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INFLUENCE OF A RIVER WATER QUALITY ON THE EFFICIENCY OF WATER TREATMENT USING ARTIFICIAL NEURAL NETWORK

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Abstract

Tigris River is the lifeline that supplies a great part of Iraq with water from north to south. Throughout its entire length, the river is battered by various types of pollutants such as wastewater effluents from municipal, industrial, agricultural activities, and others. Hence, the water quality assessment of the Tigris River is crucial in ensuring that appropriate and adequate measures are taken to save the river from as much pollution as possible. In this study, six water treatment plants (WTPs) situated on the two-banks of the Tigris within Baghdad City were Al Karkh; Sharq Dijla; Al Wathba; Al Karama; Al Doura, and Al Wahda from northern Baghdad to its south, that selected to determine the removal efficiency of turbidity and the water quality index used to assess the quality of water for drinking purposes, in addition to finding the model based on past information to predict the quality of treated wastewater produced in each WTP using an artificial neural network (ANN) approach. The selected parameters for this study were turbidity, total hardness, total solids, suspended solids, and alkalinity. The results showed that all the WTPs possessed a high rate of efficiency in the removal of turbidity from raw water. Also, the results of the water quality index for all WTPs were classified over a study period of three years from 2015 to 2017 as being a good water quality and based on these results, the water treatment plants can be considered to be doing efficient water treatment process. The ANN model has been found at all WTPs to have a coefficient of determination (R^2) for expected models was more than 0.7 to provide a WQI prediction tool that can be used with a moderate level of predictive acceptance to describe the suitability of WTP water quality for drinking purposes.

Keywords: Artificial neural network (ANN), Tigris River, Turbidity removal efficiency, Water quality index (WQI), Water treatment plants (WTPs).

1. Introduction

Pollution of water resources deals with the water contamination by chemicals, suspended particles or bacterial substances that affect the quality of water, and that leads to serious impacts such as diseases, water shortages, ecological unbalance, environmental imbalances, etc. Assessment of water quality affords an understanding of whether water quality conditions improve or worsen over time, and how natural phenomena and human activities affect these conditions [1]. Water quality is used to describe the environmental and health conditions of a water resource [2] and due to the diseases related to water which causing death worldwide more than 3.4 million people may die each year according to the World Health Organization (WHO) [3]. Water treatment plants (WTPs) are designed to provide citizens with clean, colourless water without any taste or unpleasant taste [4]. Over the last two decades, Iraq's water resources have suffered from considerable pressure in terms of water quantity for various reasons such as the dams built on the Tigris and Euphrates rivers in riparian countries, global climate change, and the sharp deterioration locally, in addition to the annual transport of sedimentation, and the unscientific planning of water usage in Iraq [5]. Therefore, water quality monitoring has become an important issue for rivers that are constantly being affected by pollutants. Where the disposal of untreated domestic and industrial waste are the main sources of water pollution [6] and the water quality control program has become indispensable to ensure the correct performance of WTPs due to the continuous qualitative change occurring in the water body [7].

Tigris River is the ultimate source of drinking water in the city of Baghdad, which has a population of over 7.5 million people [8]. In the past few years, an increase in direct disposal of wastewater has been observed in the Tigris River without any control, and some antibiotics have also been detected in the drinking water [4]. Conventional water treatment processes include coagulation, flocculation, sedimentation (clarification), filtration, and disinfection [9]. The performance of WTPs depends on many factors such as raw water quality, hydraulic parameters for each individual treatment step, the appropriate dosage of chemical products, the commitment of the operational staff to the final goal, and the treated water quality [10]. The Tigris River water quality standards throughout the Bagdad city using eleven water quality variables conform to set standards of drinking water except for turbidity, calcium, and iron, which showed increasing levels but are high in salinity which will cause damage if used for irrigation purposes [11].

Water Quality Index (WQI) and the water quality determination prior to use for various purposes like drinking, industries, agriculture and recreational sports [12]. Farmaki et al. [13] conducted a study to assess the water quality of reservoirs used for industrial and domestic water supply in Athens, Greece, using artificial neural network (ANNs) where accurate verification of the different structures in the site classification and modeling results showed that ANNs were an effective and powerful tool for assessing water quality. In India, Sinha and Saha [1] assessed the WQI of the River Hooghly. In their study, they set up an ANN model to assess the relationship between different water parameters collected from various WTPs along the river. In 2016, Sakizadeh [14] used ANNs to predict the groundwater quality in Iran using sixteen parameters. Three algorithms of ANNs were: ANNs with early discontinuation; Ensemble of ANNs; and ANNs with Bayesian regularization. The results showed that the WQI prediction has been successfully implemented through Bayesian regulation and ensemble averaging methods.

Artificial neural networks have become very common in prediction and forecasting in several areas, including environmental science and water resources, finance, medicine, power generation [15]. Heydari et al. [16] used the ANN to develop models to estimate the monthly values of the specific conductivity and dissolved oxygen of the Delaware River. The study results showed that ANNs can give results of acceptable accuracy which are close to reality to a large extent. In India, Sarkar and Pandey [17] conducted a study where ANN was used to predict the concentrations of dissolved oxygen at the downstream of Mathura City. The results showed a high coefficient of determination, so it turned out that ANN is an efficient approach for modeling water quality. Also, in India, Prajithkumar et al., [18] conducted a study to predict the WQI for the Pavna River using ANNs. Their results showed that recurrent neural networks give better results than the radial multilayer neural networks.

2. Aim of the Study

This study aims to evaluate the efficiency of WTPs in Baghdad city by two methods which are removal of turbidity, and WQI in addition to finding mathematical models to predict the quality of treated water that was discharged from each plant using ANNs.

3. Material and Methods

This paragraph includes a description of the study area, collection of data from government sources, clarification of their contents, and the method of analysis adopted in order to achieve the research objective.

3.1. Study area description

The WTPs of Baghdad City located on the banks of the Tigris River were chosen to evaluate the raw water quality from the Tigris River that entered each plant, and the treated water from each plant. These WTPs are Al Karkh; Sharq Dijla; Al Wathba; Al Karama; Al Doura, and Al Wahda from northern Baghdad to its south, in that order, as shown in Fig. 1. Table 1 explains the distance of each WTP from the reference point (Al Karkh WTP), and the distance of each WTP from the preceding one, while Table 2 shows the designed capacities of each WTP [6].

3.2. Data collection and analysis

This study has been carried out within Baghdad city and the monthly data for raw and treated water from each plant for three years from 2015 to 2017 was collected, for five parameters selected for study: turbidity, total hardness, pH, total solids and alkalinity. The work steps included three stages: the efficiency of each plant arrived during each year depending on the turbidity. The WQI for supplied water was calculated using weighted arithmetic for the WQI method by depending on the Iraqi quality standards (IQS) for potable water 417 for the year 2009, and ANN models to predict the quality of treated water for each plant based on these parameters of raw water using ANNs. All the above analyses were performed using IBM SPSS v23 and the Excel program.

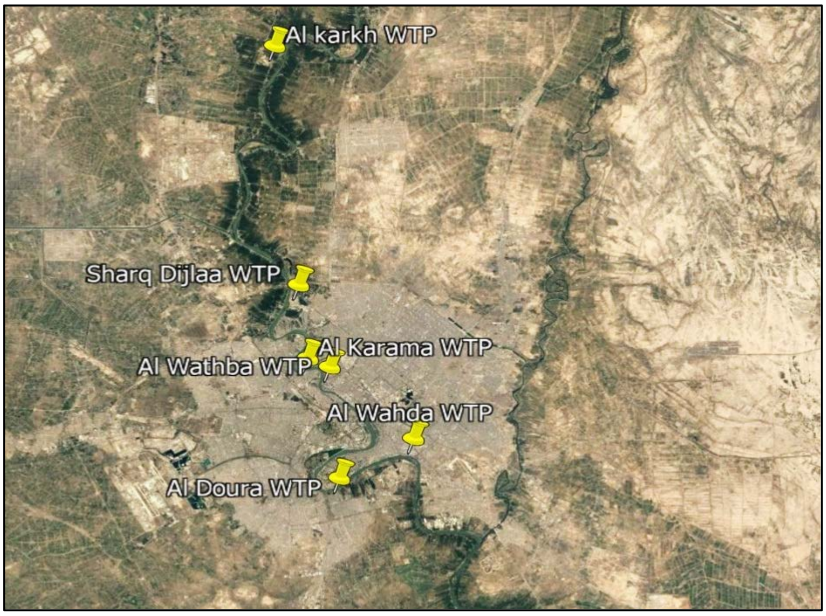

Fig. 1. Study area location in Baghdad city, Iraq: Source Google map.

Table 1. WTPs distances on the Tigris River during Baghdad city [19].

WTP	Reference point distance (km)	Cumulative distance (km)
Al Karkh	0	0
Sharq Dijla	30	30
Al Karama	10.76	40.76
Al Wathba	2.71	43.47
Al Doura	15.31	58.78
Al Wahda	8.31	67.09

Table 2. WTPs design capacities in Baghdad city [6].

WTP	Design capacity (ML/d)
Al Karkh	1365
Sharq Dijla	945
Al Wathba	105
Al Karama	227
Al Doura	115
Al Wahda	68

4. Methodology and Theoretical Concepts

4.1. River water quality concept

Water quality prediction becomes a very complex issue due to the complexity and diversity of the various sources of pollution and the limited accuracy of predicting, which can be used to enhance economic efficiency [20]. The pollution index was used to assess water quality, single-factor evaluation, the WQI, multivariate analysis, fuzzy evaluation, and the ANN method. The ANN model is a potentially useful technique for advanced nonlinear phenomena [2]. The WQI is a very useful and effective way to assess the suitability of the water quality and to communicate information about water quality [21]. In general, WQI can be defined as an estimate that reveals the combined effect that some water quality standards have on total water quality [5]. Scientists and experts in the field of water quality have considered this a preferred scientific method because many water quality and formula variables used in digital descriptive expression include the integrated effect of these variables on water quality and have an effective role in monitoring processes for water quality strategy and management so that they can classify water qualitatively for different activities under specific categories in a simple and useful scientific way [7].

4.2. Water quality index determination

The aim of the WQI is to provide a standard degree of water quality by translating the list of components and concentrations in the sample to one value [22]. WQI is a non-dimensional value ranging from 0 to more than 300, in which good water quality represents the value of a lower water quality indicator [23]. However, the index relies on some very important criteria that can provide a simple measure of water quality and provides the public with an overview of the region's potential water problems [1]. In this research, the Weighted Arithmetic Water Quality Index Method is used for selected WTP by five parameters of raw water as turbidity, total hardness, pH, total solids and alkalinity that were studied in respect to their suitability for the standards of drinking water quality. WQI is used to calculate the water quality of the Tigris River using Eq. (1) [24, 25].

$$WQI = \frac{\sum qi * wi}{\sum wi} \quad (1)$$

The rating scale of quality *(q_i)* for each parameter can be calculated as Eq. (2).

$$q_i = \left(\frac{c_i - c_0}{s_i - c_0}\right) * 100 \quad (2)$$

where, C_i: the estimated concentration of ith parameter, C_0: the ideal value of the ith parameter in pure water equal to zero, except the value of dissolved oxygen which equal to 14.6 ppm, and pH value equal to 7 and S_i: the standard value of the ith parameter. The unit weight of the ith parameter and can be calculated as Eq. (3).

$$w_i = \frac{1}{s_i} \quad (3)$$

4.3. Artificial neural networks concept

The artificial neural network is a non-linear modeling method capable of handling a large number of independent variables (inputs) to determine one or more dependent variable(s) (outputs). ANNs can find and identify complex patterns in datasets that may not be well described by a set of recognized processes, or a simple mathematical equation [28]. The most important characteristic of neural networks is their ability to learn which is called neural network training. The ANN training itself is designed to develop an internal set of features that it uses to classify information or data that ANNs provide incomplete data, sacrificial results, and are less susceptible to abnormal values. Artificial neural networks obtain a diagram of input and output variables, which can then be used to predict the desired output as a function of desired inputs. Any smooth and measurable function between input and output vectors can be approximated with a multi-layered neural network by selecting an appropriate set of connected weights and transfer functions. The most common type of structure is composed of a number of artificial neurons known as "nodes" or "units" that are ordinarily arranged in layers [29]. A layer of input units is connected to a layer of "output" units and one or more intermediate layers called hidden layers. The core element of the neural network is the artificial neuron, which consists of three main components: weights, bias, and activation function [30].

5. Results and Discussion

In this section, the results will be presented and discussed in a way that serves and achieves the research objectives in addition to comparing them with previous studies.

5.1. River water quality assessment

As is well known, water turbidity increases in the Tigris river as the river flows onward. Therefore, the WTPs receive different values of turbidity according to their location along the river. The sequence of WTPs along the river from the north to south of Baghdad city is as follows: Al Karkh, Sharq Dijla, Al Wathba, Al Karama, Al Doura, and Al Wahda. Table 3 shows the annual average concentration of the drinking water parameters resulting from each water treatment plant during the 2015-2017, as it is clear that all concentrations of the drinking water parameters are less than the Iraqi standard limits except the total hardness concentration that exceeding the permissible limits due to discharge the untreated pollutant wastes to the Tigris River, which leads to increase the parameters concentrations, including mainly calcium and magnesium, which lead to an increase in total hardness.

Table 3. Drinking water concentrations during the study period.

Parameter	Al Karkh	Sharq Dijla	Al Wathba	Al Karama	Al Doura	Al Wahda	AVG	IQS
Turbidity (NTU)	1.33	2.9	2.12	2.19	2.92	3.29	2.465	5
Alkalinity as $CaCO_3$ (mg/L)	120	140	144	154	145.3	142	141	200
T.Hardness as $CaCO_3$ (mg/L)	279	307	328	335	337.3	325	318.5	200
pH	7.54	7.6	7.58	7.74	7.48	7.45	7.572	7.5
Total Solids as $CaCO_3$ (mg/L)	458	551	587	610	571.8	604	563.8	1000

As shown in Fig. 2, the removal of turbidity during the year 2015 showed that Al Karkh WTP was the highest in water turbidity, possibly due to its location on the Tigris river as the first treatment plant for drinking water in Baghdad city from the north side, while the efficiency of the Sharq Dijla WTP was the lowest among the other WTPs since the field data proved that the river was within the normal limit, and it proves that the plant was suffering from a defect somewhere. In 2016, the turbidity level was high in the water of the Tigris, especially during the first three months of the year. However, the plants showed excellent performance in turbidity being reduced to the acceptable limits as shown in Fig. 3, where the performance of Al-Karkh WTP continued to be the most efficient in removing turbidity, followed by Al-Wathba, Al-Karama, Sharq Dijla, Al-Wahda, and Al-Doura WTPs. However, it is noted that Sharq Dijla WTP had a low performance due to its location on the upstream zone of the City of Baghdad, which confirms the existence of a defect in the plant.

During 2017, the results of all plants were good in terms of removal of turbidity, and there is a marked improvement in the performance of Sharq Dijla WTP, as shown in Fig. 4. In general, all WTPs showed excellent efficiency in removing turbidity, according to the Iraqi standards for drinking water.

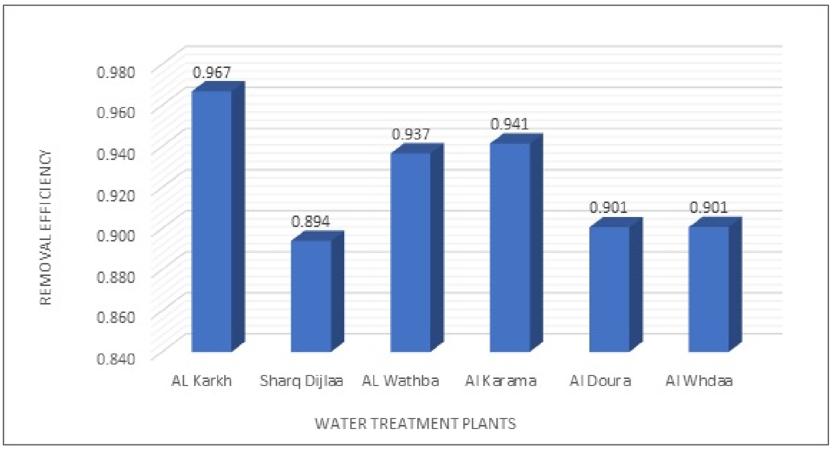

Fig. 2. Annual turbidity efficiency in water treatment plants during 2015.

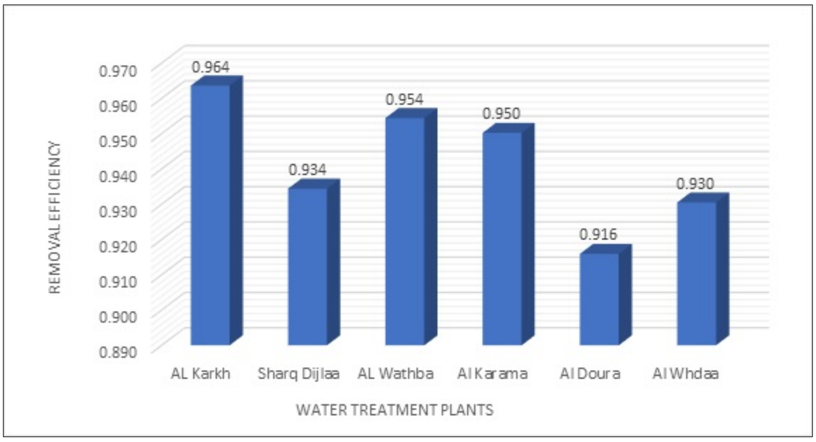

Fig. 3. Annual turbidity efficiency in water treatment plants during 2016.

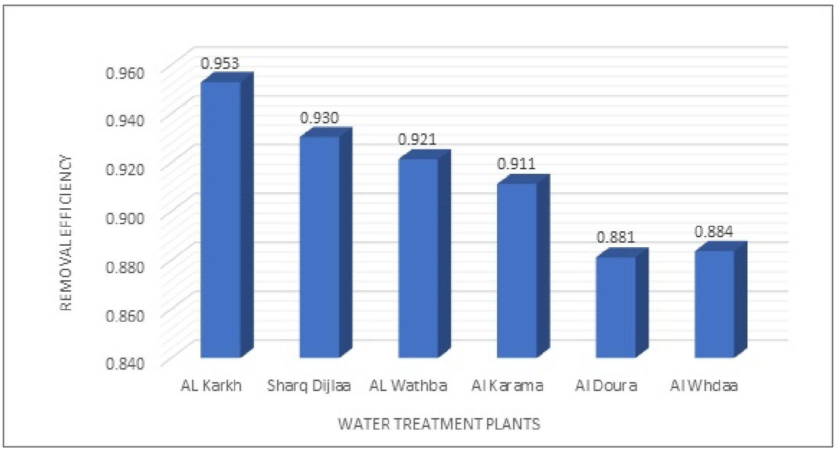

Fig. 4. Annual turbidity efficiency in water treatment plants during 2017.

5.2. River water quality assessment

The WQI was calculated for drinking water which is slated for being distributed to the consumers for three years ahead, as shown in Figs. 5 to 7 compared with the water quality classification based on WQI value as shown in Table 4. The WQI value for the treatment plants was in the range from 50 to 80, the best result of treated water during the study period was at Al-Karkh WTP due to its location in upstream of Baghdad city and the quality of raw water is less polluted with the WQI ranging from 53 to 59, while, the treated water at Al-Wahada WTP was of fairly good quality with the WQI ranging from 76 to 80 due to the untreated wastewater and rainwater discharges directly to the river, which leads to a deterioration in the quality of raw water at the downstream of the Baghdad city. In general, the quality of drinking water for all WTPs is classified as good quality as shown in Table 5.

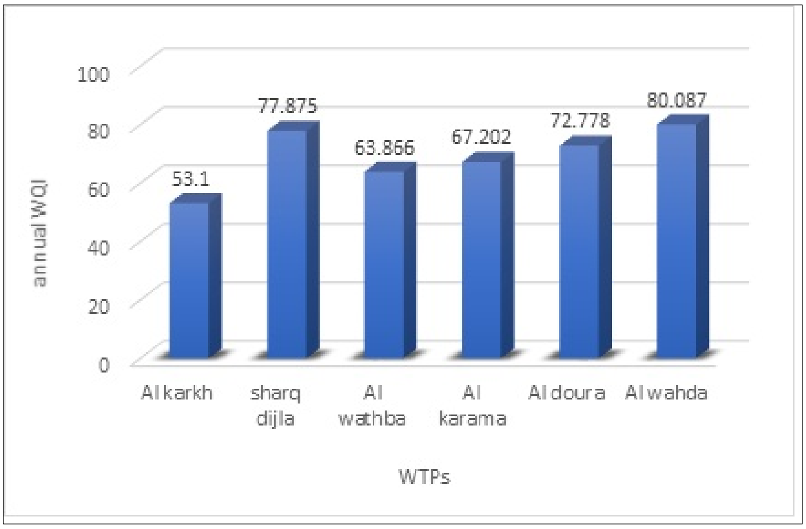

Fig. 5. Annual WQI for water treatment plants during 2015.

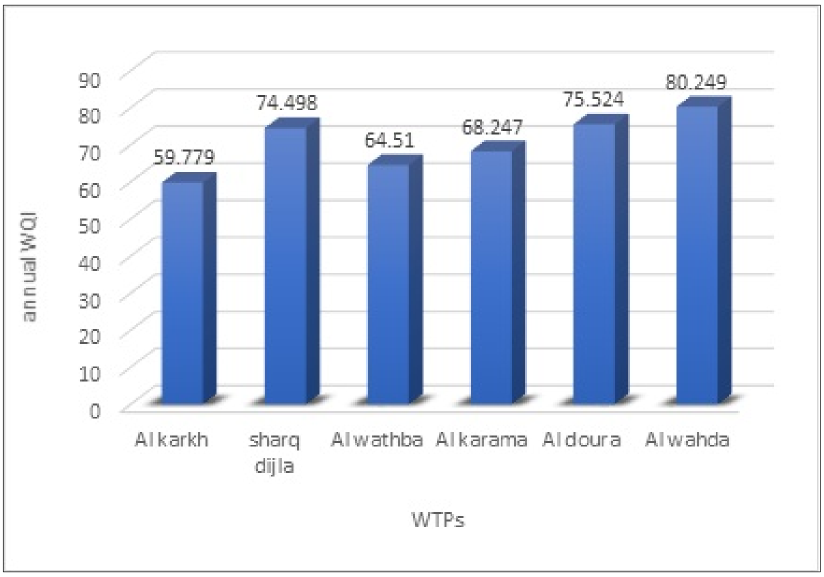

Fig. 6. Annual WQI for water treatment plants during 2016.

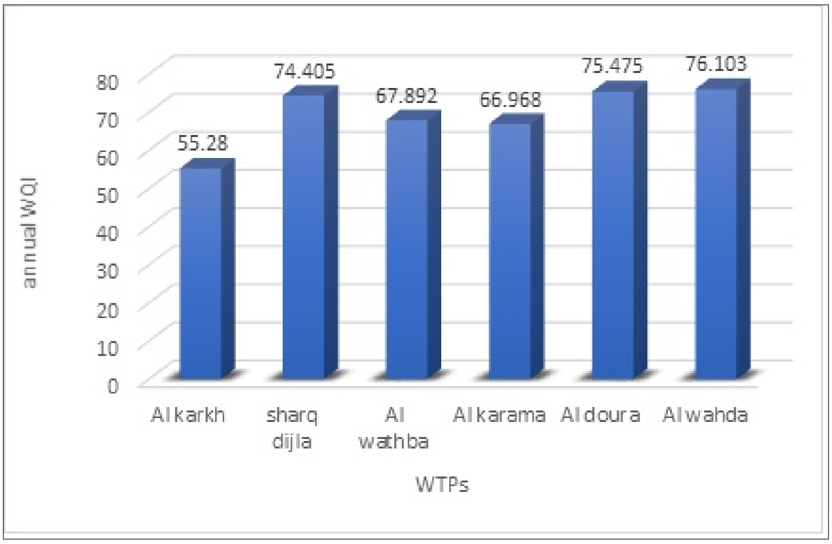

Fig. 7. Annual WQI for water treatment plants during 2017.

Table 4. Water quality classification based on WQI value [26, 27].

WQI value	Rating of water quality
< 50	Excellent
50- 100	Good
100- 200	Poor
200 - 300	Very poor
> 300	Unsuitable for drinking

Table 5. WQI classification for each WTP during the study period.

WTP	WQI classification		
	2015	**2016**	**2017**
Al Karkh	Good	Good	Good
Sharq Dijla	Good	Good	Good
Al Karama	Good	Good	Good
Al Wathba	Good	Good	Good
Al Doura	Good	Good	Good
Al Wahda	Good	Good	Good

5.3. Artificial neural networks model

In this research, each WTP has an artificial neural network (ANN) prediction model using raw water parameters as turbidity, total hardness, total solids, suspended solids, and alkalinity were used as independent parameters, and the WQI was used as a dependent parameter. The ANN model for each WTP was constructed using the standardized method to rescale the input data for covariates while the activation function for the hidden layer and output layer was hyperbolic tangent and identity respectively. In addition, the training, testing, and holdout were tested for the architecture and the optimization algorithm with a scaled conjugate gradient was used in this model for estimating the network weights.

Many run trials using the ANN model between the predicted and observed WQI were applied to obtain the highest value of the coefficient of determination and the smallest value of the sum of square error for the testing, and the importance of independent parameters for each WTP, as shown in Table 6. The predicted and observed WQI results showed that the highest and lowest value of the coefficient of determination at Al-Wathba WTP and Al-Wahda WTP respectively and also, the lowest mean square error in Al-Doura WTP. Thus, the ANN model has been found to provide a WQI prediction tool that can be used a moderate level of predictive acceptance to describe the suitability of river water quality for drinking purposes. The importance of the independent variables explains the effect of the different values of the independent variables on the value of the predicted model [30]. In this research, the most effective parameter on the predicted model value of WQI was changed from one WTP to another as shown in Table 6.

Table 6. Results prediction of Water Treatment Plants models.

WTP	Predicted and observed relationship			
	Equation	**R^2**	**MSR**	**Importance**
Al Karkh	$Y_P = 17.2 + 0.69X_O$	0.718	0.214	SS.
Sharq Dijla	$Y_P = 36.9 + 0.53X_O$	0.722	0.049	SS.
Al Karama	$Y_P = 14.12 + 0.79X_O$	0.762	0.231	Turbidity
Al Wathba	$Y_P = 13.02 + 0.8X_O$	0.805	0.779	SS.
Al Doura	$Y_P = 16.9 + 0.77X_O$	0.783	0.003	SS.
Al Wahda	$Y_P = 18.98 + 0.75X_O$	0.714	0.00007	TS

where Y_p = predicted value of WQI and X_O = observed value of WQI

6. Conclusions

In this study, the effect of the water quality of the Tigris River was studied on each WTP efficiency within Baghdad city during the study period and the most main conclusion can be summarized as, the water turbidity in the Tigris River is increasing from the north to the south of Baghdad City, therefore, the WTPs receive different values of turbidity according to their location on the river. The results showed that selected WTPs in Baghdad City were effective and efficient in removing turbidity from Tigris raw water according to the Iraqi standards for drinking water and Al-Karkh WTP is generally considered the best in removing turbidity throughout the study period, therefore, the treated water from these selected plants was rated as good quality based on WQI according to the drinking water quality standards. The prediction models that were found for calculating the WQI have a coefficient of determination (R^2) higher than 0.70 and, therefore, can be used to predict the water quality of these plants. It should be noted that the plant east of the Tigris suffers from a defect in the management, so the focus should be on maintenance works in addition to the selection of specialized staff to supervise the working of the plant.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been meticulously observed by the author.

Nomenclatures

C_i	The estimated concentration of the ith parameter.
Co	The ideal value of the ith parameter in distilled water equal to zero, except the value of dissolved oxygen which is equal to 14.6 ppm, and pH value is equal to 7.
R^2	Coefficient of determination
Si	The standard value of the ith parameter.
q_i	Rating scale of quality for each parameter.
w_i	The unit weight of the ith parameter.

Greek Symbols

Σ	Summation

Abbreviations

Alk.	Alkalinity

ANN	Artificial neural network
ANNs	Artificial neural networks
IQS	Iraqi quality standard
MSR	Mean square error
SPSS	Statistical package for the social sciences
SS	Suspended solids
TS	Total solids
WHO	World Health Organization
WQI	Water quality index
WTP	Water treatment plant
WTPs	Water treatment plants
pH	potential of Hydrogen
ppm	parts per million

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