Journal of Engineering Science and Technology
Vol. 15, No. 5 (2020) 3055 - 3066

WATER QUALITY ASSESSMENT AND SODIUM ADSORPTION RATIO PREDICTION OF TIGRIS RIVER USING ARTIFICIAL NEURAL NETWORK

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Abstract

Sodium adsorption ratio (SAR) is considered as a measure of the water suitability for irrigation usage. This study examines the effect of the physicochemical parameters on water quality and SAR, which included Calcium(Ca^{+2}), Magnesium(Mg^{+2}), Sodium (Na^{+}), Potassium (K), Chloride (Cl^{-}), Sulfate(SO_4^{-2}), Carbonate (CO_3^{-2}), Bicarbonate (HCO_3^{-}), Nitrate (NO_3^{-}), Total Hardness (TH), Total Dissolved Salts (TDS), Electrical Conductivity (EC), degree of reaction (DR), Boron (B) and the monthly and annually flow discharge (Q). The water samples were collected from three stations across the Tigris River in Iraq, which flows through Samarra city (upstream), Baghdad city (central) and the end of Kut city (downstream) for the periods of 2016-2018. Results showed that the water quality of the Tigris River water is within the world health organization (WHO) specifications for drinking water except for Sulfate concentration. An artificial neural network (ANN) was used to develop the model for the three locations to predict SAR. The sum of the squared error function and the coefficient of determination (R^2) were used to evaluate the amount of error in predicting values of SAR and performance evaluation of the model. The results showed that the highest value of the coefficient of determination was 0.992, 0.986, and 0.955 for Samarra, Baghdad, and Kut, respectively and the ANN analysis indicated that the prediction of SAR was effected by Sodium for three stations. Thus, the ANN model has been found to provide SAR prediction tool that can be used effectively to describe the suitability of river water quality for irrigation purposes.

Keywords: Artificial neural network (ANN), Sodium adsorption ratio (SAR), Tigris river, Water quality.

1. Introduction

The river water analysis of the physical, chemical and biological parameters is essential to control and estimate the most effective parameters on river water quality, which need to monitor and control pollution sources such as municipal and industrial wastewater discharges [1]. There are several methods for estimating and understanding the water quality such as the water indices, analysing the physicochemical parameter, using geographic information system (GIS) mapping system and developing an artificial neural network (ANN).

Al Suhaili and Nasser [2] were estimated the water quality of the Tigris River in Baghdad during 2000-2004 using twenty-one parameters from three water treatment plants in the Tigris River to measure water quality indices (WQI) where they found that river water is deteriorating in southern Baghdad due to various activities of agriculture and industries. In addition, other researchers were examined by analysing selected physicochemical parameters from four locations along the Tigris river (Al-Muthanna Bridge, Al-Sarrafia Bridge, Al-Shuhada Bridge, and Al-Dora Bridge) for the period from February 2017 to February 2018 and the results showed an increase in pollution, which led to poor water quality in southern Baghdad due to untreated sewage discharges to river [3]. Khudair [4] was used the WQI application to estimate the water quality of the Tigris River using data from eight stations located in Baghdad during 2004-2010. The results showed that the classification of the Tigris River is very poor quality and that the most effective parameters in WQI are Turbidity, Total Hardness, Electrical Conductivity, and Total Solids. Therefore, consistent data and an appropriate river water quality monitoring program are necessary to protect freshwater resources.

Sodium adsorption ratio (SAR) is used to measure water quality and as an indicator of irrigation water quality [5]. The investigating of SAR values is imperative because of their effects on water quality for irrigation purposes and their significant impact on the infiltration rate of the soil [6]. The value of SAR could be indicated by estimating the concentration of Na, Mg and Ca, the value of SAR is calculated using the Eq. (1) [7].

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \qquad (1)$$

The high concentration of Sodium in irrigation water increases the salinity of the water that affects soil classification and conversion from natural to saline water, thereby reducing hydraulic conductivity and infiltration rate of soil [8]. Predicting the effect of SAR is considered essential for river water quality, irrigation and agricultural. The concentration of SAR in the river can be influenced by many physicochemical parameters, the rate of discharge water into the river and many other processes occurring at the upstream location [1], in addition, the increase in SAR value in the water quality of irrigation leads to the undesirability of water [9].

Artificial neural network (ANN) has been successfully used in many researches that focused on simulating river water quality and confirmed the efficiency of using the ANN model in predicting different parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Turbidity [10, 11] and also, many articles were reviewed using ANN application on different categories such as groundwater management, water demand, flooding, rainfall-runoff modeling, and water quality modeling [12]. Application of ANN model with multilinear perception (MLP) and multivariate linear regression (MLR) model was used to estimate SAR value in rivers. The result showed that the ANN model with one hidden layer is suitable in predicting SAR with a high coefficient of determination (R^2 = 0.92) which can be defined as the variance ratio of the dependent variable to the predictable dependent variable from the independent variable and is a more effective performance than MLR [12]. The SAR prediction was studied in the Chelghazy River in Kurdistan, Iraq using ANN, and the collected parameters were pH, discharge, Sulfate, Sodium, Calcium, Chloride, Magnesium and Bicarbonate for the period 1998-2009. The results showed that SAR estimation was influenced by pH and Calcium and the increase of Sodium ions in irrigation water which leads to a reduction in the infiltration rate and affects the permeability of the soil [1] while Yesilnacar and Sahinkaya [13] were studied the prediction of SAR value in an unconfined aquifer at south-eastern Turkey and found that the most sensitive parameters to SAR were Chloride and Total Hardness and the average SAR value about 1.37 which considered below the allowable permission according to the regulation in Turkey, which mentioned that the classification of water with SAR value less than 18 is good for irrigation and water with SAR value more than 26 is not appropriate for use in irrigation. In addition, Khudair and Al-Musawi [14] investigated the effectiveness of using ANN model in predicting the water quality assessment and TDS in Al-Hawizeh Marsh South of Iraq and found that ANN model showed a highly significant of TDS predication in Al-Hawizeh Marsh with a high coefficient of determination (R^2 = 0. 927). Also, Yesilnacar and Sahinkaya [13] developed an ANN model estimating SAR value and sulfate (SO_4^{-2}) in an unconfined aquifer at Harran Plain, in Turkey. The result showed that there is a great correlation between the predicted and experimental data of the coefficient of determination (R^2) about 0.96 for SAR and 0.98 for SO_4^{-2}. Hence, they considered that the proposed ANN model as a cost-effective and easier method for managing groundwater resources.

The aim of this research is to study the water quality assessment of the Tigris River by studying the effects of physical and chemical parameters and increasing the value of SAR on the river, which provides an indication of the suitability and quality of the river water. This study estimates the ability to use the developed ANN model to predict SAR in three locations in the Tigris, Samarra city (upstream), Baghdad city (central) and end of Kut city (downstream) for the periods 2016-2018.

2. Materials and Methods

2.1. Case study description

The study was applied in Tigris River which flows in the direction from north to south through Samarra city (downstream of Samarra dam), Baghdad city near Al-Shahada Bridge and Kut city (upstream Kut dam) as shown in Fig. 1. The Tigris River flows through the central part of these cities and plays an important role in supplying natural potable water for the mentioned cities. The first station within Samarra city is sited in Samarra Dam, which located at Tigris River adjacent in Baghdad, Iraq and located at Latitude 45°11′34″N and longitude 43°51′02″ E. The dam is connected by a diversion canal with Tharthar depression, to divert the floodwater in Tigris River to Tharthar Lake. The dam was constructed in 1955 and commissioned to work in 1972. The elevation of the dam at the crest is approximately 65 m and the design capacity of the reservoir is 150,000,000 m^3. While, the second station in Baghdad city is located near Al-Shuhada bridge at Latitude 33°20'21"N and Longitude 44°23'21" E, and the third station is located near Kut dam, which is in Wasit governate in Kut city, eastern of Iraq, and located on the left bank of Tigris River at Latitude 32.498889°N and Longitude 45.817778 °E. The Dam was constructed in 1939. The approximate distance was measured using the GIS mapping system by adopting the center of the Tigris River between the Samarra-Shuhada Bridge Station, about 185 km, and the Shuhada Bridge Station-Al Kut Dam, about 311 km.

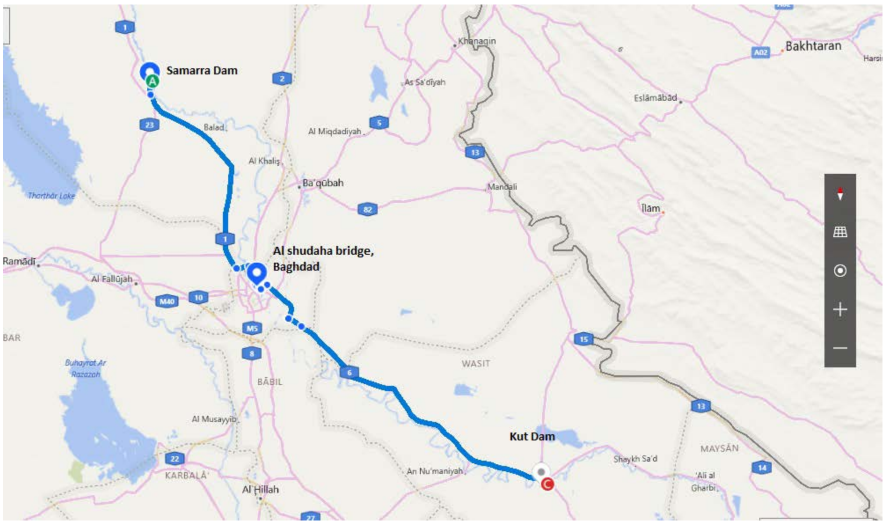

Fig. 1. Map of the study area.

2.2. Data collection and analysis

The data used in this study were collected from analysing the water quality in three stations across the Tigris River (Samarra, Baghdad and Kut city) and provided by the Ministry of Water Resources and the Ministry of Health and Environment for the period from January 2016 to December 2018. The collected data represent the averages monthly values of fifteen parameters which included Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Sodium (Na^{+}), Potassium (K), Chloride (Cl^{-}), Sulfate (SO_4^{-2}), Carbonate (CO_3^{-2}), Bicarbonate (HCO_3^{-}), Nitrate (NO_3^{-}), Total Hardness (TH), Total Dissolved Salts (TDS), Electrical Conductivity (EC), degree of reaction (DR), Boron (B) and the monthly and annually flow discharge (Q).

3. Artificial Neural Network (ANN) Concepts

ANN is a mathematical computing system consisting of many interconnected neurons that form a neuron network similar to the operation of the human brain to solve various problems and predict output data from input data that receives input signals from some resources and collects them to perform the process on the result and then the final output can be predicted [15, 16]. In this research, the Statistical Procedure for Social Science (SPSS) software, version 24 was used to build an ANN model to predict SAR. The model of the structure of ANN simulation is carried out using the training and testing method for the model with past data from 2016-2018, in order to explain the relationship between the independent variables (chemical parameters and discharge collected from the three stations) and the dependent variables (SAR). The multilayer perception (MLP) procedure is applied to the mathematical model as a function of measurements that minimize the error between the actual and predicted output. In addition, the sum of the square error function and the coefficient of determination (R^2) were used to estimate the difference between the predicted and observed values. For building ANN model structure many run trials were applied to decide the superlative model according to the lowest error function and highest coefficient of determination, (IBM® SPSS® Statistics 24 User Guide).

4. Results and Discussion

4.1. Water quality assessment

Table 1 shows the descriptive statistics analysis for the fourteen water quality parameters, with flowrate, and SAR in three stations across the Tigris River during 2016-2018 to understand the deterioration in water quality. The maximum value of average concentrations for Sodium, Calcium, and Magnesium was 93.85, 95.03, and 49.87 mg/L in Kut city which are within the permitted limit of 200 mg/L for the three elements by the WHO for drinking water [17]. Chloride ion is present in all types of natural water but with very low concentrations. The concentration of Chloride increases near sewage, waste outlets, and irrigation drains. The high concentration of Chloride gives a salty taste for water and causes corrosion in pipelines of water. The highest value of the Chloride concentration is 117.72 mg/L in Kut city which is found to be within the accepted WHO limits of 250 mg/L [17]. In water sources, Sulphate presents in the form of SO_4^{-2} and comes from atmospheric precipitation and industrial discharges. Through research, the Sulphate parameter was found higher than the limit in two sites Baghdad and Kut cities, but in Samarra Dam, it was acceptable within permitted WHO limit of 250 mg/L [17].

Nitrate is considered a significant parameter in the natural water system because the nitrate concentration facilitates the heavy growth of aquatic plants which producing eutrophication. The main resources of nitrate in water were the decomposition of organic matter and the fixation of atmospheric nitrogen. The excessive use of pesticides and fertilizers containing nitrates in agriculture has a negative impact on the health, environment and water quality, which causes an increase in nitrite ion in rivers [17]. The maximum value of average concentration for nitrates in Kut city was 4.29 mg/L which is within the standard permitted WHO limit of 50 mg/L [17]. Water hardness is caused by Calcium and Magnesium salt and causes many problems such as a blockage in the pipelines, and the deposition of the scales in the boilers. The results obtained from the statistical analysis showed that the average hardness values for three cities were within the permissible WHO limit of 500 mg/L [17]. While the maximum average concentrations of total dissolved salts in Kut city reached 807.09 mg/L which is within the standard permitted limit of 1000 mg/L [17].

The maximum Electrical Conductivity value was 1.2 μS/cm in Kut city, and the results showed that EC values were within the accepted limits. Boron presents naturally in groundwater, but it also founded in surface water due to the discharge of treated sewage effluent, which arises from using some detergent, to surface waters. The results obtained for the three cities are above the permissible WHO limit of 0.3 mg/L [17, 18]. The high contamination of the river was caused by the nearby environment or human activity such as effluent disposal of the partially or treated wastewater directly to the river, which causes further deterioration in it from upstream to downstream.

Table 1. Chemical analysis of the Tigris River raw water during 2016-2018.

Parameters	Samarra Dam	Baghdad City	Kut City	WHO Permissible Limit
Ca^{+2} (mg/L)	49.78	77.72	95.03	200
Mg^{+2} (mg/L)	26.74	49.37	49.87	200
Na^{+} (mg/L)	22.73	82.51	93.85	200
K (mg/L)	3.25	4.12	4.6	
Cl^{-} (mg/L)	23.88	91.42	117.72	250
SO_4^{-2} (mg/L)	104.94	286.38	325.68	250
CO_3^{-2} (mg/L)	3.6	6	7.09	
HCO_3^{-} (mg/L)	170.54	180.93	183.1	
NO_3^{-} (mg/L)	2.98	3.39	4.29	50
TH (mg/L)	238.8	401.48	439.7	500
TDS (mg/L)	329.2	717	807.09	1000
EC (µS/cm)	0.49	1.07	1.2	
DR (mg/L)	7.42	7.45	7.36	
B (mg/L)	0.84	0.33	0.37	0.3
Q (m^3/s)	494.84	479.19	213.22	
SAR (mg/L)	3.7	10.22	11.08	<6

Sodium adsorption ratio (SAR) is one of the important parameters to be evaluated during studying the suitability of water for use in irrigation and could be used to manage the Sodium affected soils. It is measured from the concentrations of the main alkaline and earth alkaline cations present in the water, therefore, it is considered as an indicator of the suitability of water for use in irrigation [9]. In general, it is observed that the SAR values were increased, as the discharge of the Tigris River decreases and increase the Calcium and Magnesium concentrations causing the river's deterioration from north to south. The degree of reaction is defined as an indicator of geomorphology and global environmental change by measuring the degree of water mixing and the amount of oxygen it will carry [19].

Figure 2 shows the average monthly variation of SAR during 2016-2018 at the three stations. In the Samarra station, the SAR concentration range between 2.94-4.48 mg/L with an average value of 3.66 mg/L, which it is noted that the monthly overall trend of SAR slightly increasing while in the Baghdad station, the SAR concentration range between 7.2-13.72 mg/L with an average value of 9.95 mg/L, that it is observed that the monthly overall trend of SAR significant increasing and in the Kut station, the SAR concentration range between 9.1-12.62 mg/L with an average value of 11.11 mg/L, which it is observed that the monthly overall trend of SAR significant increasing. In general, it is noted that the SAR rate for the Baghdad site and Kut site increases by 271% and 303% compared to the Samarra site, respectively, and for the Kut site increases by 111% compared to the Baghdad site which confirms the increase in the concentrations of sodium, calcium, magnesium, which leads to the deterioration of the water quality of the Tigris River as head from upstream to downstream.

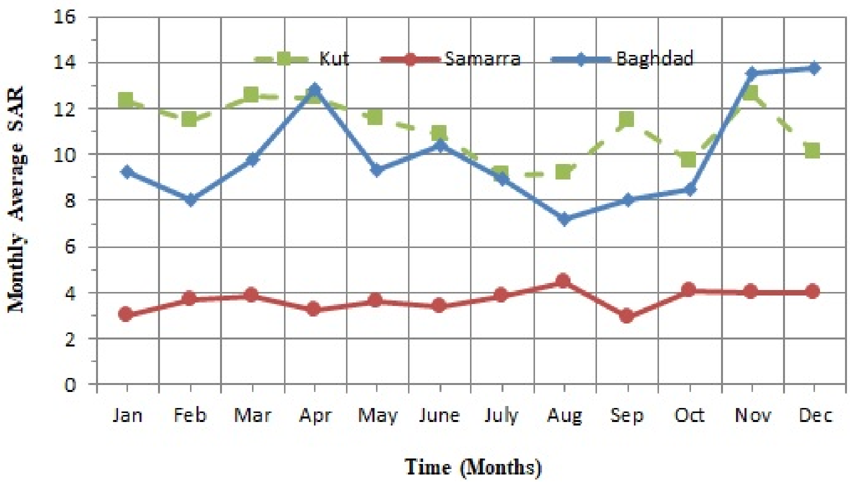

Fig. 2. Average monthly SAR for the three stations.

4.2. Artificial neural network (ANN) model

4.2.1. ANN model training and testing

For calculating the mathematical model structure, the training and testing method was applied by dividing the partitions of the contribution data into training, testing and holdout samples (IBM® SPSS® Statistics 24 User Guide). Three different models were applied for the three locations Samarra, Baghdad, and Kut cities. The approach in this paper was based on prior researches; the superior partition depends on the sum of the square error function and the coefficient of determination (R^2) for training and testing statistics. For the best ANN model that gives the highest values of the coefficient of determination and the lowest value of the sum of the square error for testing. So, for Samarra station model, the use of automatic architecture selection has resulted in six with bias neuron in a single hidden layer with the best partition (training, testing and holdout data) was found to be about 75%, 20.8%, 4.2% respectively. For the Baghdad station model, the automatic architecture selection has resulted in four with bias neuron in a single hidden layer with the best partition (training, testing and holdout data) was found to be about 63.6%, 25.3%,9.1% respectively while for the Kut station model, the use of automatic architecture selection has resulted in four with bias neuron in a single hidden layer with the best partition (training, testing and holdout data) was found to be about 43.8%, 28.1%, 28.1% respectively.

4.2.2. Activation function

The influence of changing the activation function in the output layer on the model performance was investigated based on the best partition data from the previous section. The training, testing, and holdout were tested for the Architecture (Activation function) the identified, hyperbolic tangent and sigmoid respectively. Many run trials were applied for the model and the results showed that the sigmoid function has the smallest sum of square error for testing.

4.2.3. ANN model prediction

The ANN model was constructed using the standardized method to rescale the input data. In addition, the batch training and the optimization algorithm with a scaled conjugate gradient were used in this model for estimating the network weights. In this model many run trials were performed using the ANN between the predicted and observed SAR, as shown in Table 2, the highest value of the coefficient of determination (R^2) was 0.992, 0.986 and 0.955 for Samarra, Baghdad, and Kut cities, respectively. As a result, the proposed ANN models for the study area could be successfully used to predict SAR concentration.

Table 2. The predicted and observed the value of SAR, in the study areas.

Station	Partition %	Predicted and observed relationship		Sum of the square error for testing
		Equation	R^2	
Samarra	75, 20.8, 4.2	$Y_P = 0.05 + 0.99X_O$	0.992	0.009
Baghdad	63.6, 25.3,9.1	$Y_P = 0.49 + 0.95X_O$	0.986	0.014
Kut	43.8, 28.1, 28.1	$Y_P = 1.2 + 0.89X_O$	0.955	0.02

where, Yp = predicted value of SAR and X_O = observed value of SAR

4.2.4. Independent variable importance

Calculating the importance of the independent variables explains the effect of the different values of the independent variables on the value of the predicted model. In this research, the most effective parameter on the predicted model value of SAR was concluded to be Sodium for the three stations as shown in Figs. 3, 4 and 5.

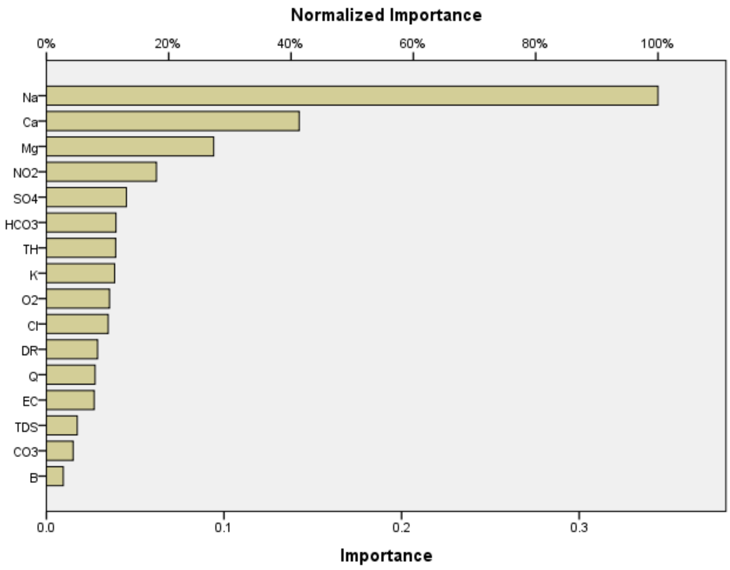

Fig. 3. Importance of the independent variables, Samarra.

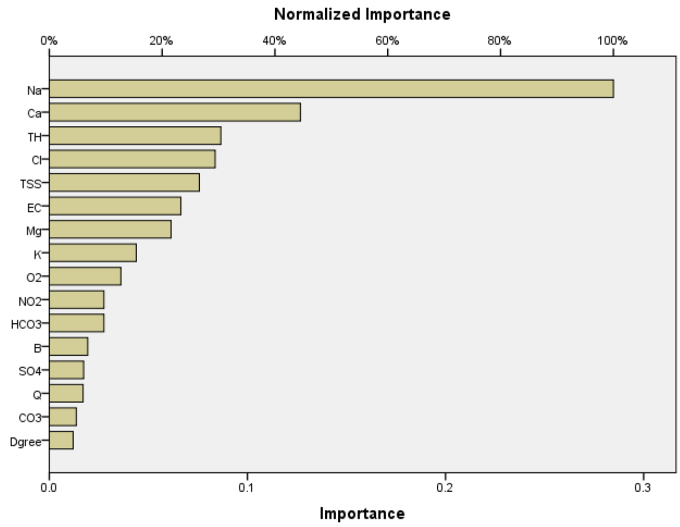

Fig. 4. Importance of the independent variables, Baghdad.

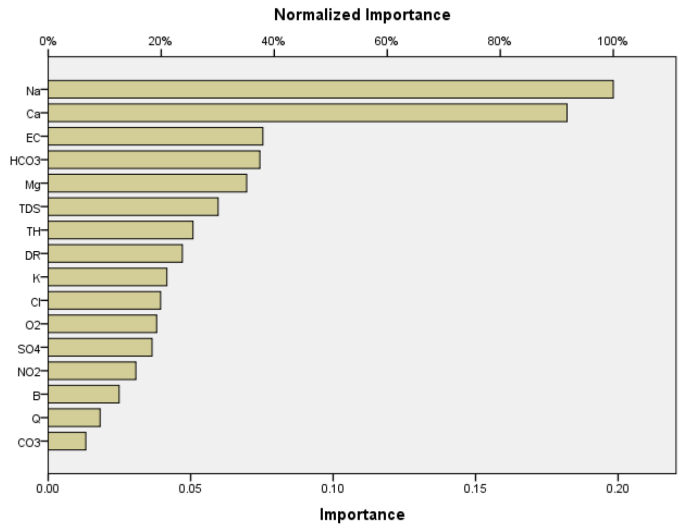

Fig. 5. Importance of the independent variables, Kut.

5. Conclusions

It is important to assess water quality and create a model for the Tigris River using ANN analysis to predict SAR in three stations (Samarra, Baghdad, and Kut) to control and improve the water quality of the Tigris River, the main conclusions as shown below:

- The water quality of the Tigris River is within the WHO specifications for drinking water, except the sulfate concentration.

- The SAR values were increased, when the discharge of the Tigris River decreases which leads to increase the Calcium and Magnesium concentrations causing the river's deterioration from north to south and it is noted that the SAR rate for the Baghdad site and Kut site increases by 271% and 303% compared to the Samarra site, respectively, and for the Kut site increases by 111% compared to the Baghdad site.
- The proposed ANN model could be used to estimate SAR value in the water river with the most significant parameter that affects the predicted model value of SAR was to be the Sodium. Therefore, a high correlation between the predicted and observed SAR model using ANN with the highest value of the coefficient of determination (R^2) was 0.992, 0.986 and 0.955 for Samarra, Baghdad, and Kut cities, respectively with the lowest sum of the square error.

Acknowledgment

The authors wish to thank the Ministry of Water Resources and the Ministry of Health and Environment for the opportunity to obtain data and to be given the facilities to be in touch with the station manager. The authors would like to thank the staff of the sanitary engineering laboratory in the Civil Engineering Department/Engineering College-University of Baghdad for their valuable support to complete this work.

Nomenclatures

B	Boron
Ca^{+2}	Calcium
Cl^{-}	Chloride
CO_3^{-2}	Carbonate
HCO_3-	Bicarbonate
K	Potassium
Mg^{+2}	Magnesium
Na^{+}	Sodium
NO_3-	Nitrate
Q	Flow discharge, m3/s
R^2	Coefficient of determination
SO_4^{-2}	Sulfate
X_O	Observed value of SAR
Y_p	Predicted value of SAR

Abbreviations

ANN	Artificial Neural Network
DR	Degree of Reaction
EC	Electrical Conductivity
MLP	Multilayer Perception
SAR	Sodium Adsorption Ratio
SPSS	Statistical Procedure for Social Science
TDS	Total Dissolved Salts
TH	Total Hardness
WHO	World Health Organization
WQI	Water Quality Index

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