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# Evaluating the Quality of Raw and Treated Water for a Number of Water Treatment Plants in Baghdad, using Canadian Model for Water Quality Index

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**A B S T R A C T**

Laboratory tests for some physical and chemical properties were conducted to evaluate the quality of potable water on some water treatment plants in Baghdad (Al-Qadisiya, Al-Dora, Al-Wahda and Al-Rasheed). Study samples were taken from raw and treated water. Water tests were monthly conducted for eight years in order to evaluate the potable water quality and the efficiency of these plants. The quality of the potable water was calculated using Canadian model index (Canadian Council of Ministry of the Environment) water quality evaluation. The following thirteen variables that contributed in the index calculation are: water temperature, turbidity, pH, total hardness (as $CaCO3$), magnesium%, calcium%, sulfate%, iron mg/L, fluoride%, Nitrate%, chloride%, color, and conductivity. The samples were taken from the treated water effluent from 2005 to 2013. The study showed that the range of the water quality index for the raw water is (49-54) and can be classified as bad water and needs an advanced treatment. While the water quality index of the treated water was (77,78, 70, 67) for (Al-Qadisiya, Al-Dora, Al-Wahda and Al-Rasheed) respectively. Therefore, the water quality index of treated water of (Al-Qadisiya, Al-Dora, Al-Wahda and Al-Rasheed) can be classified within the third category (moderate).



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## تقييم نوعية المياه الخام والمياه المعالجة لعدد من محطات المعالجة في مدينة بغداد، باستخدام مؤشر نوعية المياه الكندي

**الخلاصة**

اجريت العديد من التجارب لتقييم نوعية مياه الشرب في بعض محطات الاسالة وهي (القادسية، الدورة، الوحدة والرشيد) في مدينة بغداد، هذه النماذج تم اخذها من الماء الخام والماء المعالج وأجريت بعض الفحوصات الفيزيائية والكيميائية المأخوذة شهريا ولمدة ثمان سنوات لغرض تقييم نوعية مياه الشرب وكفاءة اداء هذه المحطات. تم حساب نوعية مياه الشرب باستخدام مؤشر نوعية المياه الكندي وذلك باستعمال ثلاثة عشر متغير في حساب هذا الدليل وهذه المتغيرات هي: درجة الحرارة م°، الكدرة NTU، الدالة الحامضية، العسرة الكلية، المغنيسيوم، الكالسيوم، الكبريتات، الحديد، الفلورايد، النترات، الكلورايد، اللون، والتوصيلية الكهربائية. أخذت هذه النماذج للفترة من 2005 الى 2013، وقد بينت هذه الدراسة ان مدى مؤشر نوعية المياه للماء الخام (نهر دجلة) يتراوح بين (49 - 54) والذي يمكن تصنيفه على انه ماء رديء ويحتاج الى معالجة متقدمة، في حين كان مؤشر نوعية المياه للماء المعالج (77، 78، 67،70) للمحطات (القادسية والدورة والوحدة والرشيد) على التوالي، لذا يمكن تصنيف هذه المياه ضمن الصنف الثالث (معتدل) من التصنيف المعلن من قبل وزارة البيئة الكندية.

## 1. INTRODUCTION

Different water sources, nowadays, are largely contaminated as a result of the large increase in population and industrial and agricultural expansion and the lack of proper planning in building cities, which led to doubling the amount of wastes deposited in these sources. Thus, water quality monitoring program has become necessary to relocate the correct functioning of the water treatment

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plants because of the continuous qualitative alteration that gets in the body water [1]. Scientists and experts in the water quality fitted developed efficient index for water quality (water quality index). Where counting this indicator favorite scientific method for being many water quality and formulation variables that used in the descriptive digital expression which includes an integrated effect of these variables on the water quality. And have an active role in operations control of the water quality strategy and its management, so they can the classify water qualitatively though various activities within a specific categories and scientific manner which are simple and useful. The water quality index was used for the first time by Horton [2], which helped to develop many of the water quality index models which appeared later such as that done by Alobaidy et al. [3] and Eassa and Mahmood [4]. The present study aims to find a water quality index value for raw and treated water in Baghdad city, based on a number of physical and chemical variables.

## 2. DESCRIPTION OF THE STUDY AREAS

The study areas consist of four selected water treatment plants in Baghdad city. These plants are the most important potable water plants because the study area was dense with numbers of the pollutants along the river banks, as well as the presence of some industrial activities, in addition to a number of wastewater outfall, which are exist on both sides of banks. Therefore, various biological, chemical and physical pollutions, which directly affect the quality of the Tigris river and these are considered in this study. This river is the main source of treatment plants in the study area as shown in Fig. 1. Physical and chemical tests were carried out by Baghdad Governorate, according to standard methods [5]. For taken samples from the site, the following tests are obtained (turbidity NTU, pH, total hardness (as CaCO3), magnesium, calcium, sulphate, iron, fluoride, Nitrate, chloride, TDS, conductivity). Tests of turbidity, TDS and pH were carried out at the site and the other tests were done in the laboratory. The data collection of this study continued for eight years, starting from 2005 until 2013.

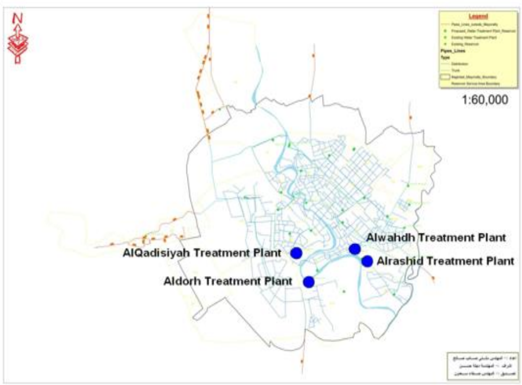


**Fig. 1.** The study area with the water treatment plant

## 3. APPLICATION OF THE WATER QUALITY INDEX FOR DRINKING PURPOSES

The collected data was classified according to time and was placed in the matrix. The water quality will be computed, using the Canadian model (CCME-WQI) [6]. This model is based on the confusion between the three mathematical factors that used in calculating the final figure crossing on the status of the water quality which are the scope, frequency and amplitude. These factors are calculated according to many equations variables which the give the final figure reflects.

***The First Factor F1 (Scope)***

This factor represents the ratio between the number of variables whose values do not match with the objectives set for the model (Objective) and the total number of variables. This factor is calculated the following equation:

$$F1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100 \quad (1)$$

***The Second Factor F2 (Frequency)***

This factor represents the ratio between the number of tests that did not meet the objectives set for the model and the total number of tests values. This factor is calculated by Eq. (2):

$$F2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \quad (2)$$

***The Third Factor (F3) (Amplitude)***

This factor represents the failed tests which do not correspond to the objectives and values set for them. The values are calculated according to the following steps
The number of times which an individual concentration is greater than (or less than, when the objective is minimum) objective is termed an "excursion" and is expressed in Eq. (3). When the test value must not exceed the objective:

$$\text{excursion}_i = \frac{\text{Failed Test Value}}{\text{Objective}_i} - 1 \quad (3)$$

Equation (4) is expressed for the cases in which the test value must not fall below the objective:

$$\text{excursion}_i = \frac{\text{Objective}_i}{\text{Failed Test Value}} - 1 \quad (4)$$

The collective amount by which an individual tests are out of compliance is calculated by summing the excursions of the individual tests from their objectives which are divided upon the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions, or *nse*, is calculated as in Eq. (5):

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{excursion}_i}{\text{No. of tests}} \quad (5)$$

$F3$ is then calculated using asymptotic function that scales the normalized sum of the excursions from the objectives (NSU) to yield a range between 0 and 100, and could be Calculated from Eq. (6) as shown below:

$$F3 = \frac{\text{nse}}{0.01\, nse + 0.01} \quad (6)$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as together they are vectors. The sum of the squares of each factor is therefore equal to the square of the index. This approach treats the index as a three-dimensional space that defined by each factor along one axis. For this model, the index is changed to be directly proportion to the changes in these three factors, then the WQI can be calculated using Eq. (7) below:

$$CCME\ WQI = 100 - \frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \quad (7)$$

The values of the water quality index ranges is 0–100 and these values are classified as shown in Table 1.

**Table 1**
Classification of water quality index according to Ref. [6].

| Water Treatment Required | Quality | Rang | Category |
|---|---|---|---|
| sterilization only | Excellent | 95-100 | I |
| Simple Treatment | Good | 80-94 | II |
| Conventiona l treatment | Moderate | 65-79 | III |
| Advanced treatment | Bad | 45-64 | IV |
| Unacceptabl e | Very bad | 0-44 | V |

## 4. RESULTS AND DISCUSSION

### 4.1. The Variables that are used in Calculation of WQI

***Temperature***

The results showed that the variation in the temperature of the raw and treated water for all treatment plants were very little. It is observed that the temperature of raw and treated water are identical and comply with the Iraqi specifications for potable water [7].

***Color***

The results showed that the color variation in raw and treated water in all treatment plants is very little, and are identical and comply with the Iraqi specifications for potable water [7], which is less than 5 units.

***Turbidity***

Fig. 2 shows the values of the turbidity in treated water during the study period, the turbidity of the raw water, is in between 25-427 NTU. It can be seen that, from this figure that the turbidity values in the treated water in all treatment plants were identical and comply with the Iraqi Specifications (less than 5 NTU), except for the Al-Rasheed treatment plant for the period 2009 to 2012, and the Al-Wahda treatment plant during 2007 only, where it didn't comply with the Iraqi specifications. The hydraulic retention time in settling tanks and filtration was reduced in order to satisfy the increasing consumption of the domestic and industrial demand for water, and this leads to a decrease in the plant work efficiency and turbidity removal from the treated water.

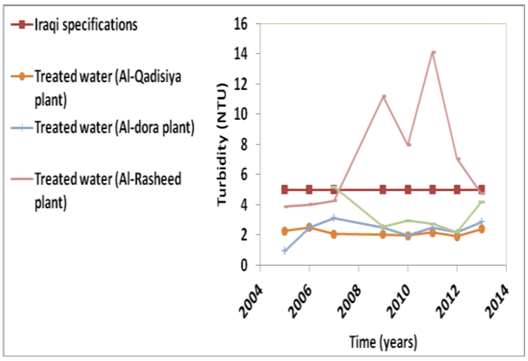


**Fig. 2.** Turbidity values in the treated water over the study period.

***pH***

Fig. 3 shows that pH values in the raw water (river water) tend to be alkaline n the ranges (7.7 to 8.2). This is because the existence of limestone soil (CaCO3) in the study area, which is one of the main sources that increases pH values [8]. This result is in agreement with the previous study in Ref. [9] which showed that the surface water in Iraq is alkaline water. The pH of the treated water comply with the Iraqi specification limits, (7- 8.5), where it ranges from (7.3 to 7.8). It is also noted that pH values are decreased significantly in the treated water as compared with the raw water. This is due to the chemical materials that added to the water in the plant, such as alum, chlorine, which reduce pH values [10].

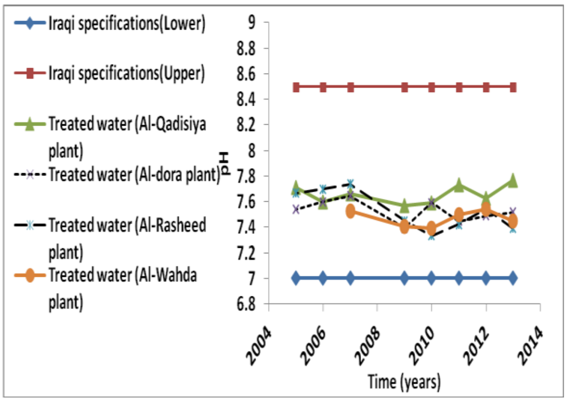


**Fig. 3.** pH values during the study period.

***Electrical Conductivity (EC)***

Fig. 4 shows the electrical conductivity values of the water that exiting from the four water treatment plants during the study period. The electrical conductivity values of the raw water are ranges the (513-932) µs/cm. While for the treated water are in the range (519-933) µs/cm. These values are acceptable sinces they are within the Iraqi specification limits.

***Total Hardness***

Fig. 5 shows the total hardness values during the study period. The total hardness of the raw water are in the range between (294-368) mg/L, and, for the treated water, are (295-370) mg/L range. These values are within the limits of the Iraqi specifications which are equal to 500 mg/L.

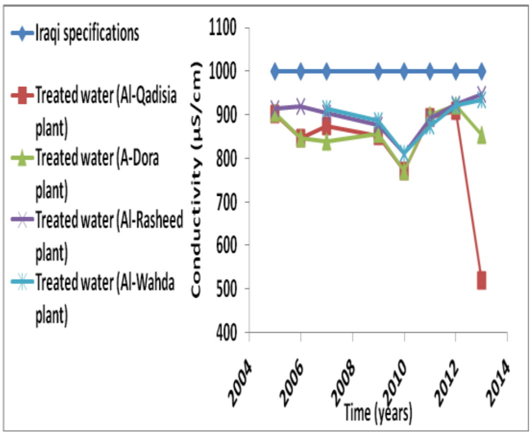


**Fig. 4.** Electrical conductivity values during the study period.

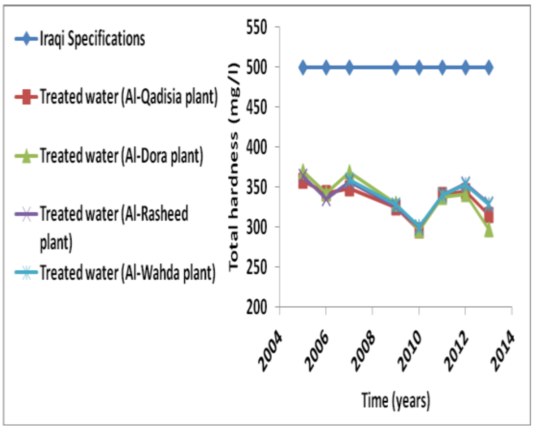


**Fig. 5.** Total hardness values during the study period.

### *Calcium (Ca)*

Fig. 6 shows the variation in the calcium concentration during the study period. The concentration of calcium in the raw water is in the ranges (75-100) mg/L. And the results also show that the (76-100) mg/L variation in calcium ion concentration in the treated water is in the range. The obtained results also show that, for the most cases, the calcium ion concentration in the treated water is greater than that in the raw water. Furthermore, the results indicated that most of the calcium ion concentration in the treated water samples dose not comply with the identical to Iraqi specification, which states that the calcium ion in the potable water must not exceed 75 mg/L.

### *Magnesium (Mg)*

Fig. 7 shows the magnesium concentrations during the study period. The magnesium concentration in the raw water is in the range (26-34) mg/L. While in the treated water is in the range (25-37) mg/L. These results prove that there is a disparity in the magnesium ion concentration in the treated water which is in agreement the study that conducted by Al-Khafaji [11] on the water of Hussein liquidation plant in Karbala city, which indicates that the magnesium ion concentration in the treated water comply the Iraqi specifications and states that the magnesium ion concentration in the potable water does not exceed 50mg/L.

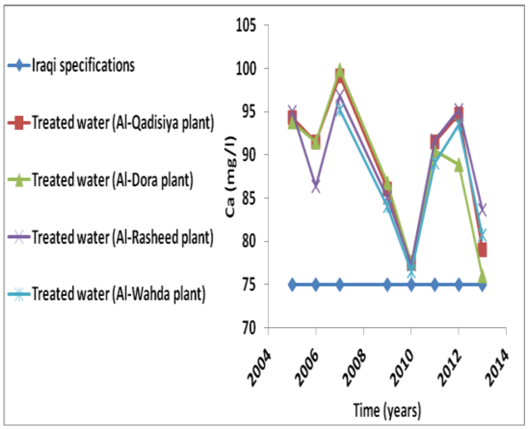


**Fig. 6.** Calcium concentration during the study period

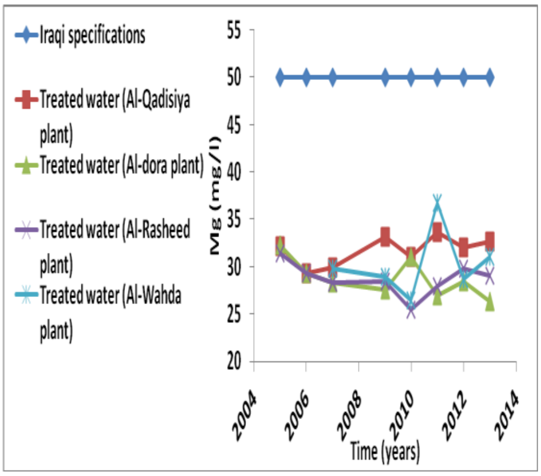


**Fig. 7.** Magnesium concentrations during the study period.

### *Chloride (Cl)*

Fig. 8 shows the chloride concentration during the study period. The concentration of the chloride in the raw water is in the range (60-82) mg/L. While in the treated water it is (61-82) mg/L range. The results show that some concentration cases of the chloride ion in the treated water are greater than that of the raw water. This is due to adding the chlorine to the water. In spite of increasing chloride ion concentration to the treated water, it remains within the limits of the Iraqi specifications.

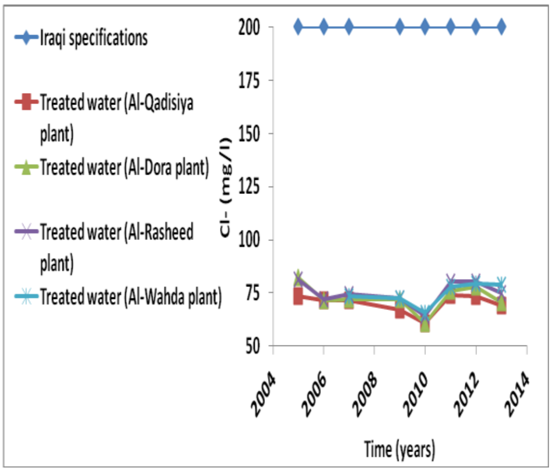


**Fig. 8.** Chloride concentration during the study period.

### *Sulfates*

Fig. 9 shows the sulfate concentration during the study period. The concentration of the sulfate in the raw water is in the range (130-256) mg/L. While in the treated water it is in the range (136-260) mg/L. These results show that an increase in the sulfate ion concentration in the treated water compared with the raw water. This is because the addition of the alum ($Al_2(SO_4)_3$) to the water, where high rate of sulfate ion forms part of composition material. The results prove that the sulfate ion concentration exceeds the Iraqi specifications limits through the study period for all plants except the year, 2010. Where this ion is within the permissible limit 200mg/L.

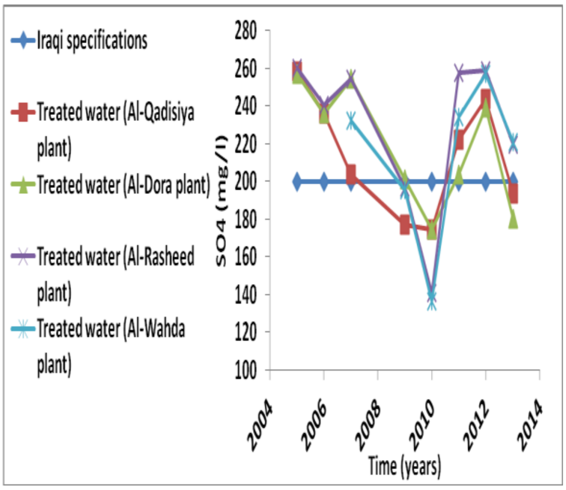


**Fig. 9.** Sulfate concentration during the study period.

### *Iron (Fe)*

Fig. 10 shows the iron concentration during the study period. The iron concentration in the raw water is (0.5-5.8) mg/L, and in the treated water is in the range (0.027-0.33) mg/L. It could be concluded from this figure. that the iron concentration ion in the water does not exceed the permissible limits (0.3mg/L), except in a single reading in Al-Rasheed plant for the year 2010. This means that the iron concentration in the treated water Is considered normal. If the iron concentrations are more than 0.3mg/L, this will give a taste and cause clothing color removal, and solid cortices in the main water pipe [12].

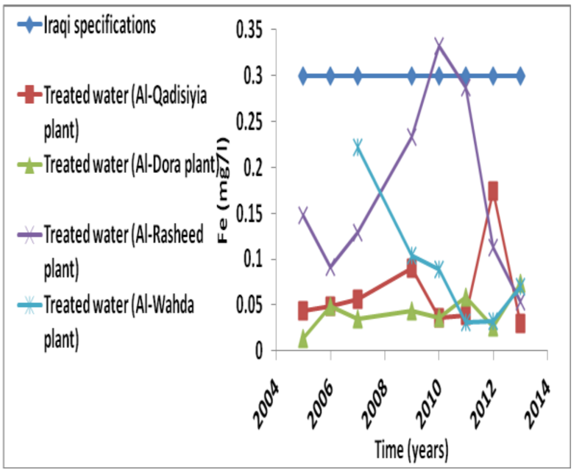


**Fig. 10.** Iron concentration during the study period.

### *Fluoride (F)*

Fig. 11 shows the fluoride ion concentration during the study period. The concentration of the fluoride in the raw water is within these limits (0.1-0.19) mg/L. While in the treated water is in the range (0.05-0.14) mg/L. It could be concluded that the fluoride ion concentration in the water is less than the permissible limits (0.5–1.5) mg/L of the Iraqi specification. The excessive presence of the fluoride ion concentrations could cause tooth decay among the consumers.

### *Nitrate (NO3)*

Fig. 12 shows the nitrate ion concentration during the study period. The nitrate ion concentration in the raw water is (0.22-1.44) mg/L, and in the treated water is (0.26-1.48) mg/L. It could be concluded from this figure. that the nitrate ion concentration in the treated water is within the permissible limits of the Iraqi specification, 40 mg/L. The excessive presence of the nitrate ion concentrations causes cyanosis for young age children.

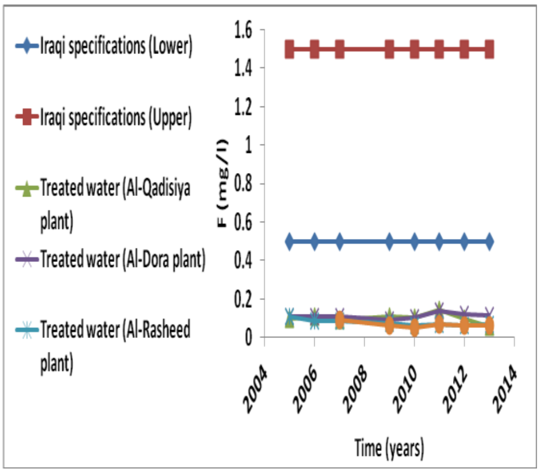


**Fig. 11.** Fluoride concentration during the study period.

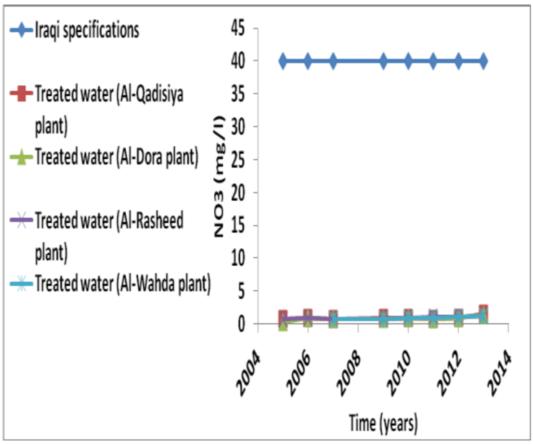


**Fig. 12.** Nitrate ion concentration during the study period.

### *4.2. Water Quality Index Values*

After completing the first stage of the water quality index calculation, which included, obtaining the variables and tabulation values, the second stage started, which include the calculation of the three factors values: Scope (F1) and Frequency (F2) and Amplitude (F3). Then last stage was completed which is included the calculation of the water quality index values for drinking purposes. As shown in Fig. 13 the water quality index of the treated water of (Al-Qadisiya, Al-Dora Al-Rasheed and Al-Wahda) plants is (77,78, 67 and 70) respectively, while the quality index values of the raw water at the same plants was (53,54,50, 49) respectively. It could be concluded that the four water treatment plants did improved the water quality index from the fourth category (for raw water) to the third category (moderate) (treated water). The results prove that the minimum value of the water quality index for the treated water is (67) in Al-Rasheed treatment plant.

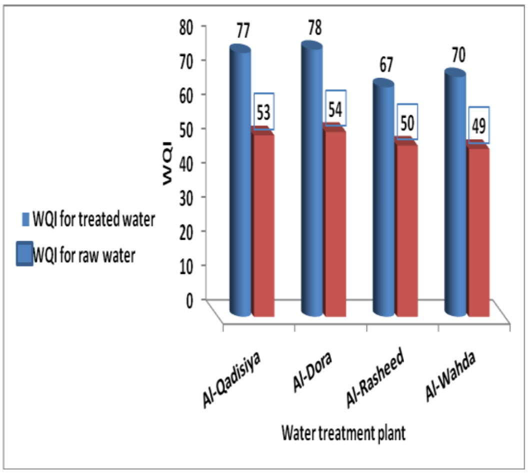


**Fig. 13.** The water quality index for all treatment plants.

## 5. CONCLUTIONS

1. The raw water of Tigris river in Baghdad city is classified as bad and polluted water. And this a needs advanced treatment.
2. The treated water for the four treatment plants in Baghdad city could be classified in the third category (moderate).

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