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Estimate stage-discharge relation for rivers using artificial neural networks- Case study: Dost Bayglu hydrometry station over Qara Su River

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The prediction of discharge and its variability in a river is an essential component of surface-water planning. For that purpose, a functional relationship between stage and discharge is established with the help of field measurement and the relationship is expressed as a rating curve. Whereas direct discharge measurement in rivers is time consuming and expensive, and sometimes it is impossible, for this purpose the relation between discharge and stage as rating curve is estimated by using of measured data. The Qara Su River in Ardabil province, Iran, makes damages with its floods every year. Informing of flood discharge's value in upstream for management activity in downstream is necessary. In this research for estimate stage-discharge relation in Dost Bayglu hydrometry station over Qara Su River, using MATLAB software, Artificial Neural Network with different state and regression methods studied and finally compared together. As a result of Artificial Neural Network with a 1-2-3-2-1 structure, compared with a simple regression, has a better answer.

Key words: Artificial neural network, stage-discharge relation, Qara Su River, Dost Bayglu hydrometry station, regression.

INTRODUCTION

In hydrometry stations, stage value was usually read while measuring the discharge value of river. At present times engineers read the stage value by advanced devices and send it to the reference centers by using modern methods. If we measure the discharge and the stage value several times, we would find a mathematical relation between them, which was called the stage-discharge relation. Measuring the river discharge constantly, is very difficult and expensive task, even in normal conditions. However, it will be more difficult and sometimes impossible in flood situations or in unfavorable climate conditions. In some rivers, when there is a reasonable mathematical relation between discharge and stage, we can use stage value, to read and send it to the center, to obtain the discharge value. The stage-discharge relation refers to all possible concepts explaining how to calculate discharge based on measuring the flow parameters. Stage-discharge relation can be defined by determining discharge measuring points and stage parallel points on x and y axis, respectively. Forming of the stage-discharge curve is a function of control station geometry. At the mathematical

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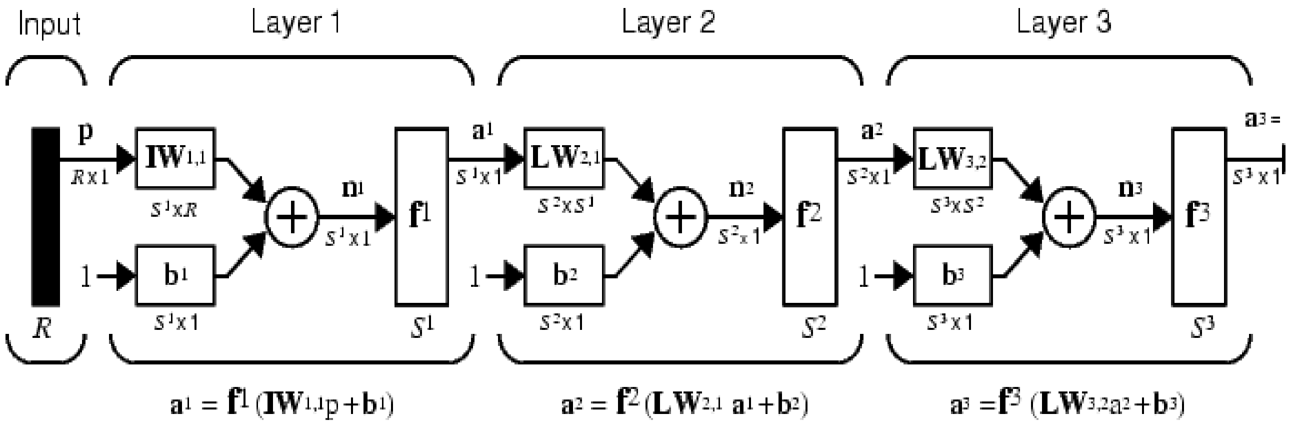

Figure 1. A schema of multiple-layer neural network.

point of view, most of stage- discharge curves haveparabolic form. But, at the regressional point of view, the stage-discharge curves could have various forms such as; polynomial, power, linear and etc.

Goel in his study discussed at the application of soft computing techniques such as back propagation feed forward neural network-based algorithm for modelling stage-discharge relation. The outcome of his study suggests that the back propagation feed forward ANN works quite well for the data sets and produced promising results in comparison to the linear regression technique (Goel, 2011). Bhattacharya and Solomatine (2000) studied the water level and discharge by using 9 years obtained datum from hydrometry station in Bagirathy River, India, by using artificial neural network. The results showed that the power model is the best, as its determination coefficient is about 0.988. Validation test showed that the error in this model is insignificant.

Jain and Chalisgaonkar (2000) studied stage-discharge relation by using artificial neural network in India. In this study, they used three informational layers in artificial neural network model for making stage-discharge curve. The results showed that there is high correlation coefficient in stage-discharge relation by this method.

ANNs are widely used in various areas of water-related research - rainfall-runoff modeling (Minns and Hal,l 1996; Dawson and Wilby, 1998), replicating behavior of hydrodynamic modeling systems (Solomatine and Avila Torres, 1996; Dibike et al., 1999), water level control (Lobbrecht and Solomatine, 1999). Muttiah et al. (1997) addressed the problem of discharge prediction, Thirumalaiah and Deo (1998) modeled the stage behavior (without considering discharge). Clair and Ehrman (1996) used ANN to model the relationship between variation of discharge and ecological parameters and climate change. However, extensive search of sources covering the problem of modeling the stage-discharge relationship delivered no result.

METHODOLOGY

In order to perform the research, we collected information and statistics related to discharge-stage on Dost Bayglu hydrometry station, by referring to regional water organization in Ardebil. Then, we analyzed the information and data. By employing simple regression, we obtained the relation between stage and discharge. To do this, in start by dividing data to four parts, we used 3/4 of data as a calibrated data and 1/4 as a validating data.

Artificial neural network (ANN)

Artificial neural network is a simplified model of human brain. The network has mathematical structure able to indicate non-linear, desired, process and compounds, and to find the relation between input and outputs of system. These networks will be used in the future to predict in the future through accomplishing the learning and teaching process.

Neural network consist of neural cells-called neuron, and some communicational units called axon. Neurons are simplified from of biological neurons. Although, the neuron made artificial neural network have higher speed than biological neuron, they have less capability when compared to them. A schema of multiple-layer neural network has been shown in Figure 1. As is shown in Figure 1, each artificial neural network consist of three layers, include: input layer, output layer and hidden layer.

There are some neurons as processor units on each layers, connected to each other by weighted connectors. In this system, errors reach to its least number through conducting some process. To transmit outputs of one layer to another transfer functions were used. Sigmoid, purelin and tan-sigmoid functions are examples of transfer functions. In general, artificial neural network divided to two groups:

(1) Feed forward networks
(2) Feed backward networks

Levenberg-Marquardt algorithm (LM)

The research, provide LM algorithm to identify the best method with the highest efficiency for learning network. This algorithm considers one approximation in varying the weights, for Heyzen matrix, like Newton's methods.

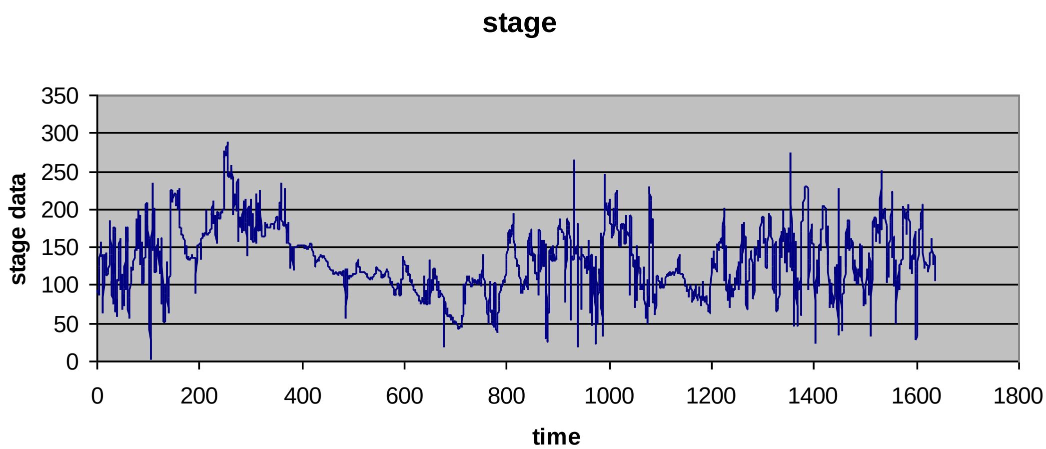

Figure 2. Time series of stage data.

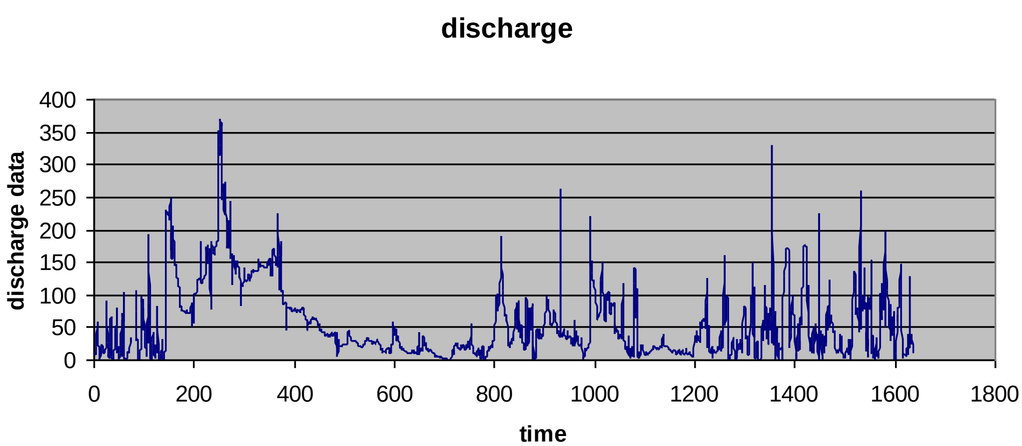

Figure 3. Time series of discharge data.

Specifications of hydrometry station

Qara Su watershed basin is one of the vast in Ardabil province, Iran, its area is about 11126.3 ha. Dost Bayglu hydrometry station established in 1351 and 840 m high from the sea level. It is in 47 – 31 longitude and 38 – 32 latitude. The upstream basin station has area about 7311.1 Km and discharge and stage data are available, until 1384. The station's equipments are: Stage, Limnogragh and etc. Normalizing is one of the re-analyzing states for modeling with artificial neural networks. In this research, we used tan-sigmoid transfer function in all layers. So the data should be normalized in respect to transfer function, by following this relation (Figures 2 and 3).

$$x_i' = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \qquad (1)$$

Model efficiency scale

There are different scales to evaluate the efficiency of the model. In this research, we use Determination coefficient (2), Root Mean Square error (3) and Correlation coefficient (4).

$$R^2 = \frac{\sum_{i=1}^{n}(Q_i - \overline{Q}_i)^2 \quad \sum_{i=1}^{n}(Q_i - \hat{Q}_i)^2}{\sum_{i=1}^{n}(Q_i - \overline{Q}_i)^2} \qquad (2)$$

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(Q_i - \hat{Q}_i)^2}}{n} \qquad (3)$$

$$CorrCoef = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2 (y_i - \overline{y})^2} \qquad (4)$$

RESULTS

As determination coefficient tended to one, it means

Table 1. The results of modeling by artificial neural network.

Type of neural network	Number of model	input	output	Network structure	logsig				
					Correlation coefficient		R^2		RMSE
					Calibration	Validation	Calibration	Validation	Validation
FFBP	1	Stage data	Discharge data	1-7-12-6-5-1	0.85	0.8	0.81	0.77	0.0043
FFBP	2	Stage data	Discharge data	1-7-12-5-1	0.88	0.84	0.84	0.81	0.0038
FFBP	3	Stage data	Discharge data	1-10-6-1	0.9	0.86	0.87	0.84	0.0033
FFBP	4	Stage data	Discharge data	1-8-5-1	0.94	0.89	0.89	0.85	0.0031
FFBP	5	Stage data	Discharge data	1-2-3-2-1	0.94	0.91	0.9	0.87	0.0028

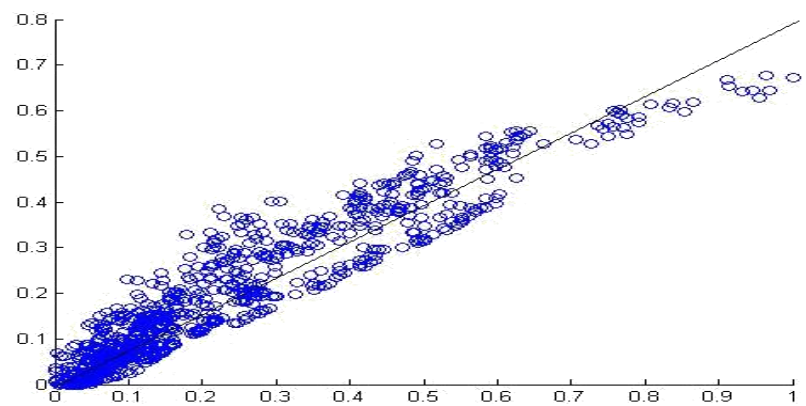

Figure 4. Scatter plot of output number 5- artificial neural network modeling, and observed data- calibration process.

there is more precise relation between stage and discharge. Data have been divided to two parts, calibrated and validating in this method. It have been used 3/4 and 1/4 of data as a calibrated and validating data, respectively, (It means that in this research data consist of 3/4 calibrated data and 1/4 validating data).

In the modeling with artificial neural network for over all models, FFBP method with Levenberg-Marquardt training algorithm (LM) as well as various states of network with different layers was evaluated that results from the best models as shown in Table 1.

Diagrams related to calibration and validation process of neural network method and, also, time series of predicted and observed data are shown in Figures 5 to 7.

In the modeling with simple regression calibrated data were used in fitting curves. So by applying regression relation on validating data, we obtained the validation correlation coefficient. The

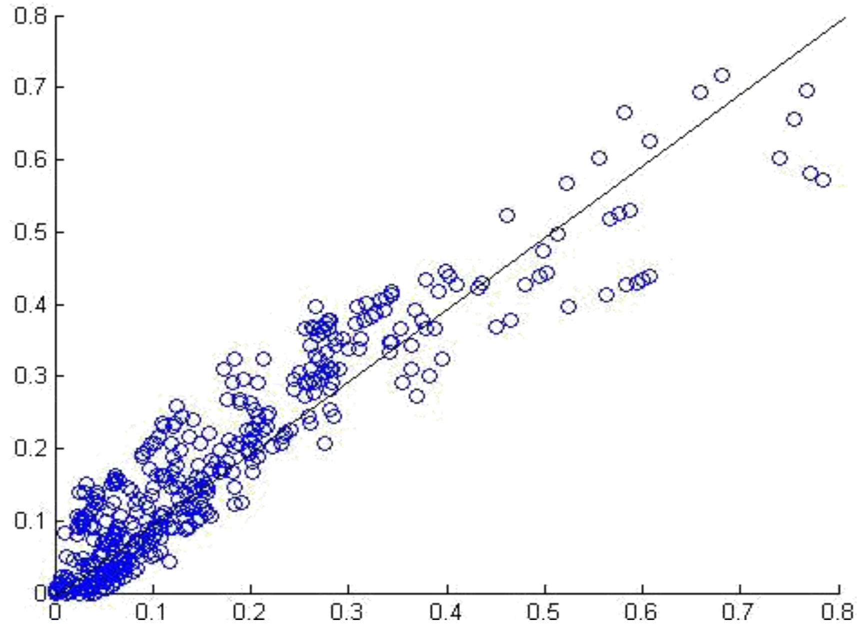

Figure 5. Scatter plot of output number 5- artificial neural network modeling, and observed data- validation process.

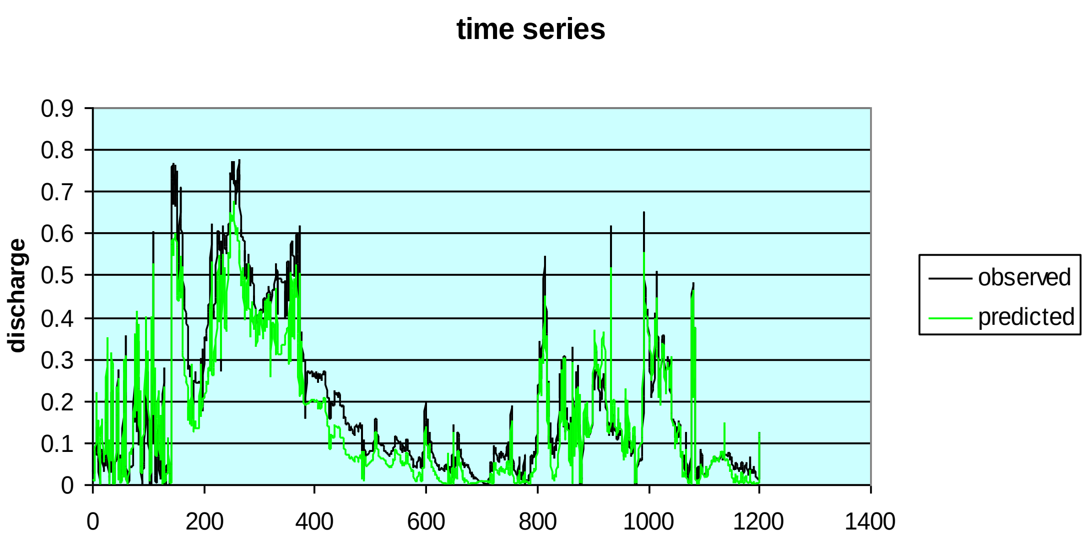

Figure 6. Time series of output number 5- artificial neural network modeling, and observed data- calibration process.

evaluation process was applied on curves and functions then, they were selected based on having the favorable determination coefficient. In this research, polynomial curve provide the best result for Dost Bayglu station. Validation and calibration correlations coefficients are shown in Table 2. Diagrams related to calibration and validation process of this method and, also, time series of predicted and observed data are shown in Figures 8 to 10.

DISCUSSION

It is finally concluded that in artificial neural network (FFBP Network with LM training algorithm), stage data as input and discharge data as output with a 1-2-3-2-1 structure with determination coefficient of 0.87 as the best model has been introduced (Table 3). It is observed that the ability of artificial neural network for stage-discharge modeling is better than other evaluated method

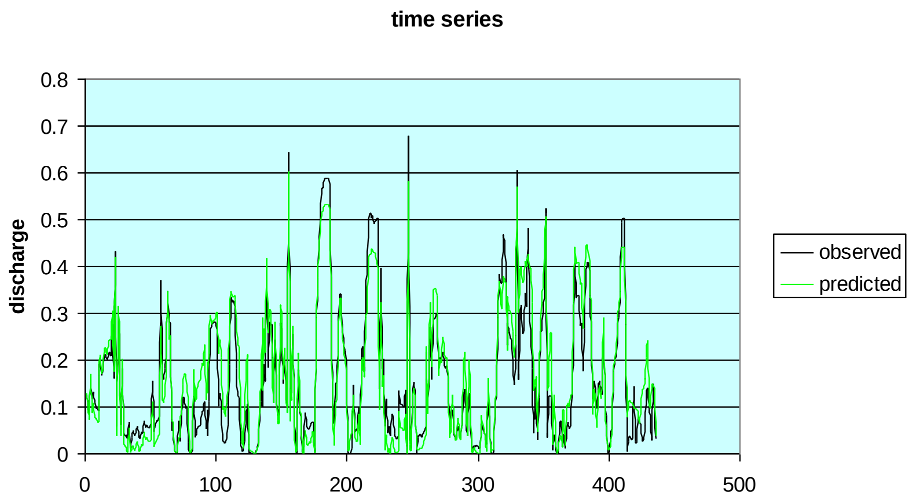

Figure 7. Time series of output number 5- artificial neural network modeling, and observed data- validation process.

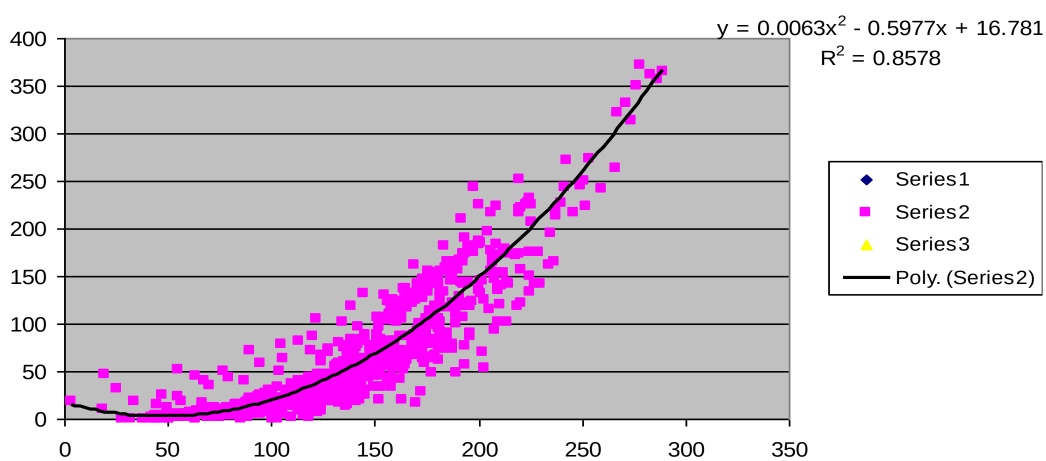

Figure 8. Rating curve - calibration process.

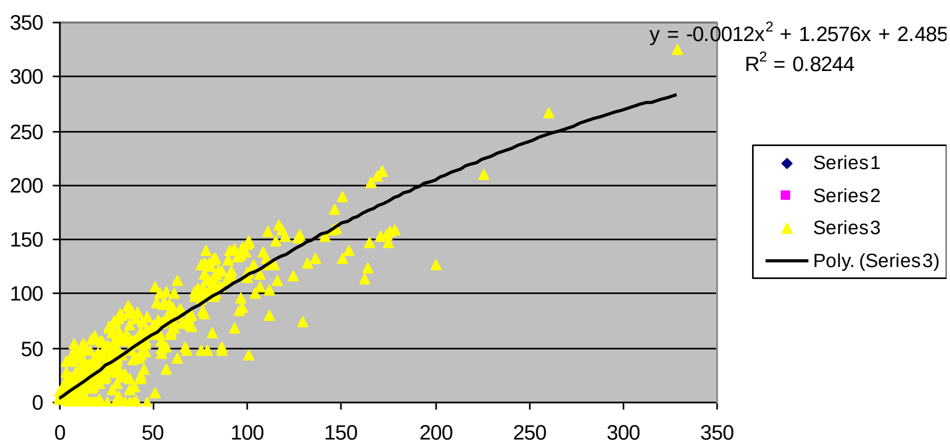

Figure 9. Rating curve - validation process.

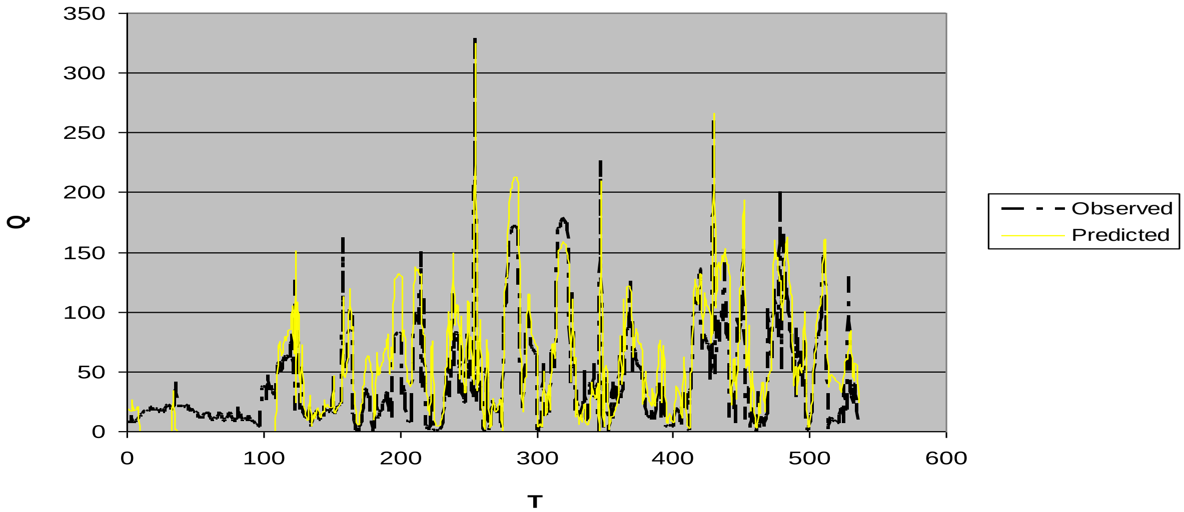

Figure 10. Time series of predicted and observed data.

Table 2. The results of modeling by simple regression.

Model	Calibration correlation coefficient	Validation correlation coefficient
Rating curve	0.85	0.82

Table 3. Comparison between results of modeling.

Modeling	Number of model	Structure	Calibration determination coefficient (R^2)	Validation determination coefficient (R^2)
Artificial neural network (ANN)	3	2-3-1	0.90	0.87
Rating curve	-		0.85	0.82

in this research (simple regression).

Conflict of Interest

The authors have not declared any conflict of interest.

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