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Prediction of Dam Reservoir Volume Fluctuations Using Adaptive Neuro Fuzzy Approach

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Abstract

Determination of reservoir volume fluctuations is important for the operation of dam reservoir, design of hydraulic structures, the hydropower for the energy production, flood damage reduction, navigation in the dam reservoirs, water quality management in reservoir and the safety of dam. In this study, reservoir volume variations were estimated using average monthly precipitation, monthly total volume of evaporation, dam discharge volume, and released irrigation water amount. In the present paper, adaptive-neuro-fuzzy inference system (ANFIS) was applied to estimating of reservoir volume fluctuations. ANFIS results are compared with conventional multi-linear regression (MLR) model. The results show that reservoir volume was successfully estimated using fuzzy logic model with low mean square error and high correlation coefficients.

Key words

Dam, Reservoir Volume, Prediction, Fuzzy Logic, Multi-linear Regression

1. INTRODUCTION

A dam reservoir is an artificial lake, storage pond or impoundment from a dam which is used to store water. Water structures such as dams are very expensive to build, and therefore, they must be well planned and management. Dam reservoir water volume predicting for different time intervals using the records of past time series is an crucial issue in water resources planning and management. Since predicting reservoir volume variations in a dam is affected by many environmental factors such as precipitations, the influence of adjacent catchments, evaporation, air and water temperature variations in catchments and reservoir surface, it is difficult to prediction of reservoir volume. Determining accurate volume of reservoir is important due to the design and operation of the hydraulic structures, the water supply, the irrigation and drainage, the energy production, flood planning and management, navigation in the dam reservoirs, water quality management and modeling in the reservoir.

Recently, the artificial intelligence techniques have been used in hydrology and water resources systems. Adaptive neuro-fuzzy inference system (ANFIS) which is one of them has been widely applied in water resources. ANFIS is a combination of an adaptive neural network and a fuzzy inference system. The parameters of the fuzzy inference system are determined by the NN learning algorithms. Since this system is based on the fuzzy inference system, reflecting amazing knowledge, an important aspect is that the system should be always interpretable in terms of fuzzy IF–THEN rules. ANFIS is capable of approximating any real continuous function on a compact set to any degree of accuracy [1].

ANFIS identifies a set of parameters through a hybrid learning rule combining backpropaga-tion gradient descent error digestion and a least-squared error method. There are two approaches for fuzzy inference systems, namely the approach of Mamdani [2] and the approach of Sugeno [3]. The neuro-fuzzy model used in this study implements Sugeno's fuzzy approach [3] to obtain the values for the output variable from those of input variables.

Keskin et al. [4] used fuzzy models to estimate daily pan evaporation in Western Turkey. Kazeminezhad et al. [5] applied ANFIS to forecast wave parameters in Lake Ontario and found ANFIS superior to the Coastal Engineering Manual methods. Kisi [6] investigated the ability of ANFIS techniques to improve the accuracy of daily evaporation estimation. Kisi and

Ozturk [7] used ANFIS computing techniques for evapotranspiration estimation. Demirci and Baltacı [8] estimated suspended sediment of Sacremento river in USA using fuzzy logic. Unes [9] predicted plunging depth of density flow in dam reservoir using the ANN technique. Unes [10], Unes at al. [11] used ANN model and Unes at al. [12] used generalized neural network (GRNN) model for predicting reservoir level fluctuation. Shiri et al. [13] used ANFIS for predicting short-term operational water levels.

The present study investigates the abilities of ANFIS and multi-linear regression (MLR) techniques to forecast daily reservoir volumes. Here, ANFIS has some daily input variables (basin rainfall, evaporation from reservoir, dam spillway release, and volume of irrigation water) and one output, reservoir volumes at the following day(s).

2. CASE STUDY

Yarseli Dam in Hatay region (Mediterranean part of Turkey) was selected for this study. Yarseli Dam was constructed Beyazçay river in Hatay, Turkey, and dam location can be seen in Figs. 1 and 2. The dam was built for the irrigation and the energy purpose and is located on the border of Hatay (Fig. 1). It is an earth fill dam having 55 million m^3 maximum reservoir volume, and 42 m height from the river bed. The data, which contains the time period between 2002 and 2012 on a daily basis, were obtained from Turkish General Directorate of State Hydraulic Works (DSI) and Turkish General Directorate of State Meteorology (MGM). The data sample consists of 10 years of daily records of basin rainfall (R), volumes of inflow river water (IR), evaporation from Reservoir (E), Dam Spillway Release (SR), volume of Irrigation water (IRGW) and change Reservoir Volume (CVO). These selected parameters are the most effective variables for reservoir volume fluctuation and measured in the field conditions and, therefore, are used in this work.

Based on these data both model development and validations are performed. Therefore, the first 3015 daily data are used for training the model, and the remaining 1004 daily data are used to test the model. Table 1 gives the statistical parameters of the used data set during the study period. In Table 1, x_{max}, x_{min}, and x_{avg} represent the maximum, minimum, and average values of the parameters within the time period, respectively. The values of s_x and c_{sx} are standard deviation and skewness coefficients respectively.

Table 1. Statistical summaries of all data of Yarseli Dam

Data	Statistical Parameters	**R** (mm)	**IR** (10^3m^3)	**E** (10^3m^3)	**SP** (10^3m^3)	**IRGW** (10^3m^3)	**CVO** (10^3m^3)
1	2	3	4	4	5	6	7
Whole Data	x_{max}	177	11883.0	50.00	9777.00	985.00	57104.0
	x_{min}	0.0	-2935.0	0.00	0.00	0.00	4960.0
	x_{avg}	2.11	167.56	9.87	10.87	132.46	26549.
	s_x	7.96	346.00	12.21	163.39	199.15	17690.9
	c_{sx}	7.45	11.85	0.92	53.54	1.23	0.34

R: Average Daily Precipitation; **IR**: Total Daily inflow river water; ;**E**: Total Daily Evaporation **SP**: Total Daily Volume Released from Spillway; **IRGW**: Total Daily Irrigation Volume; **CVO**: Total Daily Reservoir Volume.

Since the range of the variables is large, all the variables were normalized between 0.1 and 0.9 using the Equation 2 before training and testing phases.

$$x_{min} = 0.1 + 0.8\left(\frac{x_i - x_{min}}{x_{max} - x_{min}}\right) \quad (1)$$

Figure 1. The location of Yarseli dam in Turkey.

Figure 2. General view of Yarseli dam

3. APPLICATION AND RESULTS

MLR Results

Conventional multiple linear regression (MLR) technique were also used to define reservoir volume. These techniques assume a linear relationship among variables. Although a nonlinear approach is needed for the solution of reservoir volume problem, a multi_linear regression model was compared with field measurement and ANFIS model results. The MLR predicted and observed volumes are given for testing periods in Fig.3. A statistical analysis is performed between the estimated and the recorded test data to find out how well the ANFIS models perform. Performance evaluation measures, the mean square error (MSE) and the coefficient of correlation (R) between estimated and observed volume values of this statistical analysis are given Table 2. It can be seen from Fig.3 and Table.2 that MLR performance for testing and training stages is not quite satisfactory although the performance criteria have moderate values. The model estimates were quite scattered. The correlation coefficient between the predicted and the observed testing data is 0.74. The general shape of the recorded reservoir volume is not captured by MLR.

Table.2 Performance of different methods in terms of MSE, MAE and R

Method	**MLR**	**ANFIS**
MSE (Test)	0.043	0.032
MAE (Test)	0.170	0.130
R (Test)	**0.74**	**0.83**

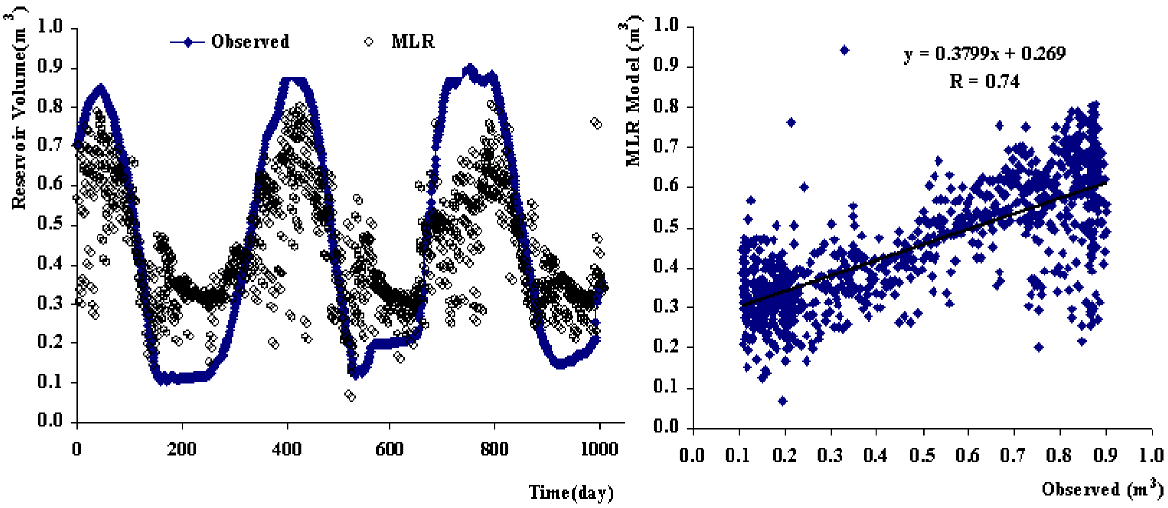

Figure 3.Observed and MLR model predicted reservoir volumes for Yarseli Dam in the test period

ANFIS Results

The back-propagation ANFIS network was applied in MATLAB code for forecasting reservoir volumes using the recorded aforementioned daily reservoir data. The testing statistics of ANFIS models in term of R, MAE and MSE are presented in Table 2. The results show that low MSE, MAE and high correlation coefficients (0.032 and 0.130 respectively) can be obtained using ANFIS. Fig. 4 shows model performance of the ANFIS. As it is seen Fig.4, ANFIS model performs better than the other MLR model in terms of the R in the test period. ANFIS model has also less scattered predictions than the other models and provided the highest R coefficient (0.83) for the input combination.

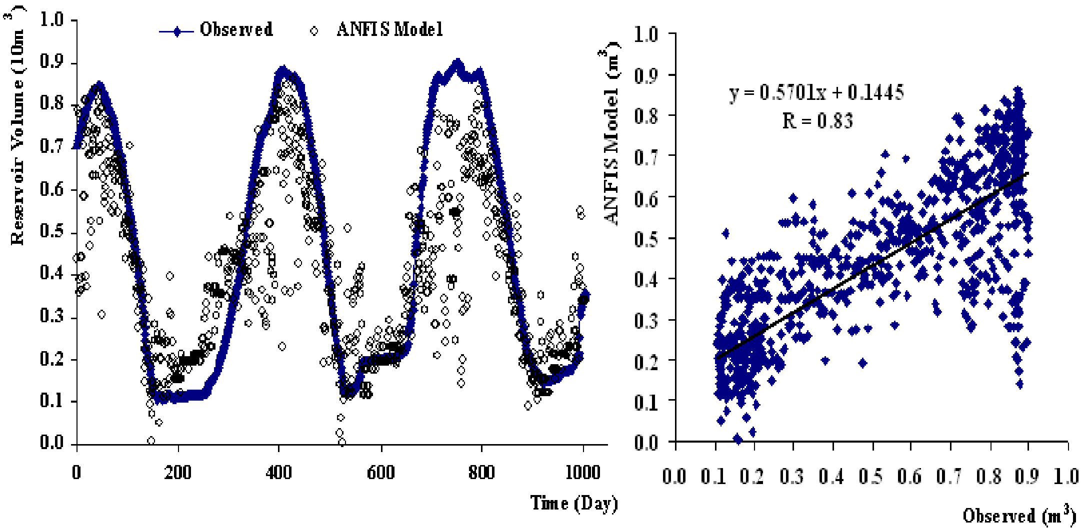

Figure 4.Observed and ANFIS model predicted reservoir volumes for Yarseli Dam in the test period

4. CONCLUSIONS

In this study, Yarseli dam reservoir volumes are predicted based on several parameters: the rainfall, the inflow river volume the spillways discharge, the irrigation, and the evaporation. The monthly reservoir volume estimations can be quite informative for the determination of the periodic water supply strategies, the hydroelectric energy computations and the flood management studies. ANFIS and MLR model used to estimate the dam reservoir volume. As a result of the study in this paper it is possible to derive the following conclusions.

- The presented ANFIS provides better estimates of the dam reservoir volume fluctuations than the conventional MLR model.

- MLR model describes empirical relations, but could not reach the desired accuracy in the same problem due to nonlinearity in the density flow behavior.

- Once an ANFIS model is developed for a specific region, the model can be quite helpful in the water resources management studies. The daily reservoir volume fluctuation prediction can be quite informative for the determination of the periodic water supply strategies, the hydroelectric energy computations and water resources management.

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