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A simplified strategy for evaluating the performance of water treatment plants

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ABSTRACT

Many people around the world rely on drinking water that has been treated by water treatment plants, which process raw water obtained from rivers or other freshwater sources in the region. This study aims to apply a simplified methodology to evaluate the efficiency of water treatment plants and to ensure that the treated water complies with water quality standards. In this study, the weighted arithmetic water quality index (WAWQI) was used as one of the simplest methods for assessing water quality in order to evaluate the efficiency and quality of the treated water from the Al-Tayyarah Water Treatment Plant, Hilla City, Iraq, and to compare it with the raw water. Samples were collected from the river next to the plant, the Hilla River, and from the treated water from January to November 2019. Eleven parameters were measured (pH, Turbidity, Temperature, EC, T.H, Ca, Mg, SO_4, TDS, Na, and K). The results showed that the quality of raw water throughout the study period was "unsuitable for human use" except for April, which had "poor" water quality. For the treated water, it was suitable for drinking water and the water quality ranged from "excellent" water quality in March to "good" water quality in July. Based on the WAWQI results for raw and treated water, the plant demonstrated good efficiency in removing pollutants, and the average efficiency of the plant throughout the study period was 82.7%. Therefore, it can be said that the Al-Tayyarah water treatment plant has revealed excellent performance in treating water, making it suitable for drinking purposes. Furthermore, the use of the WAWQI has proven its efficiency and usability as a simple strategy for evaluating the performance of water treatment plants.

Keywords: drinking water, Hilla river, water quality, water quality index, water treatment plants.

INTRODUCTION

Water is considered one of the most important natural resources used by all living organisms. Cities have been established since ancient times until the present time near fresh water sources. The quality and quantity of this water have gradually decreased over time due to many reasons, including the increase in population, urban and industrial development, and changes in rainfall rates as a result of climate change and other reasons (Mishra, 2023). The quality of water is equally as important as its quantity. As a result, the need to assess and monitor water quality has increased over time to preserve these water resources from increasing pollution. There are various strategies used to analyze water quality data depending on informational goals, the type of samples, the size of the sampling area, and the implemented approach (analytical, numerical, statistical, or machine learning). Hence, some of which are complicated methods such as numerical methods (Al-Zubaidi and Wells, 2018). One of the most popular ways to retrieve information on water quality trends is by use of the Water Quality Indices. These indices are based on the values of various physicochemical and biological parameters in a water sample. The use of indices in monitoring programs to assess ecosystem health has the potential to inform the general public and decision-makers about the state of the ecosystem (Alilou et al., 2019).

Water quality indices is an effective method for presenting information about water quality to interested persons such as ordinary citizens and policy planners. These indices therefore become important indicators for evaluating and managing the surface water, which gather the effects of all parameters of water quality into a single value. It is commuted for deciding the surface water suitability for the purposes of human consumption (Syeed et al., 2023). Water quality indices first appeared by Horton (1965) in the US, and later more methods of water quality indices appeared over the years such as employing the weighted arithmetic mean principles to determine the weighted arithmetic water quality index (WAWQI), which is one of the most widespread and easiest methods used in assessing water quality (Talukdar, 2022).

Many researchers have used the WAWQI to assess the quality of surface water in many countries. For example, Lagade et al. (2024) evaluated the water quality of the Dudhganga River using the WAWQI based on several variables (pH, TDS, turbidity, DO, NO_3, PO_4, etc). The results revealed that the water quality index ranged between 14 and 24 at all sampling sites. Although these results were initially considered good, the water is on the verge of becoming polluted if human-induced contamination increases. Also in India, Kumar et al. (2024) evaluated the water quality of the Tighra Reservoir using the WAWQI. Water samples were collected and tested for various quality parameters (pH, turbidity, alkalinity, chloride, hardness, TS, TDS, TSS, Fe, and MPN). The water quality index ranged between 15 and 121, indicating that the water quality varied from suitable to unsuitable for use, highlighting the need for appropriate measures to preserve water quality. As well, Arimieari et al. (2022) used the WQI to assess the water quality of the Woji River in Nigeria. The results showed a decline in the river's water quality, with concentrations of copper, lead, and iron exceeding the permissible limits according to World Health Organization (WHO) standards. The findings also indicated that the wastewater should be treated before being discharged into the river. In Iraq, many researches have implemented the WAWQI to evaluate the water quality in surface waters in this region, highlighting the need for increased environmental monitoring of the river. For instance, Naeem et al. (2022) studied the efficiency of the Al-Jubalia Water Treatment Plant in Basra Governorate. Physical and chemical parameters were measured across the four seasons of 2019. The results indicated that both raw and treated water were unsuitable for industrial, domestic, and irrigation purposes during the winter, summer, and spring seasons. However, in the autumn, only the treated water was classified as good. Therefore, the treated water supplied by the Al-Jubalia plant is considered unsuitable for human consumption.

In general, drinking water is closely linked to the spread of diseases. According to reports by the World Health Organization (WHO), more than 25 million people die annually due to diarrhea, with nearly one-third of them being children under the age of five. Additionally, the 1999 reports of the United Nations Environment Programme (UNEP) indicate that more than 80% of diseases and over 33% of deaths in developing countries are caused by the contamination of drinking water sources (Talukdar, 2022). Therefore, water treatment plants are considered a safe source of drinking water in many countries, where they are relied upon to purify raw water and produce potable water. Given the dangers of consuming contaminated water, there is a continuing need to evaluate the performance and efficiency of water treatment plants (Teodosiu et al. 2018). Thus, this study will demonstrate a simplified strategy to evaluate the performance of drinking water treatment plants by using the WAWQI based on field measurements from the Al-Tayyarah water treatment plant located in the Hilla City, central Iraq region, by compare the quality of the treated water with the quality of raw water obtained from the plant intake located at the Hilla River.

MATERIALS AND METHODS

Study area

This study was conducted at the Al-Tayyarah water treatment plant, located at coordinates (N 32° 29' 45.33972 and E 44° 25' 42.28752) in the Hilla

City, the capital of Babylon Governorate, central Iraq (Figure 1). Hillah City is located 100 km south of Baghdad Governorate, on the banks of the Hilla River, which is considered one of the most important branches of the Euphrates River (Al-Ani, 2019). The plant project draws its raw water from the Hilla River, and it is the main drinking water treatment plant the city. However, the river also serves as an outfall site for some untreated wastewater, which is discharged into it through highly polluted bypasses. Therefore, the water quality of this river varies for both natural and anthropogenic reasons (AbdUlameer and Al-Sultani, 2023). The plant is a major facility responsible for providing drinking water to the city residents (Hammood, 2018). It began operation in 1975 and has a production capacity of 1400 cubic meters per hour. Therefore, the efficiency of this station needs to be evaluated based on the quality of the treated water produced regularly by conducting physical and chemical tests and to determining the compliance with national drinking water specifications.

Samples collection

Samples were collected from the Hilla River, adjacent to the Al-Tayyarah water treatment plant, between January and November 2019. Eleven water quality parameters were measured for the raw water directly from the river and the treated water coming out of the treatment plant. The water quality parameters measured during the study period were: pH, turbidity (Turb), temperature (Temp), electrical conductivity (EC), total hardness (T.H), calcium ion (Ca^{+2}), magnesium ion (Mg^{+2}), sulfate ion (SO_4^{-2}), total dissolved solids (TDS), sodium ion (Na^+), and potassium ion (K^+). The statistical values of the measured water quality parameters for the raw and treated samples are shown in Table 1.

The performance evaluating strategy

In this study, the WAWQI was used to evaluate the performance of the Al-Tayyarah Water Treatment Plant. The WAWQI is considered one of the simplest methods for assessing water quality. Therefore, it can be considered the simplest model for calculating the performance of water treatment plants since it combines many water quality parameters into a single number. This provides a clear classification of water quality and its suitability for drinking purposes (Kachroud et al., 2019). Hence, the WAWQI method outperforms other WQIs because it incorporates a single basic mathematical equation for multiple

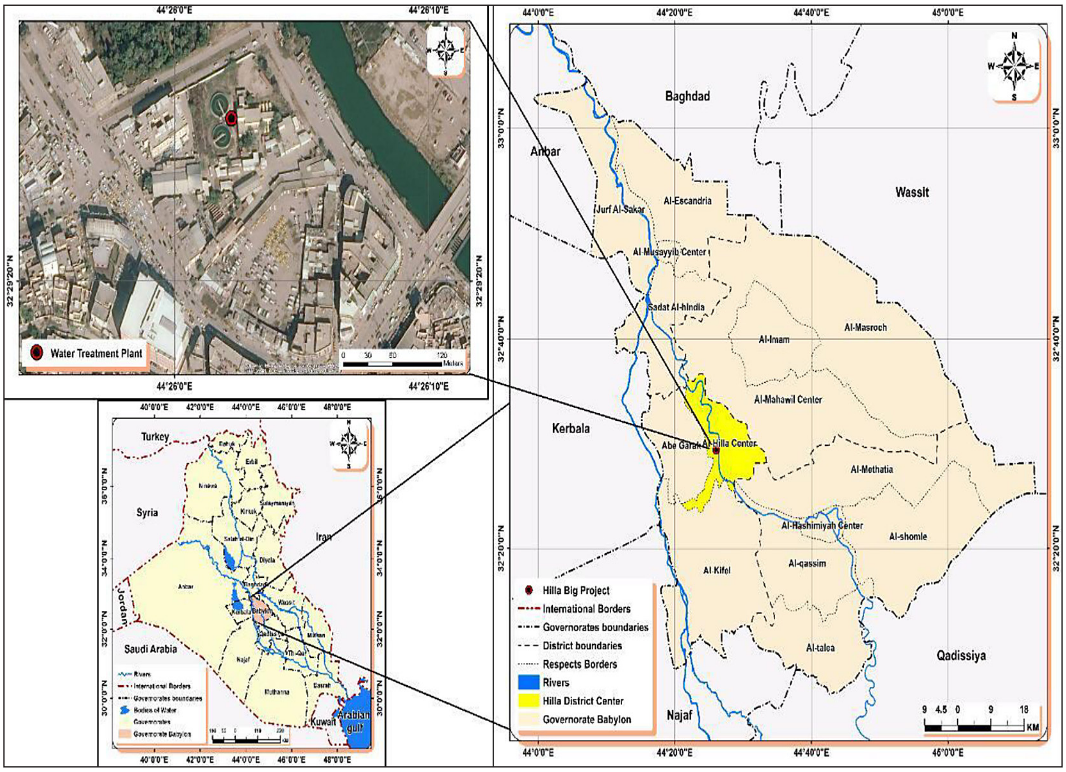

Figure 1. Al-Tayyarah water treatment plant location

Table 1. The statistical values of the measured water quality parameters for the raw and treated samples

Parameter	Unit	Raw water (RW)			Treated water (TW)		
		Min.	Max.	Avg.	Min.	Max.	Avg.
pH	–	6.50	7.70	7.28	6.50	7.60	7.21
Temp	℃	15.97	30.70	25.59	15.83	30.60	25.17
Turb	NTU	5.77	57.70	27.12	0.30	4.00	1.58
EC	μs/cm	813.00	1367.33	1031.27	696.33	1355.67	1014.42
T.H	mg/l	297.50	475.50	387.67	295.50	459.67	375.22
Ca	mg/l	70.00	128.00	98.60	73.00	123.67	97.82
Mg	mg/l	24.50	37.67	30.38	25.00	37.00	30.61
SO_4	mg/l	173.50	395.00	276.10	171.00	388.67	271.86
TDS	mg/l	498.00	875.33	648.44	502.00	843.33	644.58
Na	mg/l	36.75	112.67	68.44	35.75	111.67	66.37
k	mg/l	2.10	5.17	3.16	2.10	5.20	3.16

quality parameters (Călmuc et al., 2018). In this method, the water quality parameter (i) is linked to a weight (Wi), then the simple arithmetic mean is used to cumulate all parameters. Using the suggested water quality standard (SSi) for each parameter (i), Wi is calculated as shown in Equation 1 below (Iloba et al., 2021). Table 2 shows the Iraqi Standards used in this study for SSi values.

$$Wi = \frac{1}{SSi} \quad (1)$$

Using Equation 2, the variable (qi) is calculated for each parameter (i) to be used for determining the WAWQI from Equation 3, in which SSi is the measured value of parameter (i) in the water sample, SSo is the ideal value of parameter (i), and n is the total number of parameters. SSo is equal to zero for all parameters except pH, whose value is 7 (Iloba et al., 2021):

$$qi = \frac{SSi - SSo}{Si - SSo} \times 100 \quad (2)$$

$$WAWQI = \frac{\sum_{i=1}^{i=n} Wi \times qi}{\sum_{i=1}^{i=n} Wi} \quad (3)$$

After finding the WAWQI value for all samples, the water quality is classified based on its values into five categories, as shown in Table 3. The WAWQI value ranges from 0, which indicates excellent water quality, to greater than 100, which indicates that the water is unfit for human use.

Finally, the removal efficiency of the water treatment plant (E) during the study period was calculated depending on the raw water WAWQI ($WAWQI_{RW}$) and the treated water WAWQI ($WAWQI_{TW}$) using Equation 4:

$$E = \frac{WAWQI_{RW} - WAWQI_{TW}}{WAWQI_{RW}} \times 100\% \quad (4)$$

Table 2. Allowable water quality limits (SSi) for drinking water according to Iraqi standards (2009)

Parameter	Unit	Iraqi standards
pH	–	6.5–8.5
Temp	℃	25
Turb	NTU	5
EC	μs/cm	2000
T.H	(mg/l)	500
Ca	mg/l	150
Mg	mg/l	100
SO_4	mg/l	400
TDS	mg/l	1000
Na	mg/l	200
k	mg/l	10

RESULTS AND DISCUSSION

Variation in water quality parameters

In order to understand the difference between water quality parameters for raw and treated water, each parameter will be discussed separately to understand how the treatment plant affects it.

Temperature (Temp)

Water temperature generally follows the weather temperature in the area where it was collected. It is known, that temperatures in Iraq, particularly in Hillah, are quite low in winter and rise to high levels in summer. Figure (2a)

Table 3. Classification of water quality (Kachroud et al., 2019)

WAWQI value	Water quality class
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unsuitable for use

shows that temperatures rose in the summer and fall months to reach their highest value (30.45) in May and decreased in the winter and spring to reach their lowest value (15.83) in January. It can also be noted that there was no noticeable difference between the water temperatures of the raw and treated water. The temperature of the treated water was not lower than that of the raw water by more than approximately one degree Celsius in all samples. Therefore, there was no noticeable effect of the treatment plant on changing the temperature of the treated water.

pH

The pH is considered a measure of the acidity of water, where an increase in its value indicates that the water is alkaline, and a decrease in its value indicates that the water is acidic. From observing Figure (2b), it is noted that the pH value of the tested samples, for both raw and treated water, was within the permissible limits according to the Iraqi standard (6.5 to 8.5). The highest pH value was (7.7) in July, and the lowest value was (6.5) in March and October. It can also be observed that there was no significant difference between the pH value of raw and treated water for the same month, thus there was no noticeable effect of the treatment plant on the pH value. However, in general, since all the pH values were within the standard specifications, it is not possible to judge the treatment plant as it was not exposed to high or low pH values.

Total dissolved solids (TDS)

The TDS is a measure of all dissolved organic and inorganic materials in a water sample, including minerals and various salts. Some of these minerals are beneficial to human health, while others, if increased, can pose health risks. Figure (2c) shows no noticeable difference in TDS values between raw water and treated water. This can be due to the fact that all tested samples were within the permissible limits (1000 mg/l), thus the role of the treatment plant in reducing TDS values was not evident. The highest TDS value (875.3 mg/l) was recorded in March, while the lowest value (498 mg/l) was recorded in October.

Electrical conductivity (EC)

The EC is a measure of the water's ability to conduct electric current, and its value depends on the TDS in the water. The higher the concentration of TDS in the water, the greater its ability to conduct electric current. From Figure (2d), it can be seen that there is a remarkable consistency between the electrical conductivity and TDS values, as both increase in the winter and autumn months and decrease in the summer and spring months. It can also be noted that there is no significant difference between the electrical conductivity values of raw water and treated water, as all tested values were within the permissible standards.

Total hardness (T.H)

The T.H is a measure of the calcium and magnesium ions in a water sample. Excessive hardness can corrode mineral surfaces, thus affecting water quality for all domestic, industrial, and other uses (WHO, 2011). Figure (2e) shows that there is no noticeable difference between the total hardness value of the treated water and the raw water. Where all T.H values for all tested samples of raw and treated water were within the Iraqi standards (500 mg/l). The highest T.H value was (475.5 mg/l) for raw water in November.

Turbidity (Turb)

Turbidity is a measure of water's transparency or clarity, and reflects the presence of suspended particles in the water that scatter light passing through it. High turbidity can lead to the sedimentation of these particles in water pipelines and operational problems at treatment plants (EPA, 2023). From Figure (2f), it is clear that the turbidity values were very high for the raw water, especially in the summer, where they exceeded 57 NTU in July. In the rest of the year, they decreased relatively but remained higher than the Iraqi standards. On the other hand, the turbidity values for the treated water were all within the permissible limits (5 NTU). This demonstrates the efficiency of the treatment plant in reducing turbidity values to make the water potable.

Sodium, sulfate, calcium, magnesium, and potassium ions

The results indicate that the values of these ions [sodium (Na^{+}), sulfate (SO_4^{-2}), calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+})] for the tested samples, both treated and raw, for all months during the study period were within the Iraqi standard specifications (Figure 3). Furthermore, no significant difference was observed between the ion values of the raw and treated water. Therefore, the efficiency of the treatment plant cannot be judged based on these values alone.

The plant performance

Based on the results of the water quality parameters obtained, it is clear that relying on individual water quality parameters to evaluate the performance of a treatment plant may not be a sufficient method. A treatment plant may be highly efficient in removing a particular pollutant while

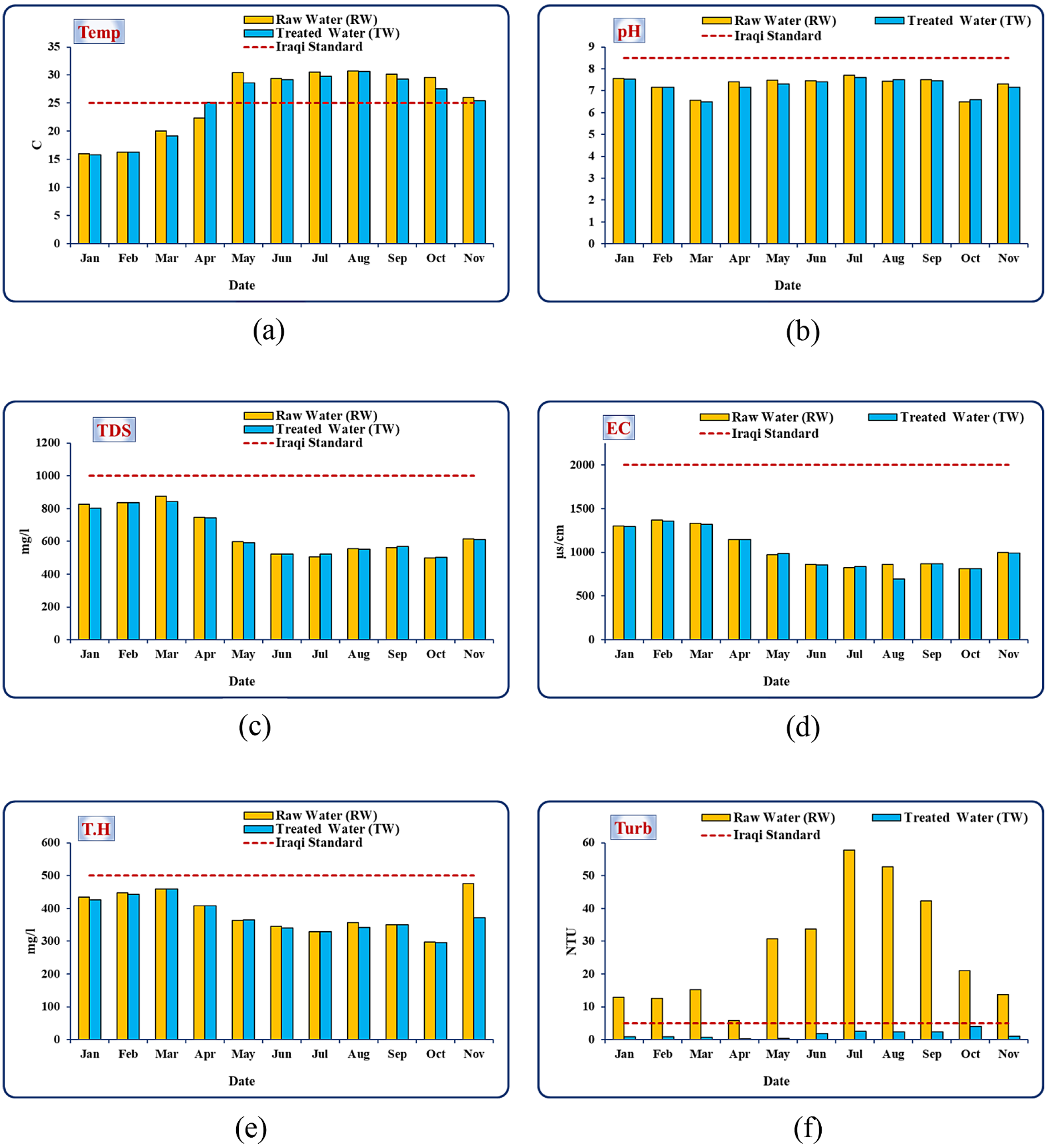

Figure 2. Change in the values of measured water quality parameters with months: (a) temperature; (b) pH; (c) total dissolved solids; (d) electrical conductivity; (e) total hardness; and (f) turbidity

not achieving the required efficiency in removing another pollutant. Hence, certain pollutants need special advanced methods to be appended to the water treatment plant to achieve the desired removal efficiency such as using adsorption and electrocoagulation (Shamkhi et al., 2023; Samaka et al., 2022; Ahmed et al., 2020). Furthermore, the variability of the measured parameter values, many of which fall within the permissible limits for drinking water, makes assessing the efficiency of the plant difficult. Therefore, a comprehensive approach must be followed to provide a clear and accurate assessment of the plant's efficiency based on the quality of the water and its suitability for drinking in general, based on the values of all tested parameters. In this study, the WAWQI was used as a simple strategy to evaluate the total removal efficiency of water treatment plants. Hence, the WAWQI values were calculated for the Al-Tayyarah Water Treatment Plant in the city based on the measured water quality data values of raw and treated water over the eleven months

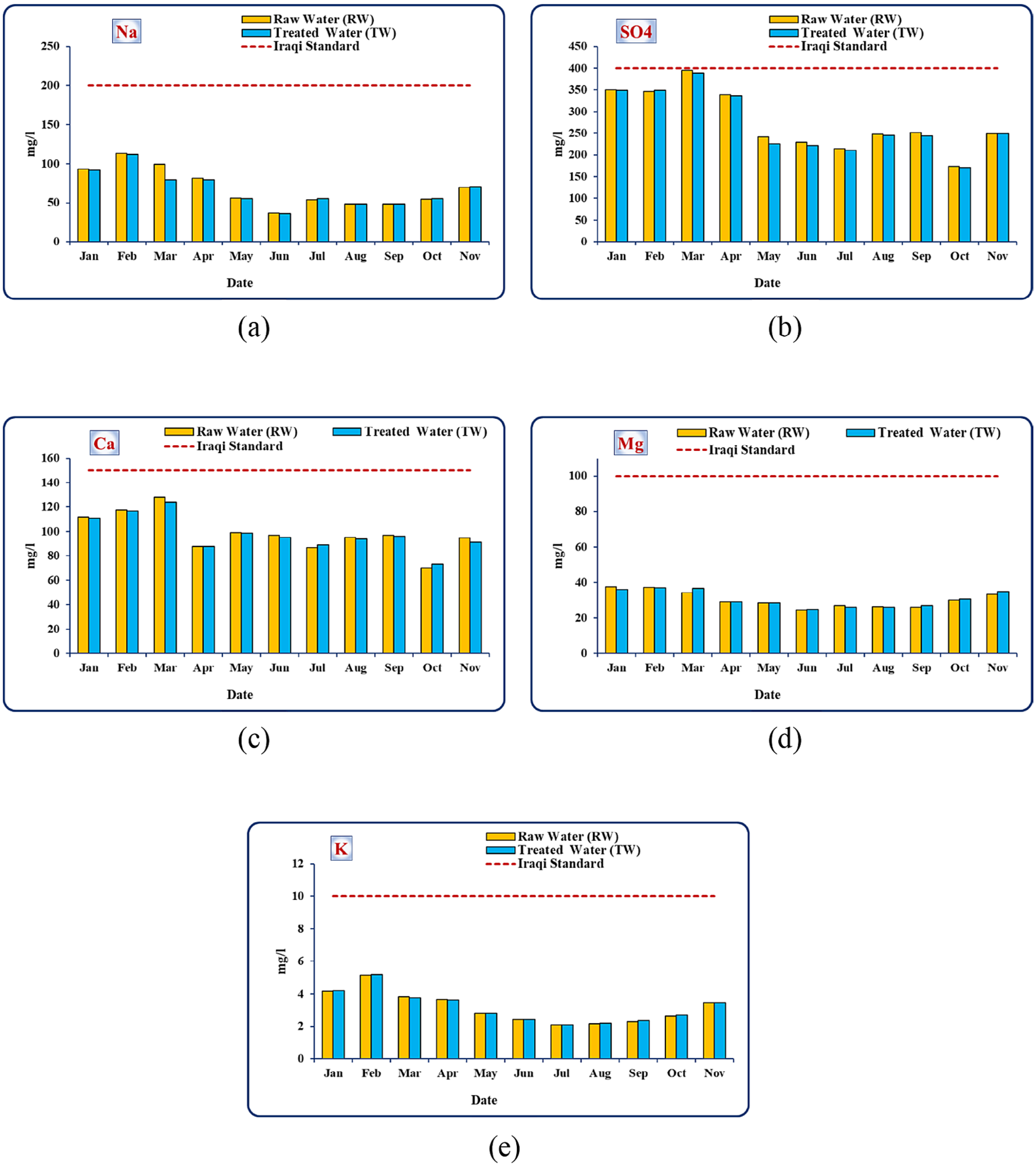

Figure 3. Change in the values of measured water quality parameters with months: (a) sodium ion; (b) sulfate ion; (c) calcium ion; (d) magnesium ion; and (e) potassium ion

of the study period. The results are presented in Table 4 and Figure 4.

The results showed that the quality of raw water in the river throughout the study period was "unsuitable for human use" (greater than 100) except for April, which had "poor" water quality (71.64). It was also noted that the water quality worsened in the summer months. The average raw water quality throughout the study period was "unsuitable for human use" (245.67). This significant increase in the water quality index values of the raw water can be attributed to the high turbidity values, which were well above the permissible limits, even though almost all other parameters were within the permissible limits. It has been noticed that turbidity is a significant water quality parameter in the Hilla River. Studies, conducted on the same river, emphasized that the river water quality index is a function of water turbidity mainly (Al-Zubaidi et al., 2025).

For the treated water, all WAWQI values were suitable for drinking water, and the water quality ranged from "excellent" water quality in March (15.06) to "good" water quality in July (47.60). Also, the average water quality of the treated water throughout the study period was "good" water quality (34.01). This is due to the fact that almost all water quality parameter values of the treated

Table 4. The WAWQI values for raw and treated water and the plant efficiency

Date	Raw water (RW)		Treated water (TW)		Plant efficiency (%) (E)
	WAWQI	Classification	WAWQI	Classification	
Jan	132.54	Unsuitable for human uses	32.89	Good water quality	75.2
Feb	126.59	Unsuitable for human uses	28.82	Good water quality	77.2
Mar	136.02	Unsuitable for human uses	15.06	Excellent water quality	88.9
Apr	71.64	Poor water quality	23.65	Excellent water quality	67
May	279.96	Unsuitable for human uses	26.10	Good water quality	90.7
Jun	301.62	Unsuitable for human uses	39.36	Good water quality	87
Jul	503.59	Unsuitable for human uses	47.60	Good water quality	90.5
Aug	457.55	Unsuitable for human uses	44.88	Good water quality	90.2
Sep	374.26	Unsuitable for human uses	43.16	Good water quality	88.5
Oct	182.38	Unsuitable for human uses	43.34	Good water quality	76.2
Nov	136.25	Unsuitable for human uses	29.20	Good water quality	78.6
Min	71.64	Poor water quality	15.06	Excellent water quality	67
Max	503.59	Unsuitable for human uses	47.60	Good water quality	90.7
Avg	245.67	Unsuitable for human uses	34.01	Good water quality	82.7

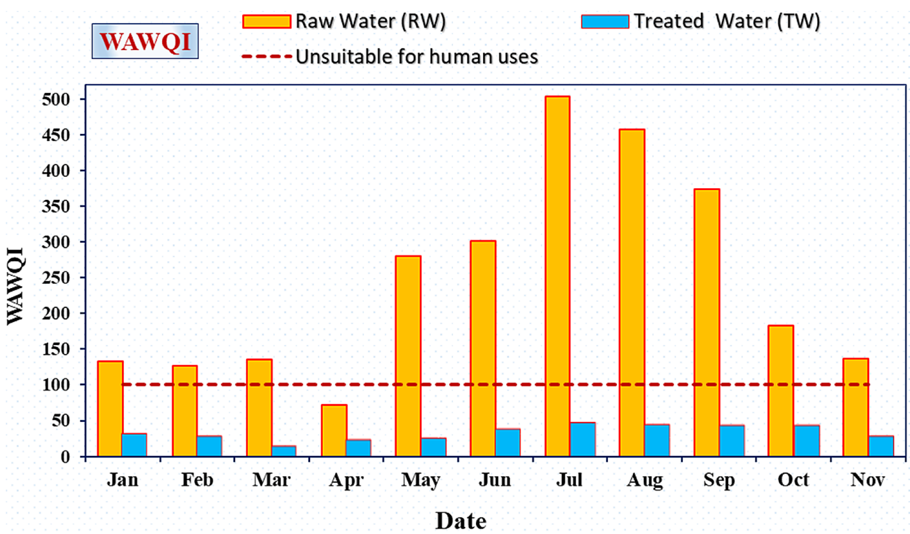

Figure 4. The WAWQI histogram for raw and treated water

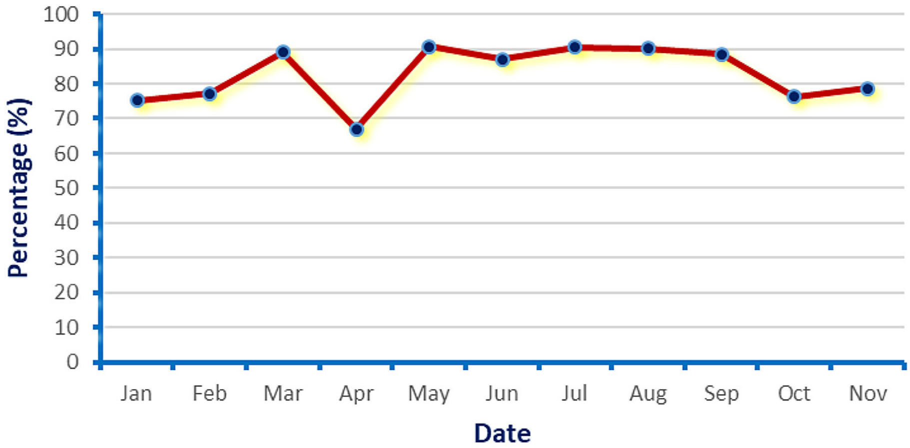

Figure 5. Efficiency variation of Al-Tayyarah water treatment plant during the study period

water were within the permissible limits, as the high turbidity values in the raw water were treated by the treatment plant, which led to a decrease in WAWQI values. Thus, the results showed that the best performance of the water treatment plant was in May, with an efficiency of 90.7%, while the lowest efficiency was in April, with a value of 67%. Overall, the average efficiency of the plant throughout the study period was 82.7%, as shown in Table 4 and Figure 5.

Therefore, it can be said that the Al-Tayyarah Water Treatment Plant has revealed excellent performance in treating water, making it suitable for drinking purposes. Furthermore, the use of the weighted arithmetic water quality index has proven its efficiency and usability as a simple strategy for evaluating the performance of water treatment plants. It can be applied to all plants after appropriate testing.

CONCLUSIONS

The WAWQI was used in this study as a simple strategy to evaluate the efficiency of water treatment plants. The WAWQI values were calculated for the Al-Tayyarah water treatment plant in the Hilla City, Iraq, based on measured water quality parameter values for raw and treated water over an eleven-month period in 2019. The results showed that the quality of raw water in the Hilla River throughout the study period was "unsuitable for human use" except for April, which had "poor" water quality. For the treated water, all WAWQI values were suitable for drinking water and the water quality ranged from "excellent" water quality in March to "good" water quality in July. The plant performance evaluation showed good efficiency in removing pollutants, and the average efficiency of the plant throughout the study period was 82.7%. Therefore, the Al-Tayyarah water treatment plant has excellent performance in treating water, making it suitable for drinking purposes. Furthermore, the use of the weighted arithmetic water quality index has confirmed its efficiency as a simple strategy for evaluating the performance of water treatment plants generally.

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