 23′46.4″	33.207	311.573
E7	Fallujah /Bridge Fallujah	43 º 45′41″	33 º 20′25.4″	25.7254	337.2984

Table 2 water quality parameter standards, assigned and unit weight (Tiwari and Mishra ,1985)

Water quality parameters	Standard value (Si)	Proportional Weight (K)	Unit Weight Factor (wi)
PH	7.5	1.00	0.074
ALK.	100	1.50	0.111
PO_4	1	1.00	0.074
NO_3	50	2.00	0.148
SO_4	250	2.00	0.148
CL	250	1.00	0.074
T.H	100	1.00	0.074
Ca	100	1.00	0.074
Mg	30	1.00	0.074
T.D.S	500	2.00	0.148
		13.5	1.00

Table 3 Water quality classification based on WQI value for drinking proposes (Tiwari and Mishra 1985).

No.	WQI level	Water quality classification
1	0-25	Excellent
2	26-50	Good
3	51-75	Poor
4	76-100	Very poor
5	More than 100	Unfit and unsuitable for drinking

Table 4 Discriptive summary of mean water quality values along Euphrates River within Al-Anbar province during 2004-2010.

Stations & Parameters	E1	E2	E3	E4	E5	E6	E7	Min.	Max.	Mean
pH	7.46	7.70	7.71	7.73	7.69	7.87	7.80	7.46	7.87	7.71
Alkalinity (mg/l as $CaCO_3$)	138.86	97.50	289.40	285.56	119.24	136.39	136.40	97.50	289.40	171.91
PO_4 (mg/l)	0.25	0.18	0.28	0.20	0.26	0.19	0.19	0.18	0.28	0.22
NO_3 (mg/l)	9.32	2.78	2.76	2.92	2.79	3.39	3.02	2.76	9.32	3.85
SO_4 (mg/l)	217.41	223.01	221.99	234.66	221.91	223.05	224.99	217.41	234.66	223.86
Cl (mg/l)	131.17	146.63	134.50	136.52	136.39	139.16	144.05	131.17	146.63	138.34
T.H (mg/l as $CaCO_3$)	328.82	365.67	316.49	317.73	323.91	328.71	340.74	316.49	365.67	331.72
Ca (mg/l)	95.53	87.83	87.26	92.44	91.06	94.13	97.45	87.26	97.45	92.24
Mg (mg/l)	32.61	37.49	31.06	34.30	34.06	35.47	35.31	31.06	37.49	34.33
T.D.S (mg/l)	563.15	643.60	610.85	619.30	589.30	593.57	624.27	563.15	643.60	606.29

Table 5 Computed overall WQI values along Euphrates River within Al-Anbar province during 2004-2010.

Parameters	Measured value (V_i)	standard value (S_i)	Ideal value (V_{10})	Proportional Weight (K)	Unit weight factor (w_i)	Quality rating (q_i)	WQI (wi*qi)
PH	7.71	7.5	7	1.0	0.074	141.67	10.49
ALK.	171.91	100	0	1.5	0.111	171.90	19.10
PO_4	0.22	1	0	1.0	0.074	22.23	1.64
NO_3	3.85	50	0	2.0	0.148	7.70	1.14
SO_4	223.86	250	0	2.0	0.148	89.54	13.26
Cl	138.34	250	0	1.0	0.074	55.33	4.09
T.H	331.72	100	0	1.0	0.074	331.72	24.57
Ca	92.24	100	0	1.0	0.074	92.24	6.83
Mg	34.33	30	0	1.0	0.074	114.42	8.47
T.D.S	606.29	500	0	2.0	0.148	121.25	17.96
WQI	107.59			13.5	1.00	1148.05	107.59

Table 6 monthly WQI variations along Euphrates River within Al-Anbar province during 2004-2010 (MoE).

MONTH	2004	2005	2006	2007	2008	2009	2010	Mean MWQI	Water quality classify
1	102.86	-	-	-	75.13	83.42	106.50	91.98	4
2	121.61	-	-	58.77	201.18	95.91	124.46	120.39	5
3	102.83	-	-	68.40	199.16	89.15	124.20	116.75	5
4	-	106.00	-	114.57	199.16	106.77	114.41	128.18	5
5	109.82	95.81	75.77	50.77	192.02	136.38	123.72	112.04	5
6	97.28	105.70	77.57	50.52	189.98	121.62	263.97	129.52	5
7	-	113.02	95.15	46.67	262.16	129.56	208.71	142.54	5
8	-	117.93	93.83	47.32	192.66	99.60	250.06	133.57	5
9	107.22	94.91	93.60	71.63	191.09	101.43	211.92	124.54	5
10	107.77	118.73	-	182.47	180.09	129.57	295.10	168.95	5
11	-	-	-	203.18	189.99	113.71	174.24	170.28	5
12	-	-	-	203.18	-	110.71	188.31	167.40	5
Mean	107.06	107.44	87.18	99.77	188.42	109.82	182.13	125.97	
Water quality classify	5	5	4	4	5	5	5	5	

Table 7 Annual WQI variations for all stations along Euphrates River within Al-Anbar province during 2004-2010.

Station	2004	2005	2006	2007	2008	2009	2010	Min.	Max.	Mean	Water quality classify
E1	105.29			59.46		116.16	81.95	59.46	116.16	90.71	4
E2	135.91	96.03	97.03	61.64		117.46	90.56	61.64	135.91	99.77	4
E3	104.64	104.92	104.13	129.91	69.67	113.56	92.75	69.67	129.91	102.80	5
E4	105.43	114.08	97.64	131.28	71.93	116.65	93.49	71.93	131.28	104.36	5
E5	104.68	106.77	87.96	74.81	76.07	119.95	95.40	74.81	119.95	95.09	4
E6	109.31	109.17	90.75	82.97	79.03	79.03	101.85	79.03	109.31	93.16	4
E7	103.75	108.20	95.79	85.26	78.07	124.26	108.13	78.07	124.26	100.50	5
Min.	103.75	96.03	87.96	59.46	69.67	79.03	81.95	59.46	103.75	82.55	4
Max.	135.91	114.08	104.13	131.28	79.03	124.26	108.13	79.03	135.91	113.83	5
Mean	109.86	106.53	95.55	89.34	74.95	112.44	94.88	74.95	112.44	97.65	4
Water quality classify	5	5	4	4	3	5	4	3	5	4	

Table 8 Correlation coefficient between MWQI and water quality parameters.

	MWQI	pH	Alk	PO4	NO3	Cl	TH	Ca	Mg	TDS
MWQI	1									
pH	.159	1								
Alk	-.155-	.355**	1							
PO_4	**.903****	.088	-.136-	1						
NO_3	.629**	-.217-	-.420-**	.517**	1					
Cl	-.290-*	.286*	.237	-.135-	-.497-**	1				
TH	.261*	-.113-	-.136-	.311*	.647**	.023	1			
Ca	.447**	.201	-.105-	.199	.114	-.348-**	-.413-**	1		
Mg	**.771****	.004	-.124-	.324**	.066	-.430-**	-.469-**	.369**	1	
TDS	-.463-**	.473**	.460**	-.376-**	-.634-**	.856**	-.014-	-.349-**	-.474-**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).