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Research Article

SIMULATION OF CHLORIDE (CL) AND TOTAL DISSOLVED SOLIDS (TDS) IN WATER USING THE CONJOINED WAVELET ANFIS NETWORK IN COMPARISON WITH THE CONJOINED WAVELET ANN CASE STUDY: DOROODZAN DAM'S WATER RESERVOIR

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ABSTRACT
Modelling and utilization of mathematical equations is a suitable tool for decision-making and predicting water resources quality changes, especially in dams, which have attracted much attention in recent years. Doroodzan Dam, the largest dam under operation in Fars province, is responsible for irrigation of more than 40,000 hectares of farmland, supplying drinking water of Shiraz and Marvdasht, factories and the surrounding areas. Therefore, the dam lake is of special importance and sensitivity due to agricultural, drinking and industrial use. In this study, the most important water quality parameters, chloride (Cl) and total dissolved solids (TDS) were examined, simulated and compared using wavelet neuro-fuzzy inference system and neuro wavelet system. For this purpose, we used 20-year statistical data. After normalization, 85% of the data were used as training network and the remaining 15% for testing the models. The criteria for evaluating models were the correlation coefficient (R^2) and root mean square error (RSME). The model with greater correlation coefficient and smaller root mean square error is selected as the best model. The results show that fuzzy neural wavelet network model is more capable in comparison with neural-wavelet model.

Keywords: *Chloride, Total Dissolved Solids, Neuro-Fuzzy Network, Wavelet-Neural Network, Wavelet*

INTRODUCTION
Recognition of water, its quality and quantity and how it is obtained, is an essential step in order to optimize its use. Although more than three-quarters of the planet is covered with water, a small share of it can be used for the purposes of agriculture and health. For about 97.3% of it is in the oceans and 1.2% in Arctic ice, and 6.0% in lakes, rivers and groundwater. Since a healthy person is the axis of sustainable development, and human health depends on optimal utilization of drinking water, without healthy water supply there is no room for positive health and well-being of the society. Therefore, awareness of the changes, simulation and prediction of water quality, according to its role, is very important.
Nowadays, many models are used to assess and predict water quality and most of them require a lot of input data which are inaccessible, or measuring them cost a lot of time and money. Among the most effective tools in this field are Fuzzy Neural Network Model and Neural Wavelet model. Much research in the world has been done in the application of artificial neural networks and fuzzy-neural network and wavelet analysis. In a very complete study, Aslan (2008) simulated EYMIR dam in Turkey and compared data, using artificial neural networks and fuzzy inference system. In this study, the concentration of dissolved oxygen is used as an indicator of quality in the water reservoir and finally they reached the conclusion that in all scenarios examined, the results provided by the neural network are dramatically more accurate and reliable in comparison with fuzzy network. The combination of input parameters is effective on the accuracy of the results in different scenarios, which indicate the importance of careful selection of input parameters. In a study, Chen *et al.*, (2009) showed that the use of genetic algorithms for optimizing input data of artificial neural networks can lead to more precise results compare to when the algorithm is not used (Chen *et al.*, 2009). Dogan *et al.*, (2007) used artificial neural network to predict BOD in Meln river. Parameters of COD, T, DO, Q, nitrates, nitrites, ammonia and chlorophyll were measured at 11 stations of the river during from 2001 to 2002. Karami *et al.*, (2012) simulated and

predicted water quality parameters in the Karun river using artificial neural network, neuro-fuzzy network and statistical regression method. The results showed that artificial neural networks and neuro-fuzzy networks have better estimations in simulation of the EC, TDS and SAR compared to statistical regression method. Ebrahimi *et al.,* (2006) studied the introduction of wavelet theory and its application in hydraulic structures. The results show that the combination of wavelet transforms and artificial neural networks can significantly reduce the computational time and accuracy of network prediction. We can use wavelet transform for optimizing hydraulic structures, reservoir routing, rainfall and etc. wavelet transform can also be combined with genetic algorithm

MATERIALS AND METHODS

The Study Area

Doroodzan project area, with an area of 123,846 hectares, is located in the Fars province and in northern parts of Kur river bay and north of Marvdasht (75 km North East of Shiraz).

The dam was dewatered in 1973, and with a capacity of 980 million cubic meters, it irrigates approximately 56 thousand hectares of downstream areas. The catchment area of the dam is part of the central catchment of the country, which is located in longitude of 42' - 51° E to 44' - 52° and latitude of 30°-20' and 10'-31° N. Doroodzan dam, built on Kur river, is a storage dam. Kur is of big rivers of Fars province which is originated from the heights of the Zagros mountains in northwest of the province and flows toward the southeast. Climate of Doroodzan dam's area is located within the range of cold wet according to the Emberger method. The purpose of construction the dam, was water supply for agriculture and industry, the supply of drinking water in the city of Shiraz and cities along the way, and also power generation. In Figures 1 and 2, catchment of Doroodzan dam and a non-scaled scheme of waterways and hydrometric stations of Doroodzan catchment are shown.

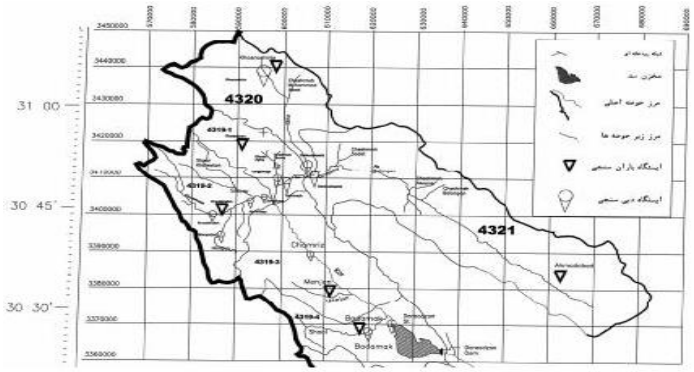

Figure 1: Doroodzan Catchment

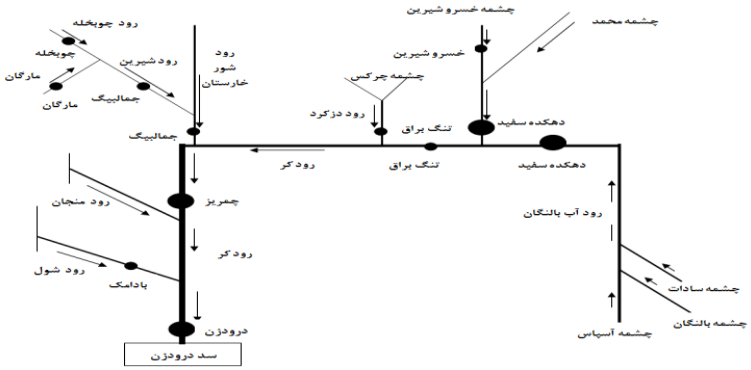

Figure 2: Schematic Non Scaled Plan of Waterways and Hydrometric Stations of Doroodzan Catchment [REWRITE PERSIAN WORD, LETTERS, NUMBERS IN ENGLISH]

Methodology

In this study, some parameters of water quality in the dam stations were studied and simulated and changes in water quality are checked. Duration of the entire statistic period was 20 years (1989 to 2009) and the data frequency was monthly. 85% of the data was used for training and testing of the network, and 15% for the evaluation of the accuracy of the simulation. In order to normalize the input data, normalization method was used between zero and one. In this method, the data are transferred to the interval of [0,1]. The following formula is used for normalization.

$$X_{normal} = \left(\frac{X_{max} - X_{io}}{X_{max} - X_{min}}\right)$$

where X_{max} = the maximum data, X_{io} = the observed data, and X_{min} = the minimum data.

Wavelet Analysis

Wavelet transform is an operation which forms a new function on base functions by applying changes on them. It was first introduced in 1980 .Wavelet analysis as a common signal analysis tool is dependent on its ability to describe the simulation of time and spectral information of signals, which overcomes the disadvantage of Fourier analysis. In Fourier method, base waves are sine and cosine (harmonic) waves, while the frequency content of each frequency is only one point. The Fourier transform method only determines wave frequency content and does not show the time of each frequency in the main wave. Wavelet is a small wave which has severe volatility on its amplitude and a quick return to zero at both ends of its amplitude and limited number of repetitions.

Wavelet transform is an efficient mathematical transform in the field of signal processing. Mathematical transforms are basically used to obtain additional information from signals that are not accessible from the signals. A large number of mathematical transforms can be used for signal processing, among which the Fourier transform is considered the most famous. As mentioned, Fourier transform is used to convert a signal from the time amplitude to the frequency amplitude; in other words, after applying the Fourier transform, if the function is drawn, one axis represents frequency, and the other axis represents intensity or amplitude. This graph can show how much of each frequency exists in the original signal. The Fourier transform provides information of the frequency in a signal, while it does not give any information about the occurrence time of a specific frequency. Being aware of the occurrence time of a specific frequency is important, therefore, the wavelet transform is used to overcome some shortcomings of the Fourier transform. So, we can use the wavelet transform in figure 4, which has the ability to analyse time series into several sub-series with different scales, and the small and large-scale behaviours of a process with studying the following time series resulting from the overall time series.

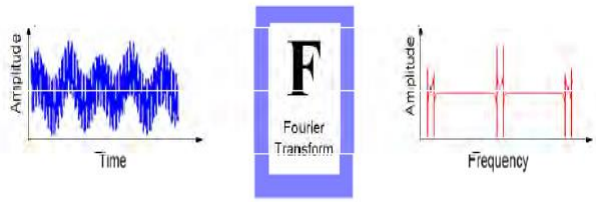

Figure 3: A Schematic Diagram of Fourier Transform

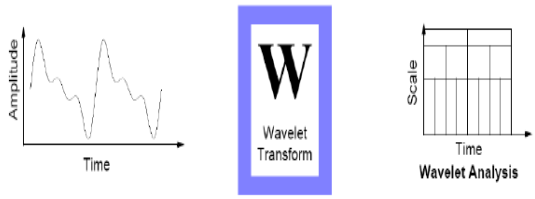

Figure 4: A Schematic Diagram of Wavelet Transform

Research Article

Mathematical Definition of Wavelet Function

Wavelet function is a function that has two important features: it is vacillatory and short-term. ψ (x) is the wavelet function, if and only if its Fourier transform ψ (ω), satisfies the following condition.

$$\int_{-\infty}^{+\infty} \frac{(\square \mid \psi(\omega) \mid \square)}{[\square \mid \omega \mid \square]^2} \, d\omega < +\infty$$

This condition is recognized as admissibility condition for wavelet ψ (x). The above mentioned equation can be considered equivalent to the following formula:

$$\omega(0) = \int_{-\infty}^{+\infty} \omega(X) dx = 0$$

This property of the function with zero mean is not too restrictive and many functions can be called wavelet function based on it. ψ (x) is the mother wavelet function, and the functions used in analysis, are resized and moved, with two mathematical operations of Translation and Dilation during the analysed signal.

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x-b}{a}\right)$$

Finally, the wavelet coefficients can be calculated at each point of the signal (b) and for any amount of scale (a) with equation (4):

$$CWT(a,b) = Wf(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(x) \, \psi\left(\frac{x-b}{a}\right) dx = \int_{-\infty}^{+\infty} f(X) \psi_{a,b}(x) dx = 0$$

Wavelet functions have many types. The most important and versatile types are: the wave function, Mexican hat, Morlet, Symlet, Haar, Daubechies, Meyer, and Coiflet. In Figure 5, function figures of four wavelets are shown.

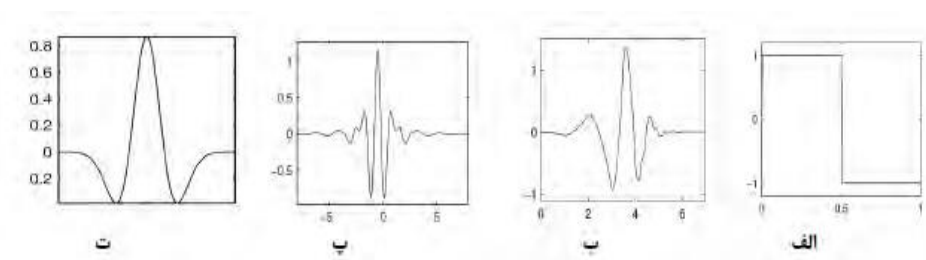

Figure 5: Figures of Wavelet Functions: Mexican Hat-Meyer- db4- Haar

Artificial Neural Networks

Artificial neural networks are established based on extensive internal communications, as well as the human brain and nervous system. Artificial neural networks are part of dynamic systems that process empirical data behind the data transfer network structure, so they are called intelligent systems, because according to calculations on numerical data and examples, they learn the general rules. These computational intelligence-based systems, try to model the structure of the human brain. Although artificial neural networks are not comparable with natural nervous system, they have some features that distinguish them in some applications such as separation of patterns, robotics, control and are generally privileged wherever they need to learn a linear or non-linear mapping. These features include the ability to learn, distributed processing and interoperability of their systems.

The overall structure of artificial neural network models consists of three layers:

1- Input layer: in this layer, inputs are introduced to the model.
2- Hidden layer or layers: the data are processed in this layer.
3- Output layer: the results of the model are produced.

The structure of a neural network is determined by determination of the number of layers, the number of neurons in each layer, the drive controller output of each neuron, methods of training, weights correction algorithm and model type. A simple example of a neural network is shown in Figure 6.
In this single-layered network, a series of input variables are placed in the nodes of the input layer and a series of output variables in output layer nodes.

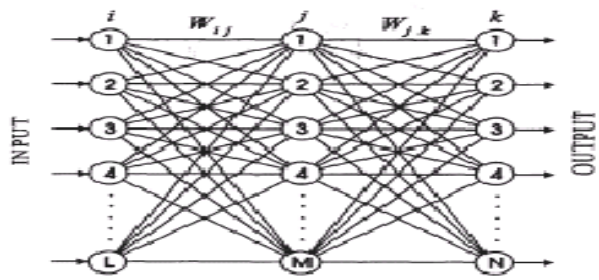

Figure 6: A Simple Example of Artificial Neural Network

Neural Networks-Wavelet
The combination of wavelet theory and artificial neural network creates a new network called neural wavelet networks which are used to approximate and increase the performance of neural networks and is very convenient for curves with large changes. Wavelet neural network is a reversible neural network and its excitation function is mother wavelet function.
Adaptive Neuro-Fuzzy Inference System (ANFIS)
When Professor Lotfi Zadeh proposed the theory of fuzzy logic for complex systems for the first time, this theory has been successfully used widely on various issues. The important point of fuzzy logic is to create a relationship between the input and output space and the primary mechanism for doing so is a list of If - Then sentences, which is called the law. In the training process, these rules are defined and evaluated in parallel. On the other hand, neural networks are capable of learning from the environments (input – output pairs). In 1993, considering the ability of fuzzy theory and neural networks, Jung provided adaptive network-based fuzzy inference system (ANFIS). Multilayer adaptive network-based fuzzy inference system consists of nodes and arcs connecting the nodes.
ANFIS model structure is shown schematically in Figure 7.

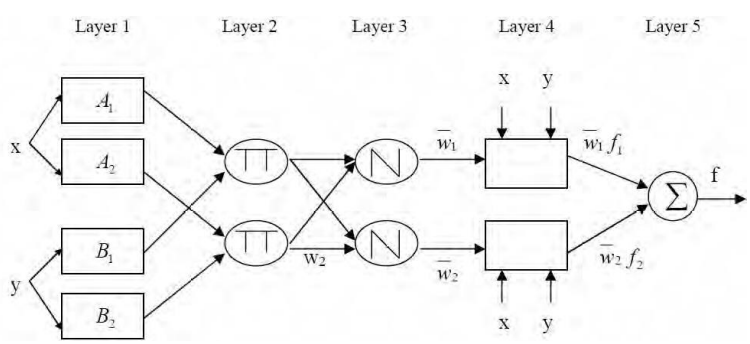

Figure 7: ANAFIS Model Structure

One characteristic of any type of ANFIS model is the membership function type intended for the model inputs. Membership functions are of different types, such as trapezoidal membership, triangular, Z, sig, pi, dsig functions, and Goss bell S function. Choosing membership function is based on tests done on different types of membership functions. It means that the membership functions are evaluated separately and ANFIS model is trained for each of these separate functions. At the end, the error values of different

models are compared and the function with results the lowest error rate in the least training time, is elected as the membership function. In Figure 8, examples of fuzzy membership functions are shown.

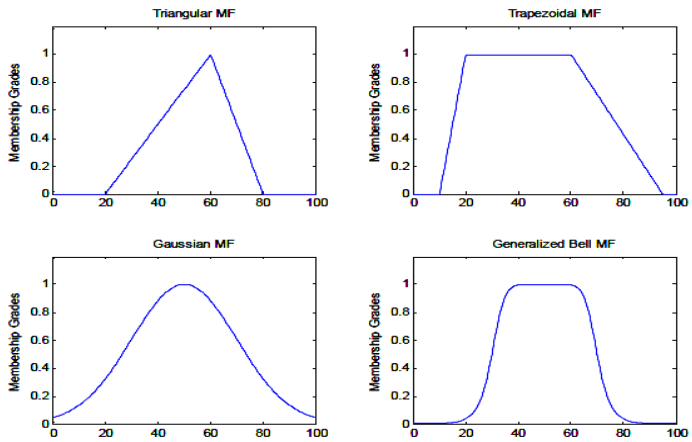

Figure 8: Examples of Fuzzy Membership Functions

Method of Data Analysis

In order to verify and compare the performance of different methods used in research for simulation of water quality parameters, the studied quality measurement data of dam water and evaluation criteria of errors, including R^2, RMSE are used.

Root Mean Square Error:

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(o_i - t_i)^2}{N}}$$

The correlation coefficient:

$$R^2 = \sqrt{\frac{\sum_{i=1}^{N}(o_i - t_i)^2}{\sum_{i=1}^{N}(o_i - \bar{o}_i)^2}}$$

RESULTS AND DISCUSSION

Cl and TDS data of Doroodzan dam's storage are inserted separately into the existing networks after sorting out and making them simultaneous on a monthly basis. Then, the results from the networks are assessed with the actual results of the evaluation criteria, correlation coefficient and root mean square error. At the next step, comparing the results of the networks, we select the best model to simulate Cl and TDS.

Wavelet Neural Network

In this system, first the data were analysed by wavelet and Grade 3 Haar function and the output from the wavelet was put as input of the neural network. After preparing the data, we specified the input and output data.

In this study, Cl with one-month and two-month delay were taken as the input parameter and Cl of the specific month as the output. And also TDS with one-month and two-month delay was taken as the input parameter and TDS of the specific month as the output. Then, the network was trained using neural toolbox in MATLAB software, and then, the network was evaluated using specified data. In this study, the output layer threshold function is *Purelin* and the middle layer threshold function is *tansig*. Network type was Feed-forward back prop and the number of neurons in the middle layer was altered from 6 to 30 for each network. Results are displayed in Tables 1, 2 and Charts 1, 2, 3 and 4.

Pattern used for Cl: Input Cl_{t-1} Cl_{t-2}, output Cl

Pattern used for TDS: Input TDS_{t-1} TDS_{t-2}, output TDS

Table 1: The Results of Cl with the Wavelet Neural Network

Wavelet Function	Analysis Degree	Neural Network Name	Middle Layer Function	Number of Neurons	Output Layer Function	R^2	RMSE
Haar	3	network1	Tansig	6	Purelin	0.4853	0.2510
Haar	3	network2	Tansig	12	Purelin	0.3843	0.2650
Haar	3	network3	Tansig	18	Purelin	0.4445	0.2662
Haar	3	network4	Tansig	20	Purelin	0.5139	0.2485
Haar	3	network5	Tansig	30	Purelin	0.1982	0.3075

Table 2: The Results of TDS with the Wavelet Neural Network

Wavelet Function	Analysis Degree	Network Name ANN	Middle Layer Function	Number of Neurons	Output Layer Function	R^2	RMSE
Haar	3	Network6	Tansig	6	Purelin	0.5403	0.1663
Haar	3	Network7	Tansig	12	Purelin	0.5238	0.1691
Haar	3	Network8	Tansig	18	Purelin	0.3978	0.1932
Haar	3	Network9	Tansig	30	Purelin	0.5193	0.1826
Haar	3	Network**10**	Tansig	40	Purelin	0.5645	0.1623

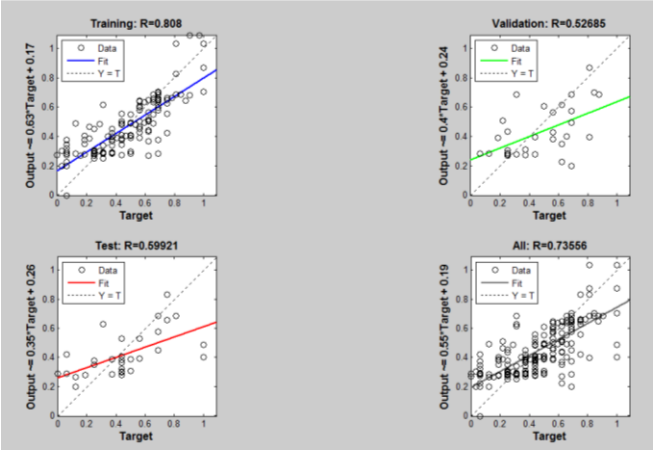

Diagram 1: Actual and Estimated Values of Cl in Wavelet-Neural Network

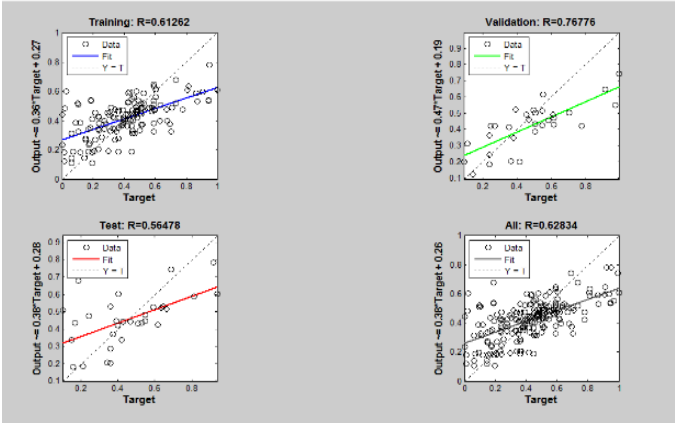

Diagram 2: Actual and Estimated Values of TDS in Wavelet-Neural Network

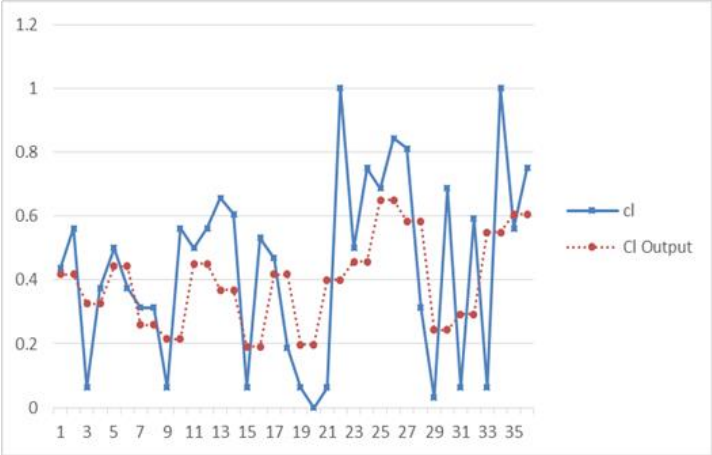

Diagram 3: Cl Amount of Real and Simulated Neural Network-Wavelet

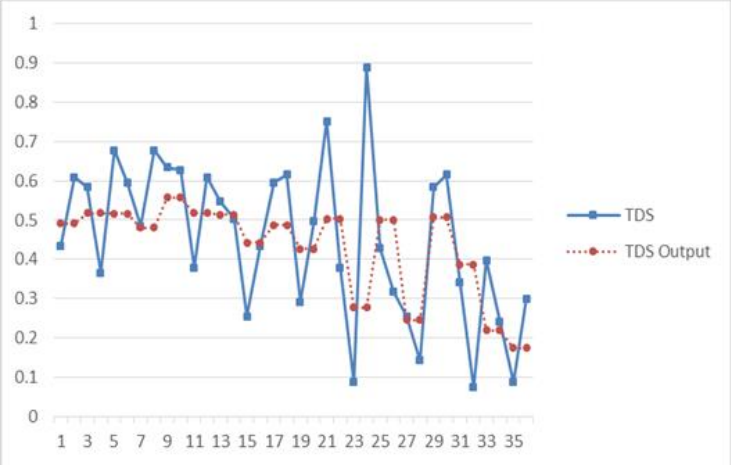

Diagram 4: TDS Amount of Real and Simulated Neural -Wavelet Network

Wavelet Neuro-Fuzzy Inference System

In this system, first the data were analysed with wavelet and Grade 3 Haar function, and the output from the wavelet was put as input of ANFIS. Then the input patterns were selected using the ANFIS toolbox in MATLAB software. After data recalling by writing anfisedit command on the command line of the program, 85% of the Cl data were chosen as training data and the remaining 15% as the test data. In Network training, Gaussian function with a membership degree of 3 was used for input membership function, and linear function was used for the membership function of the output. And in the last step, for training the membership function parameters, optimization hybrid method was used, which is a combination of the method of least squares and the method of lowering the slope in post propagation with 20 trainings, and then the network was trained and tested. Results are displayed in Tables 3, 4 and Charts 5, 6, 7 and 8.

The patterns used for Cl:

Pattern 1: Input Cl_{t-1}, output Cl

Pattern2: Input Cl_{t-1} Cl_{t-2}, output Cl

Pattern3: Input Cl_{t-1} EC, output Cl

The patterns used for TDS:

Pattern4: Input TDS_{t-1}, output TDS

Pattern5: Input TDS_{t-1} ,TDS_{t-2}, output TDS

Pattern6: Input TDS_{t-1},TDS_{t-2}, EC, output TDS

Table 3: Different Cl Patterns of Fuzzy-Neural-Wavelet Network

Wavelet Function	Analysis Degree	Cl	Error	Input Membership Function ANFIS	Input Membership Degree	Output Membership Function	Learning Method	Number of Courses	R^2	RMSE
Haar	3	Pattern1	0.1356	gaussmf	3	Linear	hybrid	20	0.3952	0.3559
Haar	3	Pattern2	0.1307	gaussmf	3	Linear	hybrid	20	0.8111	0.1431
Haar	3	Pattern3	0.1289	gaussmf	3	Linear	hybrid	20	0.7516	0.1661

Table 4: Different TDS Patterns of Fuzzy -Neural-Wavelet Network

Wavelet Function	Analysis Degree	TDS	Error	Input Membership Function ANFIS	Input Membership Degree	Output Membership Function	Learning Method	Number of Courses	R^2	RMSE
Haar	3	Pattern4	0.1611	gaussmf	3	Linear	hybrid	20	0.6377	0.1767
Haar	3	Pattern5	0.1443	gaussmf	3	Linear	hybrid	20	0.7762	0.1392
Haar	3	Pattern6	0.0033	gaussmf	3	Linear	hybrid	20	0.4592	0.4524

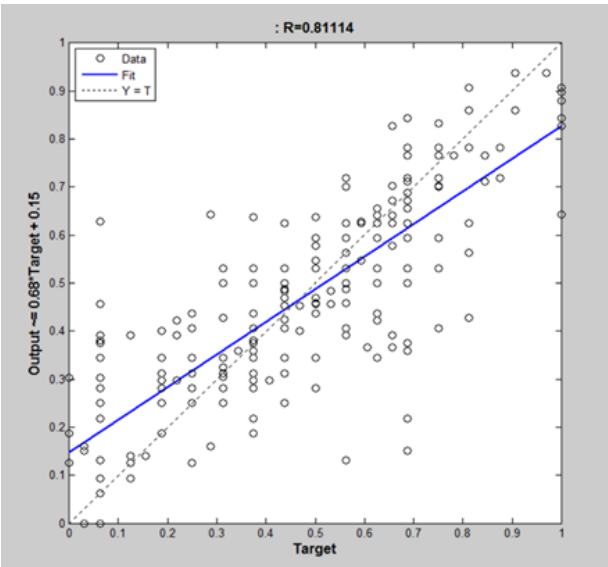

Diagram 5: Actual and Estimated Amounts of Cl in the Fuzzy-Wavelet- Neural Network

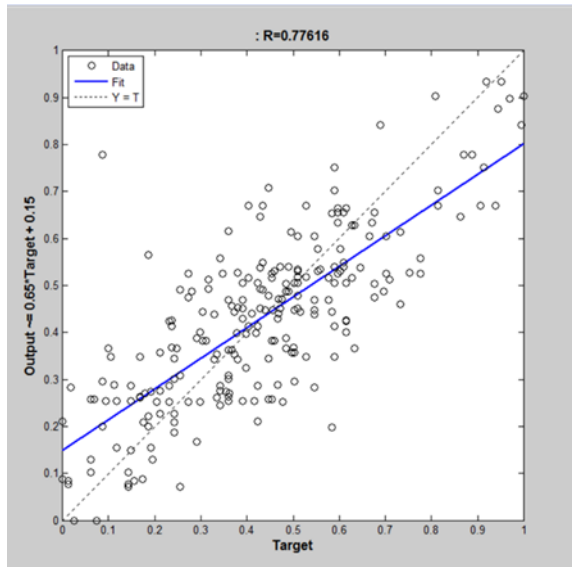

Diagram 6: Actual and Estimated Values of TDS in Wavelet-Neural Network

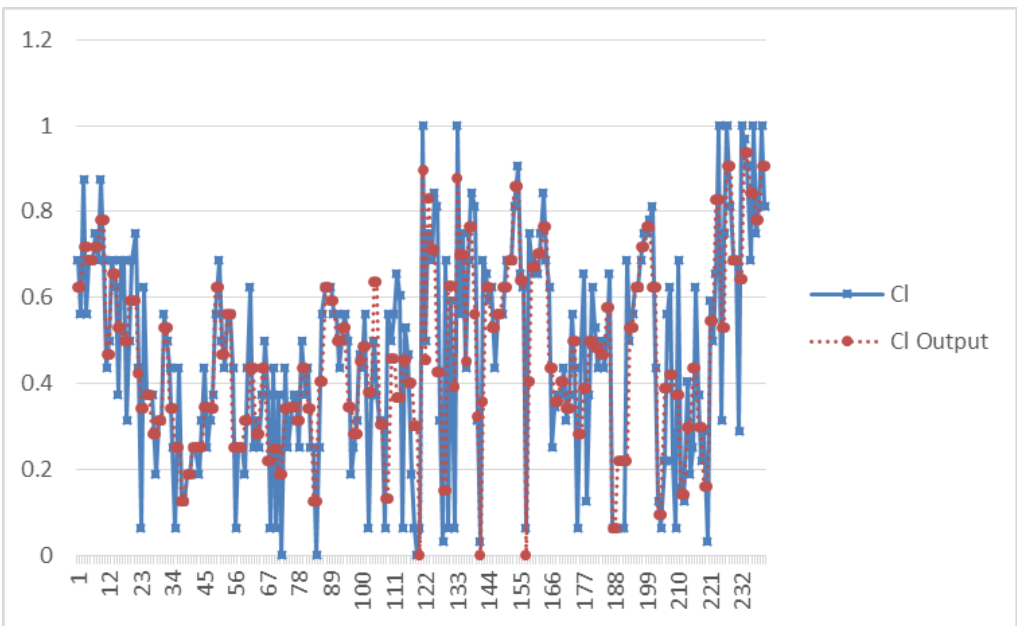

Diagram 7: Real Amount of CI and Simulated Amount by the Fuzzy-Wavelet- Neural Network

Conclusion

The results show that to simulate chloride in a wavelet-neural network model, network no.4 with maximum correlation amount of 0.5139 and the lowest root mean square error of 0.2485 was the best answer; and in the neuro-fuzzy-wavelet, pattern no.2 with the highest correlation coefficient of 0.8111 and the lowest root mean square error of 0.1431 was the best answer between the two networks; and to simulate total dissolved solids (TDS) in a wavelet neural network, network no.10 with maximum correlation amount of 0.5645 and the lowest root mean square error of 0.1623 was the best answer; and in the neuro-wavelet fuzzy network, pattern No. 5 with the highest correlation coefficient of 0.7762 and the lowest root mean square error of 0.1392 had the best result in the two networks.

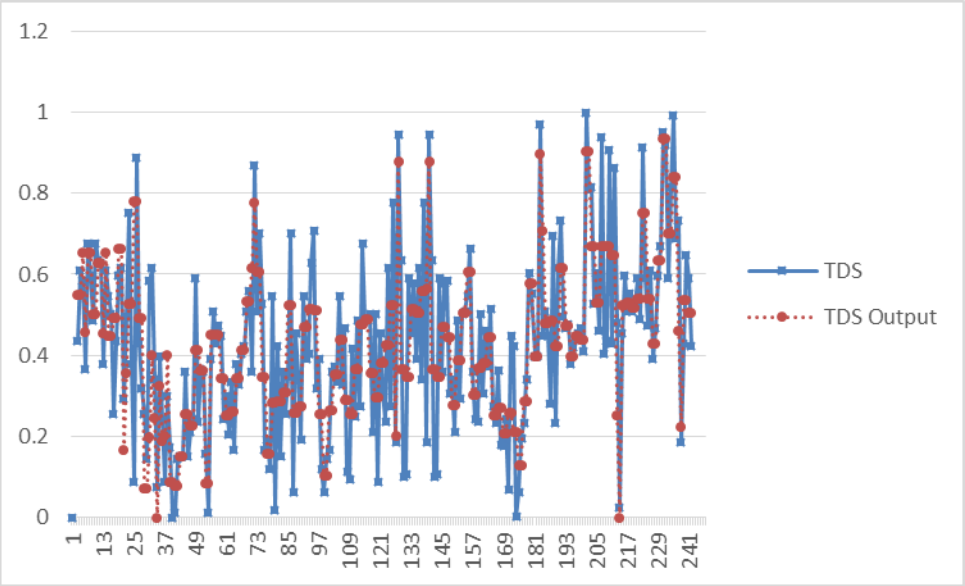

Diagram 8: Real Amount of TDS and Simulated Amount by the Fuzzy-Wavelet- Neural Network

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