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WATER QUALITY ASSESSMENT AND TOTAL DISSOLVED SOLIDS PREDICTION FOR TIGRIS RIVER IN BAGHDAD CITY USING MATHEMATICAL MODELS

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Abstract

Total dissolved solids are at the top of the parameters list of water quality that requires investigations for planning and management, especially for irrigation and drinking purposes. If the quality of water is sufficiently predictable, then appropriate management is possible. In the current study, Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) models were used as indicators of water quality and for the prediction of Total Dissolved Solids (TDS) along the Tigris River, in Baghdad city. To build these models five water parameters were selected from the intakes of four water treatment plants on the Tigris River, for the period between 2013 and 2017. The selected water parameters were Total Dissolved Solids (TDS), Total Hardness (TH), Electrical Conductivity (EC), sulfate (SO_4), and Total Solids (TS). The results showed that the Tigris river water quality was appropriate for drinking according to the World Health Organization (WHO) and Iraqi standard specifications for drinking water, the performances of the ANN and MLR models were evaluated by utilizing the coefficient of determination (R^2). The results showed that the computed values of R^2 for MLR and ANN were 0.797, 0.813, respectively; and the sensitivity analysis indicated that TS and TH had the high effects for predicting TDS.

Keywords: ANN, MLR, Prediction, River, Tigris, Total dissolved solids, Water quality.

1. Introduction

The quality of water in a river, with regard to drinking and agricultural consumption, is of considerable concern in many states. Thus, TDS prediction is a major water quality case tool in the management and planning of water resources. The data of water quality is limited and the high cost of monitoring always affects and usually poses a difficult problem during operation-based modelling [1]. Prediction of the water quality of the Tigris River utilizes the TDS parameter, which has varied from station to station along the Tigris River, over time. The salinity of water expressed as TDS, increases from the north to the south of Baghdad city due to vaporization, sewage and industrial disposal to the river agricultural drainage more over the decrease in the flowing discharge [2]. However, the TDS amount in the Tigris River, at the Turkish Iraqi borders is 280 mg/L, and it reaches 1500 mg/L and more at Amarah, south of Iraq [3]. Prediction models, to check the raw water quality parameters of the river is important for the management and planning of water resources.

One of these models is the multiple linear regressions (MLR) it may be seen as a case-specific ANN model that uses linear transport functions and no hidden layers if the linear model is used as a comparator [1]. Also, MLR models are used for the prediction of two main parameters, the Chemical Oxygen Demand (COD) and the Biochemical Oxygen Demand (BOD) of water quality in a wastewater treatment plant [4]. The application of MLR has been used in many researches, for example, in the prediction of groundwater quality, by using the physical and chemical properties of water [5]. MLR has been used by many researchers estimate the chloride in the groundwater in Chanthaburi, Thailand. As it saves time and cost for the determination and results showed that MLR was the best model of prediction chloride concentration [6].

Artificial Neural Network (ANN) that could be a perfect choice, because they are computationally quick, however, request a large amount of data input and conditions than other deterministic patterns [1]. Antanasijevic et al. [4] mentioned that successful application of ANN models to predict from DO associate with many challenges, key issues are being sounded normalize the data and select the input model that it has the most important impact on the performance of the model. ANN approach has proved its potential and applicability to simulate and model various physical phenomena in the field of water engineering, in addition, ANN captures spatial and non-linear behaviour in the problem investigated using its nonlinear structure and nature compared to other classical modelling techniques [7, 8]. ANNs have been used successfully in the prediction of TDS parameters of the water in lakes, rivers, and streams [9]. Many researchers have been studying the water quality pattern of the Tigris River, particularly in Mosul and Baghdad [10]. The potential of ANN in the BOD estimate of the Melan River was examined by comparing the results with observed BOD. From the results obtained, the ANN model appears to be a useful tool for predicting the BOD in the Melen River [11]. According to Leahy et al. [12], the multilayer perception (MLP) is utilized more, as ANN requires and utilizes it in the hydrological range model.

This study by Haciismailoglu et al. [13], estimates the interest in the MLR neural network to assess TDS. Usually, the MLR is the neural network that is ultimately utilized, because it is simple. The major objective of the present study is the assessment of water quality and prediction of temporal and spatial variations of

TDS, through selected sampling stations on the Tigris River, which were the intakes of four water treatment plants, using MLR and ANN models.

2. Material and Methods

2.1. Study area description

The Tigris River is deemed to be the only source of potable water in Baghdad city. The river separates the city into the right (Karkh) and left (Rasafa) sides and has a path that flows from the north to south. The city of Baghdad is located in the Mesopotamian alluvial plain, between latitudes 33°14' and 33°25' N and longitudes 44°31' and 44°17' E, at 30.5 to 34.85 m sea level (a.s.l) [14].

The water quality of Tigris River had deteriorated because of the reduction in the quantity of water, on account of the construction of dams in Turkey, the climate changes, and the irregular and illegal discharge of wastewater into the river. Hence, it is important to account for the raw water quality change, for both the operation and modification of water treatment plants (WTP) [15]. Prediction models, to check the raw water quality parameters, will be useful for WTP operation and modification, to produce water having the desired quality for drinking [16]. For water quality sampling data, the study took into account the intakes of four water treatment plants along the Tigris River in the city of Baghdad, which are Karkh, Karama, Qadisiyah, and Dora WTPs, as shown in the Fig. 1. Table 1 shows the location of each water treatment plant as these locations may cover the quality of the river from the north to the south of Baghdad City.

Fig. 1. WTP and Tigris River within Baghdad City (Google map).

Table. 1. Show the location of case study.

Water treatment plant	Latitudes (*N*)	Longitudes (*E*)
AL.Karkh	33º 24` 33‶	44º 21` 06‶
AL-Karama	33º 21` 19‶	44º 21` 15‶
AL-Qadisiya	33º 17` 31‶	44º 21` 50‶
AL-Dora	33º 15` 36‶	44º 23` 05‶

3. Total Dissolved Solids Models

3.1. Multiple linear regressions (MLR)

The multiple linear regression method is a statistical method that uses various explanatory variables to predict output for changing a response. The public objective of using multiple linear regression is to understand the relationship between the different independent variables and the dependent variables [17]. The general form of the regression equation is shown in Eq. (1).

$$Y = b_0 + b_1 x_1 + b_2 x_2 + ... + b_p x_p \quad (1)$$

where *x j i* (j i=1, 2, 3… p) are the predictor variables, (*j* = 1, 2, 3… *p*) are the partial regression coefficients, b_0 is the intercept coefficient, and *Y* is the criterion variable.

3.2. Artificial neural network (ANN)

Artificial Neuron Network (ANN) is a computational pattern instituted on the functions and structure of biological neural networks. The information in the input data has an effect on the structure of the ANN and because of that ANN is learned and sense from the input and output data. In recent times, ANNs have been successfully used as models in areas where water quality needs to be checked. The utilization of the ANN model is found to be better than other simulations and statistical models that are commonly used because of the compiler interrelated and nonlinear relations between its parameters [8]. The ANN model is being increasingly utilized for simulating or forecasting the source of the water variable, because of its capacity to model the complex regulation of the unknown, the hard behavioural basics, and the implicit physical procedures [11]. The ANN has nonlinear designing that enables it to handle a huge number from an independent changeable state, to define the dependent changeable state [18].

4. Results and Discussion

4.1. Water quality assessment

In the present study, water quality (WQ) assessment along the Tigris River, in Baghdad city, has been done for five years, by utilizing the annual average concentration of five different water parameters, TDS, TH, Ec, SO_4, and TS.

Table 2 shows all the parameter variations along the river, from the north to the south, in Baghdad city, during the years 2013 to 2017. All the parameters in Table 2 are within the limits of the Iraqi specifications and WHO for drinking water

The variation of TDS in this study area is shown in Fig. 2, which shows a simple increase in TDS concentrations from the north to the south and with time. TDS concentration in year 2014, ranged from-490 mg/L to 647 mg/L. This increase is due to the decrease in the flowing discharge and the illegal disposal of pollutants into the river. Based on studies by Ewaid et al. [19], the annual variation of quality and quantity of water in the river; could be due to the ecological variation and dams construction in neighbouring countries. Therefore, the water quality north of the river is better than that in the southern part, in Baghdad city, Iraq.

Table 2. Water quality parameters along Tigris River in Baghdad city from 2013 to 2017.

W.T.P	Year	Ec (μm/cm)	T.H (mg/L)	SO4 (mg/L)	T.S (mg/L)	TDS (mg/L)
Al.Karkh	2013	629	251	110	400	287
	2014	774	291	151	504	443
	2015	721	282	124	467	410
	2016	706	279	117	455	387
	2017	676	270	105	435	434
Al.Karama	2013	878	320	211	607	495
	2014	1063	390	287	732	655
	2015	893	333	237	617	543
	2016	826	329	237	617	514
	2017	874	336	218	587	513
Al.Qadisya	2013	855	322	211	553	443
	2014	1030	398	264	679	620
	2015	874	338	203	577	514
	2016	830	316	239	550	403
	2017	870	332	210	574	481
Al.Dora	2013	880	321	205	572	490
	2014	1058	388	293	688	647
	2015	914	355	218	594	556
	2016	864	333	210	561	512
	2017	902	345	188	587	534
WHO	-	-	500	400	-	500
Iraqi specification		-	500	250	-	1000

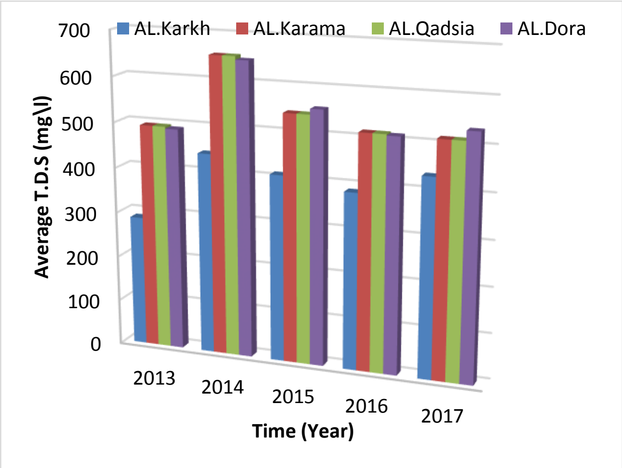

Fig. 2. Variation of TDS annual average with time (year).

4.2. TDS predication using MLR model

In the present study, the MLR utilized the selected water parameters (TDS, TH, Ec, SO_4, and TS) for five years, to build the model. The SPSS Version 23 was used to analyse the data where the results are shown in. Tables 3, 4 and 5. The MLR model gave a coefficient of determination of $R^{2,}$ 0.7987 for predicting TDS depending on the selected water parameters and the equation for predicting TDS, along the Tigris in Baghdad city is Eq. (2). This equation can be used for monitoring and management of TDS along the Tigris River by prediction the concentration of TDS.

$$TDS = -236.787 + 0.127 * EC + 1.066 * T.H - 0.59 * SO4 + 0.697 * T.S \quad (2)$$

This equation shows that Hardness (Th) has the highest effect on predicting TDS by the MLR model followed by Total Solids (TS), SO_4 then Ec.

From other research, Mokarram [6] used MLR for chloride prediction found that the most effective parameters that affected the prediction of Cl were TDS, T.H, Iron, and NO_3, respectively.

Table 3. MLR model summary.

Model	R	R square	Adjusted *r* square	Standard. error of estimate
1	.893	.797	.793	60.959

Table 4. Coefficients of TDS prediction.

Model		Unstandardized coefficients		Standardized coefficients		Significance	Correlations		
		B	Standardized. error	Beta	*t*		Zero-order	Partial	Part
1	**(Constant)**	-236.787	30.798		-7.688	.000			
	EC	.127	.134	.150	.948	.344	.875	.062	.028
	T.H	1.066	.262	.452	4.062	.000	.872	.257	.120
	SO_4	-590	.151	-300	-3.912	.000	.769	-248	-115
	T.S	.697	.180	.574	3.876	.000	.873	.246	.114

Table 5. Correlation coefficients between dependent and independent variable.

		TDS	T.H	EC	SO_4	T.S
Pearson correlation	**TDS**	1.000				
	T.H	.872	1.000			
	EC	.875	.962	1.000		
	SO_4	.769	.896	.901	1.000	
	T.S	.873	.948	.975	.920	1.000

4.3. TDS prediction using ANN model

For the ANN model, many trials should be made to find the best model, by using SPSS program version 23. The same input data for the MLR model was used in this model, which were divided into, 201 training values, 35 testings and three holdouts. The input layer covariate involved in the covariates, which were standardized. The number of nodes in the hidden layer was six, the activation function was a hyperbolic tangent and the output layer was the dependent variable TDS, The results from this model were, the sum of the squared error for training was 0.223, whereas, for testing and holdout were 0.147, 0.013, respectively. Figure 3 shows that the ANN model predicted TDS with a coefficient of determination R^2 (0.813).

Figure 4 shows that the variable total solid (TS) has the greatest effect on how the network predicts the TDS, followed by Hardness (Th), Sulfate (SO_4), and Electric Conductivity (Ec) respectively. The significance of the independent variable is a measure of the extent to which, the model predicts the depended variables expressed as a percentage, IBM® SPSS® Statistics 23 User Guide.

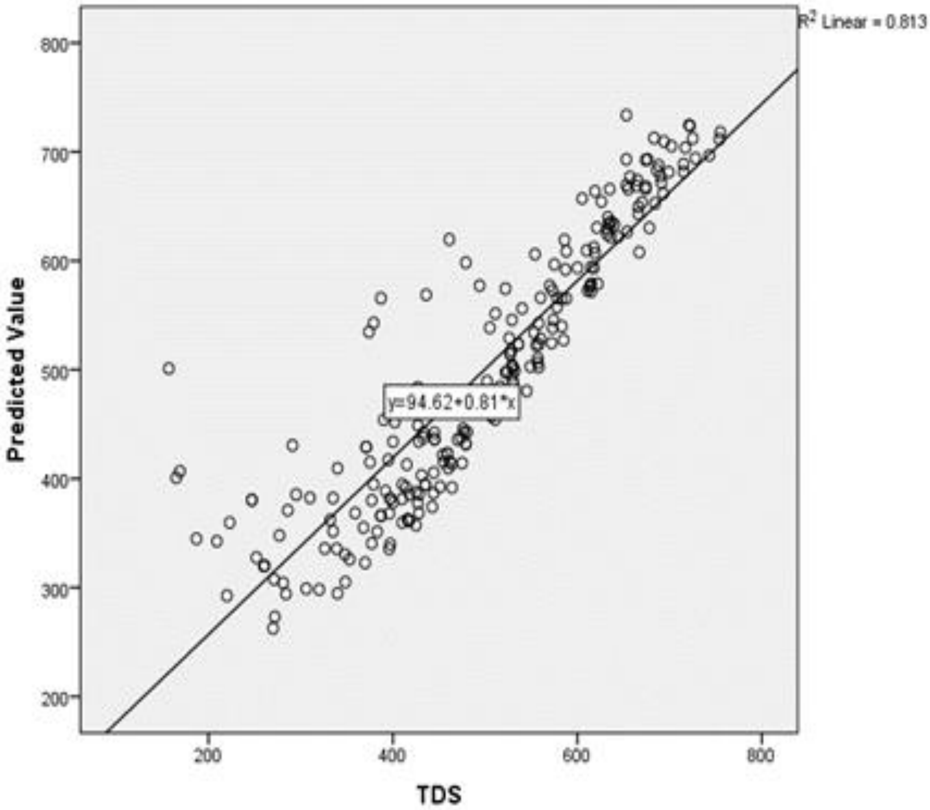

Fig. 3. Predicted and observed TDS along Tigris River in Baghdad city.

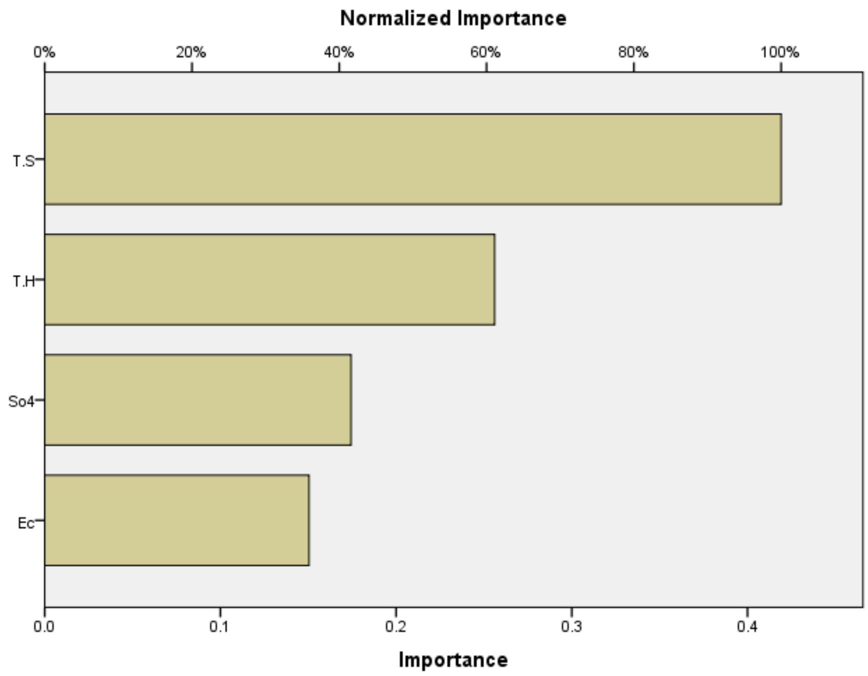

Fig. 4. Importance of independent variables on TDS for Tigris River in Baghdad city.

5. Conclusions

In this study, WQ assessment of the Tigris River in Baghdad City was done by using five parameters and comparing these parameters with the WHO and Iraqi specifications. It appeared that the water quality of the Tigris River was within drinking water specifications. Other water parameters should be checked, as the Tigris River suffers from continuous deterioration. The two models MLR and ANN were developed for the prediction of TDS along the Tigris River in Baghdad city. The Artificial Neural Network model was preferable to the Multiple Linear Regression model as the coefficient of determination was higher 0.813. The outcome, according to the ANN model indicated that total solid had the greatest impact on the prediction of TDS concentration followed by total hardness, sulfate and then electric conductivity.

Nomenclatures

bo	Intercept coefficient in MLR
R^2	Correlation coefficient (Table 3)
X_i	Predictor variables in MLR
Y	Is the criterion variable of MLR
Y_c	The output of the output neurons in ANN model

Abbreviations

ANN	Artificial Neural Network
MLR	Multiple Linear Regression
TDS	Total Dissolved Solids
TH	Total Hardness
TS	Total Solids
WHO	World Health Organization
WQ	Water Quality

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