Assessment of Water Quality Index and Water Suitability of the Tigris River for drinking water within Baghdad City, Iraq

Dr. basim Hussein khudair
E-mail: basim22003@yahoo.com
Instructor (Lecturer)
Baghdad university-engineering college/civil department

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, water quality management and decision making. The application of Water Quality Index (WQI) with sixteen physicochemical water quality parameters was performed to evaluate the quality of Tigris River water for drinking usage. This was done by subjecting the water samples collected from eight stations in Baghdad city during the period 2004-2010 to comprehensive physicochemical analysis. The sixteen physicochemical parameters included: Turbidity, Alkalinity (TA), Total Hardness (TH), Calcium (Ca), Magnesium (Mg), Iron (Fe), pH value, Electrical Conductivity (EC), Sulphate (SO_4^{-2}), Chloride (Cl^-), Total Solids (TS), Total Suspended Solids (TSS), Nitrite (NO_2^-), Nitrate (NO_3^-), Ammonia (NH_3), and Orthophosphate (PO_4^{-3}). The average annual overall WQI was 224.32 through the study period. The high value of average annual overall WQI obtained is a result of the high concentrations of turbidity, total hardness, electrical conductivity, and total solids which can be attributed to the various human activities taking place at the river banks. From this analysis the quality of the Tigris River is classified as "very poor quality" ranging poor water at the river upstream near Al-Karhk WTP and unsuitable for drinking at the river downstream near Al-Wahda WTP and would need further treatment. The present study demonstrated the application of WQI in estimating and understanding the water quality of Tigris 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, Tigris River, drinking water quality, physicochemical parameters, turbidity, total hardness, electrical conductivity, total solids, and orthophosphate.

تقييم مؤشر نوعيةِ الماءِ وملائمةِ ماءِ نهرِ دجلة للماء الصالح للشربِ ضمن مدينةِ بغداد،العراق

د. باسم حسين خضير/ مدرس
جامعة بغداد-كلية الهندسة/القسم المدني

الخلاصة

في هذه الدراسة تم تقييم نوعبة المياه من خلال مؤشر نوعية الماء والذي يحسب من عدة مواصفات للماء. هذا المؤشر يعتبر 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 دجلة للشرب. ولتحديد المؤشر تم الاعتماد على ستة عشر عنصر لمواصفة ماء النهر المقاصة في محطات تصفية الماء في بغداد للفترة 2004-2010. العناصر المقاسة هي العكارة، القاعدية، العسرة الكلية، الكالسيوم، المغنسيوم، الحديد، درجة الحامضية، التوصيلية الكهربائية، الكبريتات، الكلوريد، المواد الصلبة الكلية، المواد العالقة،

النترات، النتريت، الامونيا والاورثوفوسفات. ان المعدل السنوي الكلي لمؤشر نوعية الماء كان 224,32. وهذه القيمة العالية لهذا المؤشر كان بسبب التراكيز العالية للعكارة، العسرة الكلية، التوصيلية الكهربائية والمواد الصلبة الكلية والتي تعزى الى الفعاليات البشرية على ضفاف النهر. من هذا التحليل تعتبرنوعية مياه نهر دجلة "رديئة جدا" وتحتاج الى معالجة حيث تتدرج من صنف "ردي" في مقدمة النهر وقرب محطة الكرخ الى مياه غير ملائمة للشرب في مؤخرة النهروقرب محطة الوحدة. هذه الدراسة تمثل تطبيق لمؤشر نوعية المياه في تخمين وفهم نوعية ماء نهر دجلة. يمكن اعتبار مؤشرنوعية الماء اداة فعالة في ادارة نوعية المياه وكذلك للتعرف على مصادر التلوث في المياه السطحية.

الكلمات الرئيسية: مؤشر نوعية المياه، نهر دجلة، نوعية مياه الشرب، العناصر الفيزوكيميائية، العكارة، العسرة الكلية، التوصيلية الكهربائية، المواد الصلبة الكلية، الاورثوفوسفيت.

INTRODUCTION

The concern that fresh water will be a scarce resource in the future has forced the developing countries into the evaluation of the river water qualities in recent years. The quality of surface water within any region is governed by natural processes such as the precipitation rate, weathering processes and soil erosion also the anthropogenic effects such as urban, industrial and agricultural activities (Pesce and Wunderlin, 2000). In natural aquatic ecosystems, it is well known that clean water is an essential requirement of human and industrial developments where it is of vital concern for mankind, since it is directly linked to human activates (Ramakrishnaiah et al., 2009). Organic and inorganic pollutants are of worldwide concern, increasing human land occupation and industrial pollutions of river water, have made the river water quality evaluation a crucially important matter (Quinones, et al., 2010). It is imperative to prevent and control river pollution and to have reliable information on the quality of water for effective management. Many efforts have been directed toward making qualitative and quantitative decisions based on monitoring water quality data and interpreting the results (Koklu, et al., 2010). River water quality monitoring program is becoming a necessity in order to safeguard public health and to protect the valuable fresh water resources. Assessing river water quality is based on the comparison of experimentally determined parameter values with the existing local normative requirements (Debels, et al., 2005).

Water quality concept can be defined as a conventional ensemble of physical, chemical and biological parameters, formed in a certain category, which expresses the possibility of its anthropic usage to meet a certain purpose such as potable, agricultural, recreational and industrial water usages, etc. (Sargaonkar and Deshpande, 2003).

Water Quality Index (WQI) is one of the most effective tools to communicate information on the quality of water to the concern of citizens and policy makers. It becomes an important parameter for the assessment and management of surface water as a synthetic indicator (Kaurish and Younos, 2007). The concept of 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, which translates the list of constituents and their concentrations present in a sample (Khan et al., 2003; Abbasi, 2002).

The index was firstly used by Horton (1965) to reveal the physical and chemical changes occurring in the flowing water. Monitoring and quality management activities were attempted through mathematical methods to indicate the global quality of surface waters with the help of a qualitative index (House,1989). 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., 2001). Water quality index provides a single number that expresses overall water quality at a certain location and time, based on several water quality parameters. (Bordalo et al., 2006). WQI also permits the assessment of changes in water quality and to identify water trends (Cude, 2001).

Many studies using WQI were performed on the Tigris River to evaluate its anthropic usage such as potable, agricultural, recreational and industrial water usages.

Al Suhaili and Nasser, (2008) studied the water quality indices for Tigris river in Baghdad city for the period 2000 to 2004. They used twenty one water quality parameters taken from the river at three water treatment plants. The index was the ratio of the pollutant concentration to the permissible value of its usage. The results showed a general deterioration in water quality at the south of Baghdad city. High indices values were determined indicating that the water is not suitable for drinking.

Hameed et al., (2010) evaluated WQI of the raw and treated water from the eight treatment plants in Baghdad city for 2002 to 2008. They showed that WQI varied from poor to unsuitable as the raw water river flowed from the north to the south of Baghdad city. As for the treated water, WQI varied from good to poor indicating more treatment is required at the plants in the south.

The quality of irrigation water had also been evaluated to avoid or, at least, to minimize impacts on agriculture. Muthanna M., (2011) made a trial to use Irrigation Water Quality Index (IWQI) to classify Tigris River within Salah- Alddin Province by taking water samples from January 2010 until December 2010. He showed that the samples from the north to the south of the study area had high values of: Electrical Conductivity (EC), concentrations of Chloride (Cl^-) and Sodium (Na^+). Also the results revealed that all sectors fall within the second category (76.02-80) when using IWQI, therefore, the use of water for irrigation in Salah-Alddin province is potentially leading to solve many problems in heavy textured soils.

The objective of the present work is to provide information on the physicochemical characteristics of Tigris River water quality within Baghdad city, and the impacts of unregulated waste discharge on the quality of the river as well as to discuss its suitability for human consumption based on computed water quality index values (WQI).

Study area description

Tigris river water is considered the only source of potable water for the city of Baghdad, and the river divides the city into right (Karkh) and left (Risafa) sides with a flow direction from north to south. The study area within Baghdad City 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 at sea level (a.s.l). 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).

In Baghdad city, a tremendous increase in freshwater demand is required due to the rapid growth in population and accelerated industrialization. As well as the pollution increase in the river stretch due to effluent discharges by various uncontrolled sources as domestic, industries, agriculture along the downstream stretch. Therefore river water quality monitoring is necessary to evaluate the water quality for different purposes. Many researches and studies were made to evaluate the water quality of Tigris River suffering from the effect of conservative pollutants within Baghdad city (Al-Shami, et al., 2006).

DATA COLLECTION

Water samples were collected from the influent of the eight water treatment plants along the Tigris River within Baghdad city (Figure 1), in order to give a comprehensive idea of the overall water quality of the river. The data used in this paper were provided from Mayoralty of Baghdad for the period from January 2004 to December 2010 which represented the monthly average values for sixteen water parameters.

CALCULATIONS OF THE WQI

For calculating the Water Quality Index, a set of sixteen water quality parameters have been selected based on both importance and availability of data from each station. These sixteen parameters are Turbidity, Alkalinity

(TA), Total Hardness (TH), Calcium (Ca), Chloride (Cl^-), Magnesium (Mg), pH value, Electrical Conductivity (EC), Sulphate (SO_4^{-2}), Total Dissolved Solids (TDS), Suspended Solids (SS), Iron (Fe), Nitrite (NO_2^-), Nitrate (NO_3^-), Ammonia (NH_3), and Orthophosphate (PO_4^{-3}).

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter (q_i) was calculated by using equation (1):

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \qquad (1)$$

A quality rating scale (q_i) for each parameter is assigned by dividing its observed concentration (C_i) in each water sample by its respective standard value (S_i) and the result is multiplied by 100.

Relative weight (w_i) was calculated by a value inversely proportional to the recommended standard value (S_i) of the corresponding parameter using equation (2):

$$w_i = \frac{1}{S_i} \qquad (2)$$

The overall Water Quality Index (WQI) was calculated by aggregating the quality rating scale (q_i) with the unit weight (w_i) linearly in equation (3) as follows:

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

Where:
qi: the quality of the ith parameter.
wi: the unit weight of the ith parameter.
n : number of the parameters considered.

Generally, WQI is to be discussed for a specific and intended use of water. In this study the WQI for drinking purposes is considered a permissible WQI if its value is 100 using equation (4):

$$\text{Overall WQI} = \frac{\sum_{i=1}^{i=n} w_i \times q_i}{\sum w_i} \qquad (4)$$

RESULTS AND DISCUSSION

Water Quality

The descriptive statistics analyses for the collected water quality parameters are shown in **Table 1**. In order to reach a better view on the causes of deterioration in water quality the results are discussed below.

The mean turbidity value obtained from the research carried out is 62.18 NTU which is above the standard permissible level recommended by the World Health Organization (WHO) for drinking water. This could be attributed to the presence of organic matter pollution, other effluents, run-off with a high suspended matter content and heavy rain fall (UNESCO/WHO/UNEP, 2001).

Hardness of water causes chocking and clogging troubles in pipelines, formation of scales in boilers leading to wastage of fuel and the danger of overheating of boilers (Egereonu, 2004). The results obtained by water surveys conducted in this investigation showed that TH average values reached 328.5 mg/L were often higher than the minimal permissible level recommended by the WHO for drinking water (WHO, 2004).

The mean concentrations of Calcium and Magnesium were 86.65 and 28.5 mg/L which are within the recommended permissible limit of 200 mg/L for both elements.

Chloride is one of the most important parameter in assessing the water quality, and the higher concentrations of chlorides indicate higher degree of organic pollution which can occur near sewage, irrigation drains and waste outlets (Munawar, 1970). Chloride is a widely distributed element in all types of rocks and is an indication that the water is of a marine source (Amadi et al., 2010). Its affinity towards sodium is high and hence its concentration is high in groundwater due to geothermal gradient. Soil porosity and permeability play a key role in building up the chloride concentration. High concentration of chloride makes water unpalatable and unfit for drinking and livestock watering (Egereona, 2004). However, the mean chloride value concentration of the samples is

66.54 mg/L which is found to be within the permissible levels of 250 mg /L.

pH is a parameter that determines the suitability of water for various purposes and the extent of pollution in the watershed areas. The results of pH varied from 7.33 to 8.14 which is within the allowable limits for surface water indicating that the water samples are almost neutral to sub-alkaline in nature. The observed values of alkalinity were slightly higher than the permissible level recommended by the WHO for drinking water.

The importance of Electrical Conductivity (EC) is due to its measure of cations which greatly affects the taste and thus has significant impact on the user acceptance of the water as potable. It is an indirect measure of total dissolved salts. High conductivity may arise through natural weathering of certain sedimentary rocks or may have an anthropogenic source, e.g. industrial and sewage effluents (Amadi et al., 2010). The conductivity average value was 845.37 µS/cm and the results showed that EC values were slightly higher than the permissible level recommended by the WHO for drinking water.

Sulphates are naturally present in surface waters as SO_4^{-2}. Industrial discharges and atmospheric precipitation can also add significant amounts of sulphate to surface waters. The mean concentration sulphate was 208.95 mg/ L which is within the tolerable limits of 500 mg/L (Ikomi and Emuh, 2000).

Water containing high dissolved solids may cause laxative or constipation effects. High concentration of dissolved solids (TDS) in surface waters is a pointer to the fact that there are intense anthropogenic activities along the course of the river and run-off with high suspended matter content (UNESCO/WHO/UNEP, 2001). The mean concentrations of total dissolved solids reached 530.26 where the permissible limits in drinking water are in the range 500- 1500 mg/L (WHO, 2004).

The mean value for iron was 1.68 mg/L which is above the permissible limits. This can lead to coloration of the water thus initiating sedimentation in the water supply system; also it can result to corrosion. In addition, iron can affect the organoleptic quality of water as others metals such as copper, aluminum and zinc (Egereonu, 2004).

Nitrate and Nitrite are naturally ions that are part of the nitrogen cycle. Nitrate ion in water is undesirable because it can cause methaemoglobinaemia in infants less than six months old (Egereonu and Nwachukwu, 2005). Farming and dumping of animal waste, leachates from fertilizer and waste disposal sites, sanitary landfills can lead to high nitrate concentration which causes eutrophication in surface waters (WHO, 2004). Nitrate was the most abundant form of the nitrogen compounds 0.8 mg/L during the present study, but still complies with the WHO recommendations, while nitrite was found in small amounts 0.01 mg/L and the mean concentration value of ammonia was (NH_3) is 0.11 mg/L.

High concentrations of phosphates can indicate the presence of pollution and are largely responsible for eutrophic conditions. Domestic wastewaters containing detergents, industrial effluents and fertilizers run-off contribute to elevated levels of phosphates in surface waters (WHO, 2004). The phosphate value obtained is within the tolerable limits.

WATER QUALITY INDEX (WQI)

In this study, the water quality index (WQI) of the Tigris river within Baghdad city has been calculated using the weighted arithmetic index method by sixteen 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).

The WQI and overall WQI of all the samples taken were calculated according to the procedure explained above and the results are presented in **Table 2**. **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 unsuitable for drinking.

The computed annual overall WQI for all samples from 2004 to 2010 was 224.32, which implies that the water is generally "very poor quality". The river water quality ranged poor water at the upstream near Al-Karhk WTP and unsuitable for drinking at the downstream near Al-Wahda WTP which reflect the effects of pollution as shown in **Table 4**. The result obtained from this study indicates that the overall WQI of Tigris 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 turbidity, total hardness TH, electrical conductivity EC, and total solids TDS in the water and can be attributed to the various human activities taking place at the river bank.

Identical findings were reached by Al-Suhaili and Nasser in 2008, but it is hard to make a comparison in WQI values obtained as they used a different procedure in the determination of WQI.

Hameed et al., (2010) also indicated WQI was good at the north of Baghdad in 2002 to 2004 but was poor in 2006 to 2008. At the south region it was very poor to unsuitable for the same years. They concluded the effect of dryness in the area in the last three years might be behind the clearly observed depletion of WQI, especially in the upstream stations where there is no high intervention between the effects of dryness and those of human activities.so, all WQI values indicate that the water of Tigris River is unsuitable for drinking purposes.

CONCLUSIONS

WQI identifies and compares water quality conditions over time which can be used in a variety of ways:

a. As an environmental indicator
b. Evaluate the effectiveness of water quality management activities,
c. Improves comprehension of general water quality issues,
d. Illustrates the need for and effectiveness of protective practices.

Application of WQI in this study has been found very useful in the assessment of the overall water quality. Analysis the WQI along eight stations from upstream to downstream of Tigris River within Baghdad city during the study period revealed that the water quality is not suitable for drinking purposes. The results indicated that the water quality of Tigris River is generally "very poor" and it ranged poor water at the upstream and unsuitable for drinking at the downstream which reflects the effect of pollution due to domestic and industrial effluents.

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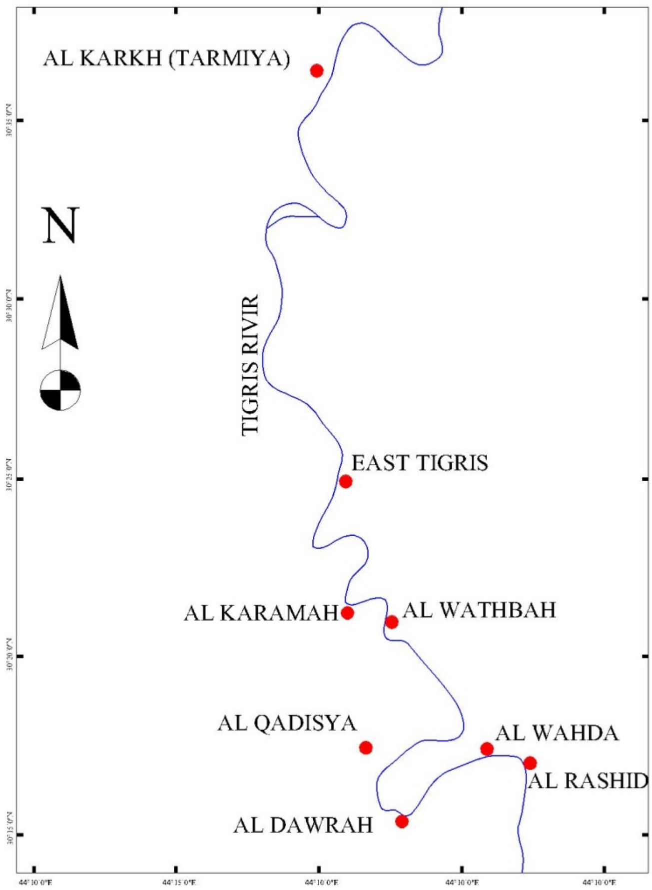

Fig. 1. Sampling locations across Tigris River, within Baghdad City.

Table 1: Discriptive statistical summary of Tigris River within Baghdad city water quailty data from 2004-2010.

Test Type	Minimum	Maximum	Average
Turbidity (NTU)	15.73	192.77	62.18
Total Alkalinity as $CaCO_3$ (mg/L)	117.84	180.70	145.16
Total Hardness as $CaCO_3$ (mg/L)	242.13	400.11	328.50
Calcium as Ca (mg/L)	64.56	112.52	86.65
Chloride as Cl^- (mg/L)	46.32	86.13	66.54
Magnesium as Mg (mg/L)	21.76	34.73	28.50
pH	7.33	7.70	7.98
Conductivity ($\mu S\ cm^{-1}$)	540.91	1201.48	845.37
Sulfate as SO_4 (mg/L)	137.18	283.30	208.95
Total Dissolved Solids (mg/L)	384.75	649.27	530.26
Iron as Fe (mg/L)	0.37	5.24	1.68
Nitrite as NO_2 (mg/L)	0.00	0.02	0.01
Nitrate as NO_3 (mg/L)	0.35	0.97	0.80
Ammonia as NH_3 (mg/L)	0.05	0.19	0.11
Orthophosphate as PO_4^{-3} (mg/L)	0.02	0.11	0.04

Table 2: Computed WQI values for Tigris River within Baghdad city from 2004-2010.

Test Type	C_i	S_i	wi	q_i	WQI (w_i*q_i)
Turbidity	62.18	5	0.2	1243.6	248.72
Alkalinity as $CaCO_3$	145.16	150	0.01	145.16	1.451
T.Hardness as $CaCO_3$	328.50	500	0.01	328.5	3.285
Calcium as Ca	86.65	200	0.01	86.65	0.866
Chloride as Cl^-	66.54	600	0.004	26.616	0.106
Magnesium as Mg	28.50	150	0.033	95	3.166
pH	7.98	7.5	0.133	106.4	14.186
Conductivity	845.37	250	0.004	338.148	1.352
Sulfate as SO_4	208.95	400	0.004	83.58	0.334
Total Dissolved Solids	530.26	1500	0.002	106.052	0.212
Iron as Fe	1.68	0.3	3.33	560	1866.667
Nitrite as NO_2	0.01	3	1	1	1
Nitrate as NO_3	0.80	50	0.02	1.6	0.032
Ammonia as NH_3	0.11	0.2	5	55	275
Orthophosphate as PO_4^{-3}	0.04	1	1	4	4
			$\sum wi=10.76$	$\sum qi=3204.299$	$\sum w_iq_i=2414.981$
			$WQI = \frac{\sum_{i=1}^{i=16} w_i \times q_i}{\sum_{i=1}^{i=16} w_i} = 224.32$		

Table 3: Water quality classification based on WQI value (House, 1989).

No.	WQI value	Water quality classification	Water samples (%)
1	<50	Excellent	20
2	50-100	Good water	36
3	100-200	Poor water	30
4	200-300	Very poor water	0
5	>300	Water unsuitable for drinking	14

Table 4: Annual WQI for all stations from upstream to downstream within Baghdad city.

Year	Al-Karkh	East Tigris	Al-Karamah	Al-Wathbah	Al-Qadisiya	Al-Dawrah	Al-Rashid	Al-Wahda	Average
2004	138.21	147.01	138.65	192.49	207.51	213.89	292.14		189.99
2005	76.60	134.52	82.80	54.09	229.38	182.44	179.29		134.16
2006	231.99	246.70	355.49	133.94	351.78	394.34	345.36		294.23
2007	155.43	234.00	231.91	98.87	387.75	224.93	257.72	162.69	381.85
2008	73.71	153.94	126.78	61.81	177.19	128.99	126.95	617.62	183.37
2009	139.48	254.42	463.54	215.78	416.15	256.42	357.39	337.40	305.07
2010	122.79	237.70	103.74	317.58	292.08	429.83	225.98	224.12	244.23
Average annual overall WQI	134.03	201.18	214.70	153.51	294.55	261.55	254.98	335.46	224.32
classification of water quality	3	4	4	3	4	4	4	5	4