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Sensitivity analysis of the discharge coefficient of a modified triangular side weir by adaptive neuro-fuzzy methodology

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ABSTRACT

The discharge coefficient of a modified triangular side weir is analyzed regarding various non-dimensional input sets. It is desirable to select and analyze factors or parameters that are truly relevant or the most influential to triangular side weir discharge coefficient estimation and prediction. The Adaptive Neuro-Fuzzy Inference System (ANFIS) is applied for the selection of the most prominent triangular side weir discharge coefficient parameters based on ten input parameters. The input variables were searched using the ANFIS network to specify the input parameters' effects on the discharge coefficients. According to the obtained results, the side weir included angle has the most effect on modeling the discharge coefficient. Then by using the selected input variables, the discharge coefficient was modeled with ANFIS, artificial neural network, support vector machine and multi non linear regression methods. The results show that ANFIS could predict the discharge coefficient significantly better than the other investigated models.

1. Introduction

Side weirs are used in various hydraulic structures, such as flood control structures, irrigation and drainage systems, and combined sewer systems in order to divert the main channel flow to a tributary channel. The first study in which a mathematical discharge coefficient model was used was done by De Marchi [1] who presented the following equation:

$$-\frac{dQ}{dx} = \frac{2}{3} Cd\sqrt{2g}(y-w)^{3/2} \qquad (1)$$

where Cd is side weir discharge coefficient, dQ/dx is the upstream main channel discharge to the distance from the beginning of the weir, y is depth of flow, w is weir height and g is gravity acceleration. Eq. (1) was obtained with the assumption that upstream and downstream side weir specific energy is identical. Traditional side weirs have a rectangular shape and are placed in a straight channel. In these side weirs, the efficient parameters are the Froude number in the beginning section of the side weir (Fr_1), w, upstream flow depth (Y_1), weir length (L), and main channel width (b) [2]. In various studies, Fr_1 is considered the most important parameter and it is assumed that Cd is only related to Fr_1 [3–6].

In case of overflow, when the side weir can not divert the required flow from the main channel to the tributary channel, there is no choice but to increase the weir length.

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Increasing the weir length leads to increased tributary channel width. Due to geometric and economic limitations, it is not always possible to increase the tributary channel width and side weir length. Thus, an alternative is to increase the weir length without increasing the tributary channel width using shape modified side weirs. So, triangular, labyrinth and elliptical weirs can be used [7–12]. Such geometrical modifications can increase side weir discharge capacity by 1.5–4.5 times more than traditional rectangular ones [13,14].

In labyrinth and triangular side weirs, a wide range of non-dimensional parameters can be selected as input parameters for soft computing models. As seen from Eqs. (2)–(5), there is no agreement among researchers regarding non-dimensional input parameter combination selection.

$$Cd = f(\cos\theta, \sin\theta, Fr_1) \quad \text{Ura et al. [15]} \tag{2}$$

$$Cd = f(\sin\theta, L/b, L/l, w/Y_1, Fr_1) \quad \text{Emiroglu et al. [7,11]} \tag{3}$$

$$Cd = f(Fr_1/\sin(\theta), w/Y_1, w\sin(\theta)/Y_1, Fr_1) \quad \text{Borghei and Parvaneh [14]} \tag{4}$$

$$Cd = f(Fr_1/\sin(\theta), w/L, w/Y_1, w\sin(\theta)/Y_1) \quad \text{Zaji and Bonakdari[16]} \tag{5}$$

In the above equations, l is the weir crest length and θ is the weir included angle.

The high capacity of soft computing methods to model complex problems has led to using them for various engineering problems. There are many different soft computing methods, among which the Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Support Vector Machine (SVM) that are widely used in flow characteristic prediction [12,17–21].

To better analyze side weir discharge coefficients it is appropriate to select a subset of most side weir discharge coefficient effective parameters through the variable selection procedure using neural networks [22–24]. A neural network is an architecture comprising massively parallel adaptive processing elements interconnected via structured networks. Thus, the neural network models generated from this data rely on how effectively the selected sensor data represents the system. Then, to run a soft computing model for a particular problem, it is advisable to select the input variables from all variables that could be considered inputs by using an input variable selection model.

The main objectives of this study are: (1) To determine how the ten non-dimensional parameters affect the modified triangular side weir discharge coefficients using ANFIS. (2) To identify which parameters are significant for the modified triangular side weir discharge coefficients. The basic idea in neuro-adaptive learning is to form a method for the fuzzy modeling procedure to collect data and gain information about it [25,26]. One of the methods of organizing the fuzzy inference system with given input and output data pairs is ANFIS [27]. This method enables fuzzy logic to adapt the membership function parameters that best allow the associated fuzzy inference system to track the given input and output data. (3) After finding the appropriated input variables in the second step, the ANFIS, ANN, SVM and Multi Non Linear Regression (MNLR) methods are developed for modeling the side weir discharge coefficient and the models' performance is compared. (4) The most appropriate model considered is compared with previous studies.

2. Materials and methods

2.1. Experimental study

To verify the ANFIS model, Borghei and Parvaneh [14] results were used. A schematic overview of the considered modified triangular side weir is shown in Fig. 1.

The main channel was horizontal rectangular, 11 m long and 0.4 m wide. The variation range for L, w, θ, Fr_1, upstream discharge (Q_1) and Y_1 is shown in Table 1. From this table, it can be seen that all runs were done in a subcritical condition with $Fr_1 < 1$. The experimental study shows that the maximum Cd in the considered situations was obtained with L and $\theta/2$ of 0.4 m and 30, respectively. The minimum Cd was obtained with L and $\theta/2$ of 30 and 70. It is obvious that decreasing the weir included angle leads to significant increase in the Cd. In addition, the laboratory study indicates that the Cd and Fr_1 had an inverse relation. The relation between the non-dimensional combinations of θ and Fr_1 with Cd is discussed in more detail in the results section.

A total of 200 experiments were done for various geometric and hydraulic conditions (Table 1) to calculate Cd. Water head and discharge measurement accuracy were ±1 mm and ±0.0001 m^3/s, respectively.

2.2. ANFIS method

The MATLAB fuzzy logic toolbox was used for the processes of training and evaluating the fuzzy inference system. ANFIS, introduced by Jang [28], is widely applied in various engineering problems up to now [29–32]. ANFIS is a combination of a fuzzy inference system and Artificial Neural Network (ANN). ANN is used to determine the fuzzy inference system parameters. One of the typical fuzzy inference system types is Sugeno [33]. In this study, the Sugeno fuzzy inference approach is used to evaluate the most effective input parameters in discharge coefficient prediction problems.

2.3. ANN method

Multi-Layer Perceptron (MLP) artificial neural network is one of the common soft computing methods that are used successfully for various problems [34]. An ANN model comprises three main layers: an input layer, a hidden layer and an output layer. Layers are constructed using neurons. The input layer receives information about the samples and transfers it to the model. The hidden layer nonlinearly transforms the information received from the input layer. Finally, the output layer collects the last hidden layer's