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Application of Artificial Neural Networks in the River Water Quality Modeling: Karoon River, Iran

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Abstract: To achieve goals of this research program, Karoon river in Iran is selected to assess the capability of ANNs for water quality simulation. This river is the longest river in Iran. It is located in Khuzestan province, South-West of the country. Several water quality variables including; CO_3, HCO_3, SO_4, Cl, Na, Ca, Mg, K, EC, TDS and SAR have been simulated. Data from 1985 to 2006 at monitoring stations including; Arabhasan, Valiabad, Molasani, Ahwaz, Farsiat and Darkhoyen have been used for training of the selected ANN. Qnet 2000 ANN is selected for modeling purposes in the present research. Results show that Qnet 2000 is able to predict water quality variables of the Karoon River very successfully with more than 90% accuracy.

Key words: Water quality, artificial neural networks, Qnet2000, Karoon river

INTRODUCTION

Nowadays, water resources are the main basis for stable development around the world. Therefore, quality and quantity of these resources are so important. Khuzestan Province at South West of Iran secure rather of water exposed to need from Karoon, Karkheh, Dez, Jarahi and Zohreh rivers. Between these rivers Karoon River is the most important waterway in the country which provides water for many cities, villages, agricultural projects and industrial factories along 300 km length in the basin. Therefore, the flow discharge of the river is decreased continues decreasing discharge of Karoon river and use of the river as outlet for several industries in the basin cause deterioration of the river water quality. Future development of the river basin can cause more crucial than today. Therefore, knowledge about proceeding change, simulation and forecasting water quality of Karoon River as for increasing industry, population, accomplishment and development different project are so important. In recent years, several deterministic water quality models have been developed to investigate about waterways such as; QUAL2E, WATEVAL, MIKE11, HEC5Q and WASP.

Artificial Neural Networks are one types of intellect artificial system which were simulated from neural cells of existent live. They can perform learning any mechanism related every phenomena. They are able to remember their knowledge like human brain and they can apply this knowledge to the same phenomena to predict their variation. The backgrounds of Artificial Neural Networks come back to 19th and 20th century. In this period of time some studies in physics, psychology and physiology by favor of some scientist as, Ivan Pavolov had accomplished. These initial studies on the theories of eventual, learning and discernment accent and did not implied to operation of mathematical models (Menhaj, 2000).

The new point of view on Artificial Neural Networks with Warren McCulloch and Walter Pitts's investigations was begun. They showed that neural networks can calculate each logical and arithmetical function. The first applications of neural networks were introduction of Perceptron Network by Frank Rosenblant (1958) and delineation Adelin comparative Neural Network by Bernurd Widrow in 1960. Until 80 decade by reason of computer with high speed did not investigation about Neural Networks has low speed but with development of microprocessor proceeding increase (Menhaj, 2000).

In general, the proceedings of development neural networks have been divided to three stages:

- Study on development of neural neuron and determination restrictive factors by Minsky and Papert
- Finding and generalization back propagation algorithm by Rummelhart and Mcland
- Evaluation restrictive of neural networks and comparison with other methods such as, genetic algorithm and phase theory (Dawson and Wilby, 2001)

Each neural network consist of three layers; input layer with dependent variable, output layer with independent variable and one or more hidden layer with proceeding element. Network is trained for some existing

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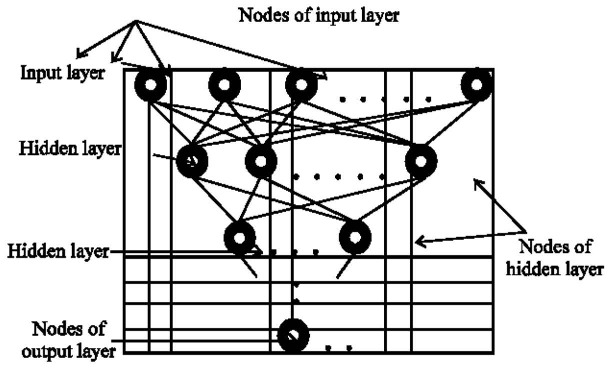

Fig. 1: Components of an artificial neural network

data and if this did with suitable iteration and transfer function can be expected to analyze phenomenon and give suitable results later. Schematic of an Artificial Neural Network is shown in Fig. 1.

Approximately, Artificial Neural Networks have been used in all branches of science. Several application of ANN in water resources and environmental issues has been gathered in Coskun *et al.* (2008). ANN is not much used in Hydraulics and river engineering. There is small number of research conducted in this field of study. Wen and Lee (1998) applied a neural network approach to multi objective optimization for water quality management in a river basin. Neural network has been base for several researches such as; neural network assisting in water quality modeling (Daniell and Wundke, 1993), application of Artificial Neural Network for water quality management (Zaheer and Bai, 2003), forecasting salinity using neural network and multivariate time series model (Maier and Dandy, 1994), river flow modeling using Artificial Neural Networks (Ozgur, 2004) and application of Artificial Neural Network in stage-discharge relationships (Bhattacharya and Solomatine, 2000).

In this study, Artificial Neural Network has been used to simulate water quality of Karoon River, Iran.

MATERIALS AND METHODS

Karoon River with catchments area equivalent to 62570 km^2 is one of the most waterways in Iran. It is the longest river in the country which collects the runoff of extensive areas and convey to the Persian Gulf. The head stream of Karoon is in central Zagros Mountain. Karoon River flows from Ravine in head stream to Khuzestan plain at South-West of Iran then pass from Khorramshahr and Abadan. Finally, through Bahmanshir and Arvandrood the branches of Karoon River flow to Persian Gulf. The width of this river in along path is different. In mountainous part about 25-40 m and in plain near Ahwaz

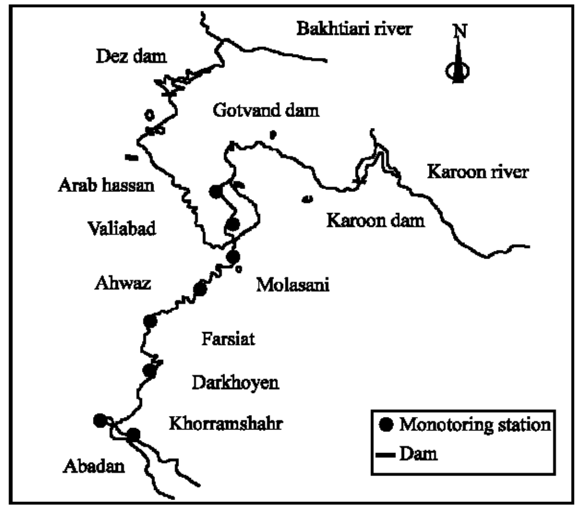

Fig. 2: Plan of Karoon river, Iran

Table 1: Characteristics of the monitoring stations in the Karoon river

Station	Longitude	Latitude	Height (m)
Arabhassan	48°52'45"	31°50'51"	20
Molasani	48°52'50"	31°35'00"	20
Ahwaz	48°41'30"	31°29'30"	21
Farsiat	48°22'47"	30°59'20"	9
Darkhoyen	48°25'00"	30°44'45"	5

250-400 m and around Khorramshahr reach to 350-700 m. The depth of Karoon River in mountainous area ranges about 4-5 m and around Ahwaz City reach to 5-7 m. Plan of Karoon River and location of its monitoring stations and dams' structures are shown in Fig. 2.

The characteristics of water quality and quantity monitoring stations on the Karoon river are showed in Table 1.

In this study, Qnet2000 with back propagation scheme is used to simulate water quality of Karoon River. Data that was used in this study are; flow discharge, HCO_3^-, CO_3^{--}, SO_4^{--}, Cl^-, Na^+, Mg^{++}, Ca^{++}, K^+, EC, TDS and SAR for 22 years from 1985 to 2006 at Arabhassan, Valiabad, Molasani, Ahwaz, Farsiat and Darkhoyen stations. Seventy percent of data is used for training the ANNs and 30% of available data is used for validations. The ANN model of Karoon River is applied for prediction of the water quality variables in 2006. Data was measured several days of each month, then average of measured data divided on maximum of each series to achieve relative quantity of the selected parameters which was dimensionless between 0-1 to speed up the calculation. Flow discharge, HCO_3^-, CO_3^{--}, SO_4^{--}, Cl^-, Na^+, Mg^{++}, Ca^{++}, K^+ were used as independent variables, EC, TDS and SAR were considered as dependent variables to be predicted. Firstly, initial weight is selected and model is run to train Qnet 2000 for the Karoon River. Comparison of results with observed data and agreement between them would the goal of this stage. The selected weight will be changed until the best agreement is obtained. The river flow discharge, HCO_3^-, CO_3^{--}, SO_4^{--}, Cl^-, Na^+, Mg^{++}, Ca^{++}, K^+ were selected as independent variables (input node), EC, TDS and SAR as dependent variables (output node). To chase the modelling purpose, different transfer function for hidden and output layers with one hidden layer were selected. The purpose of this simulation was comparison between measurement and predicted values, determination of suitable transfer function for hidden and output layer, suitable number of hidden layer. Finally, this research is trying to find out whether the ANN model is applicable to predict water quality variables in the river systems or not.

RESULTS AND DISCUSSION

Modeling process includes training, calibration, validation and forecasting. Two statistical criteria have been used for comparing of the models outputs; Root Mean Square Error (RMSE) and coefficient of determination. Root mean square error equal to zero and coefficient of determination equal to one denote the best agreement between predicted and observed data. In each station Sigmoid, Gaussian, Hyperbolic tangent and Hyperbolic secant by way of transfer function for hidden and output layer, 10000-200000 iteration, one hidden layer with 9 and 10 nodes were tested and were determined that Gaussian and Hyperbolic tangent for hidden and output layer, 200000 iterations and 10 nodes in hidden layer were represented the best results. After that the effect input variation on output were evaluated. Table 2 shows the results of model in training at Farsiat station with 10000 iterations, one hidden layer, 9 nodes and different transfer function.

The results of model for each station, maximum and minimum of effective input parameters in the ANN training stage have been shown in Table 3 and 4.

Overall, it seems ANN is able to predict several chemical water quality parameters of the Karoon River very successfully.

After determination of the best transfer function of hidden and output layer, suitable number of node in hidden layer and iteration number, TDS, EC and SAR in each station were predicted. Figure 3 compares the predicted TDS profile along the selected reach of the river.

Table 2: Comparison of using different function for TDS prediction in Farsiat station

Output layer function	Hidden layer function	RMS	R^2	Output layer function	Hidden layer function	RMS	R^2
Sigmoid	Gaussian	0.0188	0.9863	Sigmoid	Sigmoid	0.0205	0.9839
Gaussian	Gaussian	0.3779	0.4394	Gaussian	Sigmoid	0.3779	-0.2887
Tanh(x)	Gaussian	0.0185	0.9868	Tanh(x)	Sigmoid	0.0199	0.9846
Sech(x)	Gaussian	0.0188	0.9863	Sech(x)	Sigmoid	0.0201	0.9843
Sigmoid	Sech(x)	0.0194	0.9855	Sigmoid	Tanh(x)	0.0195	0.9853
Gaussian	Sech(x)	0.3779	0.5767	Gaussian	Tanh(x)	0.3779	-0.3992
Tanh(x)	Sech(x)	0.0188	0.9863	Tanh(x)	Tanh(x)	0.0192	0.9858
Sech(x)	Sech(x)	0.0193	0.9855	Sech(x)	Tanh(x)	0.0190	0.9859

Table 3: Predicted TDS, SAR and EC for different stations on Karoon River, Iran (200000 iterations and 10 nodes in hidden layer)

Stations	Variables	RMS	R^2	Maximum input effective parameter	Minimum input effective parameter
Arabhassan	TDS	0.01265	0.9978	Na	CO_3
	EC	0.01050	0.9991	Cl	Q
	SAR	0.00114	0.9999	Na,Ca,Mg	Q
Valiabad	TDS	0.01264	0.9965	Na	Q
	EC	0.01301	0.9983	Cl	Q
	SAR	0.00113	0.9999	Na,Ca,Mg	CO_3
Molasani	TDS	0.01205	0.9939	K	Q
	EC	0.01234	0.9940	Cl	HCO_3
	SAR	0.00113	0.9999	Na,Ca,Mg	Q
Ahwaz	TDS	0.01404	0.9950	Na	CO_3
	EC	0.01403	0.9960	Cl	Mg
	SAR	0.00112	0.9999	Na,Ca,Mg	K
Farsiat	TDS	0.01335	0.9912	SO_4	CO_3
	EC	0.01089	0.9953	Cl	CO_3
	SAR	0.00119	0.9999	Na,Ca,Mg	CO_3
Darkhoyen	TDS	0.01478	0.9928	Na	Q
	EC	0.01210	0.9956	SO_4	Q
	SAR	0.00115	0.9999	Na,Ca,Mg	Q

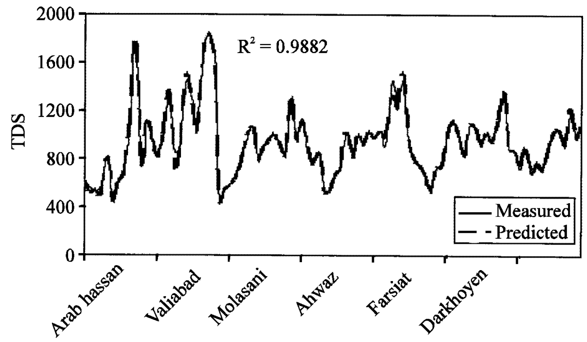

Fig. 3: Comparison of predicted and measured TDS along Karoon river, Iran

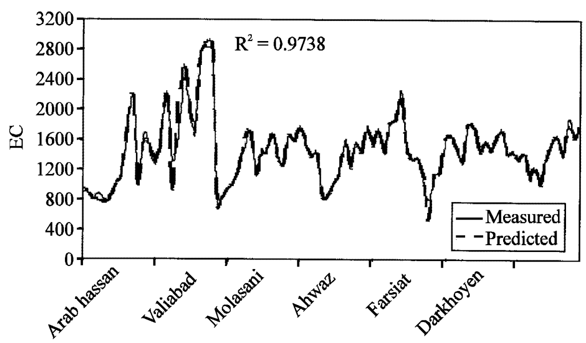

Fig. 4: Comparison of predicted and measured EC along Karoon river, Iran

Table 4: Results of ANN model validation in different stations Karoon river, Iran

Station name	Iterations	No. of hidden layer nodes	R^2(TDS)	R^2(EC)	R^2(SAR)
Arabhassan	10000	9	0.90020	0.92003	0.94051
		10	0.91130	0.93000	0.94631
	200000	9	0.95421	0.96105	0.96870
		10	0.95670	0.97780	0.97500
Valiabad	10000	9	0.92500	0.94587	0.90100
		10	0.92961	0.95006	0.91235
	200000	9	0.94780	0.98610	0.96541
		10	0.94900	0.99000	0.96890
Molasani	10000	9	0.91783	0.90022	0.90282
		10	0.91936	0.90056	0.92878
	200000	9	0.93381	0.95910	0.91323
		10	0.97532	0.96566	0.93515
Ahwaz	10000	9	0.92641	0.90330	0.98579
		10	0.94632	0.91058	0.98655
	200000	9	0.93045	0.96552	0.98596
		10	0.96457	0.96645	0.98731
Farsiat	10000	9	0.95361	0.93200	0.90120
		10	0.96006	0.94451	0.91547
	200000	9	0.99917	0.95146	0.96421
		10	0.99949	0.96064	0.96525
Darkhoyen	10000	9	0.90615	0.94140	0.97428
		10	0.90931	0.94556	0.97710
	200000	9	0.97706	0.96401	0.97614
		10	0.97706	0.97906	0.97733

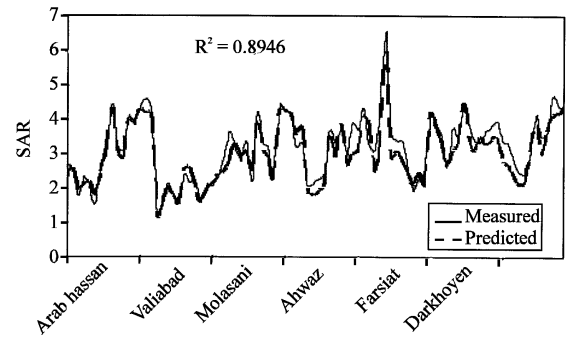

Fig. 5: Comparison of predicted and measured SAR along Karoon river, Iran

It is shown a very good agreement between predicted and measured profiles with $R^2 = 0.99$ which shows that ANN is capable of TDS simulation in the Karoon River.

Figure 4 compares the predicted profile of the electrical conductivity of the Karoon river water using ANN along the selected reach. The predicted profile is very close to the measured profile. The coefficient of determination, $R^2 = 0.97$. It denotes that ANN can produce the TDS profile very successful.

Finally, Fig. 5 presents the comparison between predicted and measured SAR profiles. R^2 of almost 90 for this prediction shows good agreement.

Overall, it seems ANN is able to predict several chemical water quality parameters of the Karoon River very successfully.

CONCLUSION

This study presents a study on application of the Artificial Neural Network to water quality simulation in the river system. Using river data such as, discharge, HCO_3^-, CO_3^{--}, SO_4^{--}, Cl^-, Na^+, Mg^{++}, Ca^{++}, K^+, EC, TDS and SAR, Qnet2000 as an ANN has been trained. 70% of data have been used for calibration and 30% of data have been used for validation. In calibration and validation coefficient of determination between predicted and measured results was more than 90%. Also, according to Fig. 3-5 coefficient of determination (R^2) between measured and predicted water quality variables are approximately 90% that shows the ability of artificial neural network in forecasting several water quality variables in the river systems.

Results show that ANN model with Gaussian and Hyperbolic tangent functions for hidden and output layer with 10 nodes in hidden layer and 200000 iterations give the best results. Also, in TDS simulation the most effective parameters were Na^+, Ca^{++}, K^+, SO_4^{--} and Cl^-

and the less effective input parameters were discharge and CO_3^{--}. In EC simulation the most effective input parameter were Ca^{++}, SO_4^{--} and Cl^{-} and the less effective input parameters were discharge and CO_3^{--}, HCO_3^{-}, K^{+} and Mg^{++}. Also, in SAR simulation the most effective input parameters were Ca^{++}, Mg^{++} and Na^{+} and the less effective input parameters were discharge, CO_3^{-} and K^{+}.

Overall, it is shown that Qnet 2000 is a very trustable ANN model for simulation of several water quality variables in the river systems.

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