Forecasting of Dissolved Oxygen in Shatt Al-Arab River Based on parameters of water quality Using Artificial Neural Networks

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Abstract. The quality of water is considered as a vital quality factor that affects the life quality in different areas. Thus, its assessment and forecasting became an essential subject matter for several researches. Analytically, the common adopted feed forward error back propagation neural network technique is used to developed two types of ANN models. The first model is applied having experimental data that gotten from the Department of Environment, Basrah-Iraq, during year 2009-2014 and the data set for the current year (2019), while the second model is applied according to the data for the current year (2019) only. The parameters of input of the neural network are pH value (pH), electrical conductivity (EC), Total Dissolved Solid (TDS), Calcium (Ca), Magnesium (Mg), nitrate nitrogen (NO₃), phosphorous (PO₄³⁻) and Sulfate (SO₄²⁻), the output parameter of the neural network is dissolved oxygen (DO). Through comparing the outcomes of ANN models depending on high value of regressions coefficient (R²) and lower value of mean square error (MSE). For the first model R =0.96143 and MSE=0.00125 for testing. The second model is R=0.99225 and MSE=0.00532. The results show the proposed ANN prediction model has a great potential significance for the assessment and forecasting the dissolved oxygen.

1. Introduction

Rivers, lakes, and springs are the most important sources of fresh water and they have the characteristic of being dynamic system and might have variable nature severally within their course due to the change in the physical circumstances like the slope and bedrock geology and chemical properties due to the dissolved gases, organic as well as non-organic material. Horizontal and continuous one-way flows of a significant load of matter are carried by them in dissolved oxygen and certain matters from the natural as well as anthropogenic sources [1].

The physical and chemical properties of water play a direct role in the distribution and behavior of organisms and have a significant impact on the suitability of this water for human consumption. It is these characteristics PH and high water temperature which lead to increase the concentration of salts and contaminated elements as well as turbidity. The elements of calcium (Ca) and magnesium (Mg) are important elements that have a significant role against some diseases of the cardiovascular system. The increased concentration of nitrates and phosphates in water leads to the phenomenon of Eutrophication which has environmental effects on water pollution. Hence, the poor quality and unfit for other uses depended on the same criteria or water quality standard.

As an indication of healthy body of water, dissolved oxygen is usually used, wherein a correlation between the highly concentrated dissolved oxygen with high grade of productivity with much less
pollution. It is an important parameter when assessing the quality of water due to the influence it has on the creatures and plants that lives in that particular body of water. In the scientific studying of lakes - limnology, the oxygen that is dissolved is an extremely important element that comes secondly to that of water. Its level which could be either extremely high or low could affect water systems and harm marine life [2].

Artificial Neural Networks (ANN) represent computational metaphor that has been come through studying the system of brain as well as nerves of organisms. ANN indicate an ideal modal of mathematics of the current point of view concerning these complex systems. Ideally, the network is composed of a group of units that have layers that performs processes and interrelated connections. Their operations are performed depending on the assumption of acquiring knowledge through training sets. A set of different neural network models and learning strategies are available. Feed-forward networks and recurrent networks are considered as the wide-spread models of neural networks which could be adopted to predicate applications. For the former, the weighted connections feed activations just towards forward from the input to the output layers while for the later, for feeding the former activations back into the network, the additional weighted connections could be in use [3].

Within the present study, two types of ANN classes are developed. Both of them are adopted to identify important parameters that are affected through water quality (Dissolved Oxygen). Doing so, the preliminary procedure of the model prediction is done to lessen the non-significant parameters through conducting a statistical analysis using (IBM SPSS Statistics 21) that contains the leave one out methodology that depends in its basis on the correlation that holds every given parameter with certain water quality so that to identify which parameter contributes most in the water quality of Shatt Al-Arab River. Several studies of modeling were conducted for computing dissolved oxygen concentrations in streams [4], rivers [5], lakes [6], as well as canals. The fundamental aim behind the present study is analyzing the operations of neural network (NN) models. The structure of the ANN program that is adopted here is used for the assessment of water quality of the river and predict the dissolved oxygen based on the data of the experiments of both the present and previous ones.

2. Materials and Methods

2.1 General Description of Shatt Al-Arab River
The Shatt Al-Arab River is the main fresh water source in the south of Iraq (Figure 1). It originates from the confluence of two other Iraqi rivers, the Tigris and the Euphrates and its water empties into the Arabian Gulf after travelling about 190 km from Al-Qurna city north of Basrah Governorate (31° 00’17”N and 47° 26’29”E). Then, it flows from north to south of Basrah Governorate to the Arabian Gulf. The river width ranges from 250m at the central city of Basra, to about 1500m at the end point in Al-Fao city before entering the Arabian Gulf. The maximum depth of this river is between 5 to 12 m [7]. Shatt Al-Arab River plays a vital role in developing of the industry and agriculture in Iraq. In addition, it has other values as it serves water transportation, irrigation as well as providing the people of Basrah with the drinking water. The physical, chemical and hydrological regime aspects of the river’s water have been affected by the quality of water coming from its tributaries. At its mouth, the river is also affected by the saline water tides which come from the Arabian Gulf [8].
2.2 water quality data

The data that is used in this study is provided by the ministry of Water Resources in Iraq-Basrah for the year 2009-2014 which represent the monthly measurements at rate of twice measured values for fourteen water parameters that are used for modeling water quality in Shatt Al-Arab River. To give a comprehensive idea about the general water quality of rivers in a study area, and for the purpose of assessing water quality, 538 data have been selected to the purpose of the current study. The physic-chemical water quality parameters are:

"pH value, Total hardness (TH), Chlorides (Cl), total dissolved solids (TDS), electrical conductivity (EC), Calcium (Ca), Sulfate (SO$_4$), Nitrate (NO$_3$), Alkalinity (ALK), Magnesium (Mg), sodium (Na), potassium (k), dissolved oxygen (DO) and Phosphate (PO$_4$)" as illustrated in Table 1.

![Figure 1. Map of Shatt Al-Arab River.](image)

| PARAMETERS               | UNITS    | Experimental value | MIN | MAX  |
|--------------------------|----------|--------------------|-----|------|
| Dissolved oxygen         | mg/l     | 2.19               | 2.19| 13.3 |
| pH value                 | -        | 6.7                | 6.7 | 9.2  |
| Electrical conductivity  | µS/cm    | 1303               | 1303| 52200|
| Total dissolved solids   | mg/l     | 96                 | 96  | 39462|
| Calcium                  | mg/l     | 35                 | 35  | 1008 |
| Sulfate                  | mg/l     | 100                | 100 | 3000 |
| Magnesium                | mg/l     | 27                 | 27  | 1728 |
| Nitrate                  | mg/l     | 3.212              | 3.212| 19.64|
| Phosphate                | mg/l     | 0.03               | 0.03| 2.56 |
| Chlorides                | mg/l     | 142                | 142 | 19550|
| Alkalinity               | mg/l     | 100                | 100 | 1905 |
| Total hardness           | mg/l     | 8.2                | 8.2 | 8600 |
3. Input selection technique

This technique is adopted to select the inputs which have strong correlation with dissolved oxygen. Table 1 shows the parameters of water quality in the Shatt Al-Arab River. Since a general suggestion for the present study is that an input should be removed when its regression is low as less than such number which indicates the existence of weak correlation.

The aim behind the present study is evaluating an improved model that determines the quality of river water through measuring the values of DO as outputs of the model. Since estimating these values of DO are basic, it is proposed that these represent the outputs of the FFNN based model. This indicates that the values of: "power of hydrogen (pH), Phosphate(PO4), Magnesium (Mg), Calcium (Ca), Sulphates (SO4),electrical conductivity (EC) and total dissolved solid (TDS)" are represent the input of the model.

The parameters have been chosen since it is seen from the training model that the eight parameters have shown higher regression (R) with DO values and less mean square error (mse).

4. Sample Collection

The measurement of the physical, chemical and biological parameters of water was done for eight sites along Shatt Al-Arab River in two seasons, (wet and dry). The first fieldwork started in winter during January 2019, March 2019 and May 2019 from the following stations: Al-Qurna, Al-Shafi, Al-Dair, Al-Haritha, Al-Sindibad, Al-Maqal, Al-Corniche and abufrous. while the second fieldwork was done in summer during the beginning of July (2019) as shown in Figure 2 show the location of water samples from the areas of the study.

The analysis procedure of fieldwork and laboratory work are explained as below:

1. Sampling usually started during the period of islands in Shatt Al-Arab River.
2. Each sample bottle was provided with an identification label such as:
   • Numeration of the sample.
   • Time and date of collecting the sample.
   • Geographical coordinates of sampling stations.
3. The water samples were collected in the middle of the main river by using boat and van water sampler.
4. Water sample for other analysis such as pH, EC, Tur, TDS, DO, and Water temperature (T) were measured immediately in the field, by using Hatch (HQ40d) multi device [9].
5. The concentrations of chemical parameters (NO$_3$-, PO$_4$-, Ca, Mg, SO$_4$-) were measured in the laboratories of Basrah, in the Water Analysis Laboratory in Marine Sciences.

5. **Artificial Neural Networks**

ANNs are considered as a newly initiated mathematical model which influenced the scientific community. The interest of the scientific community has increased recently which resulted conducting several studies that seeks solving a variety of problematic issues. Experiments have shown that it is more robust in comparison with the conventional statistical classifiers in identifying the patterns from noisy and complex data and in measuring their nonlinear relations. In brief, experts consider it highly effective at learning the internal representations of data in any given way.

ANNs are heuristic algorithms as they could acquire knowledge from experiences through samples and as a result, they could be used to identify new data. Such systems are set very simply to perform behavioral imitation of the network of neurons in the human brains. The basic objective behind using ANNs is to enhance the operation of the computer identification processes through the simulation of the superior features of brain [10]. Due to the great ability of the human brain in acquiring knowledge, recalling, synthesis, and solving problem, it has attracted the attention of the scientific community in different fields to try to design a model that simulates its operations. According to the biological mechanism of the brain, ANNs are models which try to have parallel simulation of the functions as well as decision making operations of the human brain’.

6. **The Mathematical Model**

The network is composed of interrelated artificial neurons which its structure is layered typically. It has three functional groups that are: the inputs that receives signals from the network’s outside and presenting them to its inside, the neuron that processes information and the neurons that initiates results.

ANN model is illustrated in figure 3. The model includes X inputs, y one output, a summation block and an activation block [11].

![Figure 3. Model of artificial neurons](image)

7. **Architectural of ANN Model**

Artificial neural networks (ANNs) are used for the assessment and forecasting of dissolved oxygen in Shatt Al-Arab River by other water quality parameters. The neural network toolbox that is available in MATLAB program (R2013a) is used for implementing the neural network in this study. This program has many advantages such as containing several types of networks and implementing many different training algorithms, such as the back-propagation algorithm.

Back-propagation neural networks are proposed to learn the relations between the input and output parameters by using the feed-forward back-propagation algorithm. The trial and error process is performed to set and train the neural networks because of the indeterminate parameters such as the number of hidden layers, nodes number in the hidden layers, number of learning patterns, and the learning parameters.

In this study, two case studies were studied in:
• Evaluating the overall quality of Shatt Al-Arab water during the period (2009-2014) of previously recorded data

• Assessing and forecasting the dissolved oxygen of the Shatt al-Arab River for pre-recorded and currently recorded data in 2019.

Table 2. Specifications of the Proposed Network

| Items                                      | Descriptions |
|--------------------------------------------|--------------|
| nodes in the input layer                   | 8            |
| hidden layers                              | 1 & 2        |
| nodes in the hidden layers                 | [1-20]       |
| Types of activation function               | First: tansig|
|                                           | Second: purelin|
|                                           | Third: purelin|
| Training functions                         | Different types of functions |
| Nodes in the output layer                  | 1            |

8. Back-propagation Training Functions

FFBP neural network which is adopted here is a wide-spread kind of artificial neural networks in hydrological time series modelling and including an input, hidden and output layers. The BP algorithm is a gradient descent method used to have the minimum mean square error.

Developing the proposed model (ANN), the Levenberg-Marquardt back-propagation algorithm (trainlm) was first used to train the network of the proposed model (ANN). This network is trained with different back-propagation algorithms to choose the algorithm that produces the best results and to reach the least error and the best network in predicting the dissolved oxygen. The LM Back Propagation (BP) algorithm is used for training the artificial neural network model, since it is often fast and highly accurate and reliable [12], related literature has shown that LM is a well-designed algorithm for setting ANN models.

A training data set was used for training the networks, and this in turn was tested by the test data set. Selecting the size of the optimal network through: "the resulted maximum coefficient of regression (R) and minimum of root mean square error (MSE) in training and testing data sets".

9. Neural Network Model (M1)

The data set utilized in the first model was produced through monitoring of water quality of Shatt Al-Arab River. Monthly sampling was carried out of 4 years (2009-2014) in addition to (2019) for the analysis of 570 data records [(data collection & samples collection (preparations data)]. 538 recordings of the training set and 32 recordings of the test set. The Levenberg-Marquardt algorithm has been used for the training the neural networks. The hidden nodes number affects the operation of network in a direct way. The hidden nodes number is identified to acquire the optimal results.
**Data Collection**

**Table 3.** Description of Variables Training and Testing.

| Item       | Variables   | Training Range of Data | Testing Range of Data |
|------------|-------------|------------------------|-----------------------|
|            |             | Min - Max              | Min - Max             |
| Input      | pH -        | 6.7 – 9.2              | 7.47-8.61             |
|            | PO₄ (mg/l)  | 0.03- 2.56             | 0.01-0.088            |
|            | SO₄ (mg/l)  | 100 -3000              | 161-839               |
|            | NO₃ (mg/l)  | 3.212 - 19.64          | 0.362-12.79           |
|            | Mg (mg/l)   | 27- 1728               | 57.34-194             |
|            | Ca (mg/l)   | 35 - 1008              | 102.7-420             |
|            | TDS (mg/l)  | 96-39462               | 566-1449              |
|            | Ec (µS/cm)  | 1303 -52200            | 1109-1883             |
| Output     | DO (mg/l)   | 2.4 -13.30             | 5.58 – 11             |

**Table 4.** ANN operation having One and Two Hidden Layers

| Training function | One hidden layer | Two hidden layers |
|-------------------|------------------|-------------------|
|                   | Nodes No. | mse (test) | R (test) | Epoch | Nodes No. | mse (test) | R (test) | Epoch |
| trainlm          | 10        | 0.00125    | 0.96143  | 100   | [14,9]   | 0.00235    | 0.96864  | 100   |
| trainrp          | 8         | 0.0212     | 0.95324  | 100   | [9,9]    | 0.0065     | 0.9494   | 100   |
| trainingda       | 11        | 0.00253    | 0.94555  | 98    | [10,10]  | 0.00257    | 0.95594  | 100   |
| traingdx         | 11        | 0.00276    | 0.94616  | 100   | [10,10]  | 0.01566    | 0.95931  | 100   |
| traingcfg        | 20        | 0.002456   | 0.96279  | 100   | [11,8]   | 0.003991   | 0.95776  | 100   |
| Traincgp         | 20        | 0.00312    | 0.9633   | 100   | [12,7]   | 0.0511     | 0.95577  | 29    |
| traincgb         | 20        | 0.00221    | 0.96334  | 76    | [13,8]   | 0.00342    | 0.95975  | 57    |
| trainscg         | 20        | 0.002991   | 0.96173  | 500   | [13,8]   | 0.00411    | 0.96167  | 100   |
| trainbfg         | 8         | 0.00622    | 0.94246  | 100   | [12,10]  | 0.00412    | 0.96104  | 100   |
| trainoss         | 20        | 0.00198    | 0.9647   | 100   | [8,6]    | 0.00699    | 0.96209  | 100   |
| trainingdm       | 18        | 0.0255     | 0.96224  | 5000  | [9,9]    | 0.00211    | 0.95005  | 5000  |

As illustrated in Table 4, (trainlm) training functioning has given the most suitable tested operation having one and two hidden layers, while (trainbfg) has given the best tested operation having two hidden layers only.

Finally, the architecture of the network is having less error and high regressions 8-10-1. The input nodes are 8 which represent the parameters of input of water quality which have an effect on the dissolved oxygen, the hidden nodes are 10 with one hidden layer. The output nodes are only 1 which
represents dissolved oxygen (DO). No significant variation among the results if two hidden layers are used, still if the architecture is used 8-[12,10]-1, the input nodes are 8, which represent the input parameters of water quality which have an effect on the dissolved oxygen, the hidden nodes are set to [12,10] having two hidden layers, that architecture of the (trainbfg) training function network gave less error (mse) and high regression. Thus, it could be selected (trainlm) training functioning as the best network for the predications of the dissolved oxygen throughout Shatt Al-Arab.

Figure 4, illustrates the regression while figure 5 shows the operation of the selected network.

![Figure 4](image1.png)

**Figure 4.** Regression in one and two hidden layers of the suggested Network

![Figure 5](image2.png)

**Figure 5.** Operation of the suggested network (mse) with one and two hidden layers

10. **Neural Network Model (M2)**

In the second model of artificial neural network, the data of water quality of Shatt Al-Arab River that were measured have been collected from current year (2019). The range of the training to test information recording is used. It indicates that 32 data recording samples collection (preparations data) 24 recordings for the training set and 8 recordings for the test set have been used. The artificial neural network has got training and tested having one and two hidden layers with variable number of nodes (1–20) for every hidden layer (see table (6)). Some of the functions of training have been tested to get the best results.
Data Preparation

Table 5. Train, Test, and Range of Variables

| Item | Variables   | Range of Data |          |          |
|------|-------------|---------------|----------|----------|
|      |             | Training      | Testing  |          |
|      |             | Max Min       |          |          |
| pH   | 8.61-7.47   | 8.03-7.61     |          |          |
| PO₄ (mg/l) | 0.088-0.01  | 0.021-0.01   |          |          |
| SO₄ (mg/l) | 839-161     | 298 – 225    |          |          |
| NO₃ (mg/l) | 12.79-0.362 | 3.84-0.86    |          |          |
| Mg (mg/l)  | 194-57.34   | 104.4-62.24  |          |          |
| Ca (mg/l)  | 420-102.76  | 192-140.48   |          |          |
| TDS (mg/l) | 1449-566    | 667-578      |          |          |
| Ec (µS/cm) | 1883-1109   | 1285-1126    |          |          |
| DO   | 11-5.58     | 8.4-5.74     |          |          |

Table 6. ANN operation having One and Two Hidden Layers

| Training function | One hidden layer | Two hidden layer |
|-------------------|------------------|------------------|
|                   | Nodes NO | mse (test) | R (test) | Epoch | Nodes NO | mse (test) | R (test) | Epoch |
| trainlm          | 8        | 0.00532   | 0.99225  | 7     | [10,8]   | 0.0233    | 0.9948   | 8     |
| trainrp          | 8        | 0.0223    | 0.9902   | 99    | [12,9]   | 0.00225   | 0.99389  | 99    |
| trainlda         | 8        | 0.000955  | 0.99455  | 1000  | [8,8]    | 0.00376   | 0.99461  | 1000  |
| traindx          | 8        | 0.0167    | 0.9910   | 1000  | [12,6]   | 0.00443   | 0.99177  | 1000  |
| traincfgf        | 11       | 0.00499   | 0.98988  | 1000  | [12,9]   | 0.000501  | 0.99765  | 100   |
| traincgp         | 11       | 0.00398   | 0.99029  | 1000  | [12,11]  | 0.00698   | 0.99282  | 100   |
| traincgb         | 8        | 0.0235    | 0.98678  | 550   | [10,7]   | 0.0001578 | 0.99554  | 196   |
| trainscg         | 14       | 0.00544   | 0.99001  | 1000  | [11,5]   | 0.00455   | 0.9966   | 100   |
| trainbfgf        | 9        | 0.00688   | 0.99056  | 300   | [10,8]   | 0.00344   | 0.99116  | 257   |
| trainoss         | 8        | 0.0189    | 0.99105  | 1000  | [8,8]    | 0.00205   | 0.99376  | 100   |
| trainfdm         | 8        | 0.0212    | 0.99313  | 5000  | [11,10]  | 0.0211    | 0.99374  | 5000  |
As can be seen in Table 6, (trainlm) training functioning has given the most suitable tested operation having one and two hidden layers. No significant variation among them if variable training functions are used, still it gives the most suitable variation having less error and high regression. Thus, this could be selected as the suggested network for the predication of dissolved oxygen allover Shatt Al-Arab. Figure 6 illustrates the regression while figure 7 shows mse of the suggested network.

11. Results and Discussion
For two neural network models construction with monthly data randomly partitioned into (training and testing) the cascade correlation algorithm choose the training of neural network which is feed-forward and supervised algorithm. The suitable number of neurons has been identified through least value of MSE of the training set as well as the test set. Being highly correlated indicates that there is a great a good homogeneity among the tested information. To specify the suitable number of neurons within the hidden layer, eight to twenty neurons every time have been employed individually within the network. The optimal number of hidden neurons is variable in the two models, but the models could result the maximum coefficient correlation and minimum error.

The current study has also concluded that the first Artificial Neural Network model that got training with algorithm (trainlm) is highly efficient to predict the concentration of DO. The selected structure has shown the maximum correlation value (R = 0.96143) as well as the minimum error (RMSE = 0.00125 for Test data) after epoch 100 for one hidden layer, the structure of this network is 8-
In addition, the network that is trained with algorithm (trainbfg) has affected predicting the concentration of DO. The selected structure has the maximum correlation value ($R = 0.96104$) and the minimum error (RMSE = 0.00412 for the tested data) after epoch 100 for two hidden layers, the structure of the network is $8- [12, 10] -1$.

Secondly, the model that got training with algorithm (trainlm) has an effect on predicting the DO concentrations. The selected structure has the maximum correlated value ($R = 0.99225$) and the minimum error (RMSE = 0.00532 for test data) having one hidden layer. In addition, the network that is trained with algorithm (trainlm) has affected predicting the concentration of DO through the use of two hidden layers. The selected structure has the maximum correlation value $R = 0.9948)$ and the minimum error (RMSE = 0.0133 for test data) for two hidden layers. This indicates that ANN has a considerable capability for learning and making predictions. The results have shown that ANNs could make prediction of DO concerning unknown data sets. Thus, it is highly worth using the ANN model for water quality prediction.

12. Conclusions

Two well-known artificial neural models have been used in the present study to model and forecast DO having 8 water quality variables. Both of these models have provided a good and powerful model for studying and measuring DO.

Three-layers (input layer, hidden layer, output layer) with BPNN of the Levenberg-Marquardt algorithm (LMA) with water quality variables such as pH, total dissolved solid (TDS), EC, Ca, Mg, SO$_4$, PO$_4$ and NO$_3$ have been applied as input data to get the output of DO. The present study has concluded that the second model approach proved that it is an effective method for water quality modeling depended on the operation of the model. It has been estimated having regression correlation (R) and MSE, 8 neurons in one hidden layer and [10, 8] in two hidden layers which were selected as the most suitable number of neurons.

R=0.99225, MSE=0.00532 for one hidden layer R=0.9948, MSE=0.0233 for two hidden layers. It could be suggested that a future study is important for improving the accuracy of the prediction of the suggested model with longer periods.

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