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Assessment of some famous empirical equation and artificial intelligent model (MLP, ANFIS) to predicting the side weir discharge coefficient

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ABSTRACT

Allocation and removing of excess water from the irrigation and drainage network is one of the most important activities in the management of these networks. Side weir is one of the most common structures for this purpose. Study on the flow Hydraulic characteristics of this structure included two parts, defining the water surface profiles and estimating the discharge coefficient. To estimate the discharge coefficient, many ways as experimental formulas and artificial intelligent models are propose. The empirical formula for simplifying in developing process that assume by the authors, contained significant error so using the AI models are inevitable. In this paper, some of the famous empirical formula and AI models such as Multilayer neural network (MLP) and Adaptive Neuro fuzzy inference system (ANFIS) are assessing with a laboratory experiment. Among the experimental formula, Borghei formula is most accurate (R^2=0.83) and the performance of the AI model in Training and testing stage is more suitable (R^2=0.96).

1. Introduction

Today, due to the shortage of water resources for agriculture, the modern agriculture has increased interest. One of the most important problems in the modern agriculture is the managing the water. One of the most powerful tools to do this more better is modeling of water structure that used common in the irrigation and drainage network (Misra. 200).

Modeling and Predicting the hydraulic phenomenon is an important part of hydraulic engineering activities that leads to do more better managing of the Hydraulic structures.

Estimating the flow rate through the Hydraulic structure is one of the most important issues in Hydraulic engineering (Hager. 1987)

Side weir is an overflow and set into the side of the channel. This structure has been used to Allocation and removing excess flow therefore it used in the most water engineering project such as irrigation network, land drainage, urban sewage systems and sometimes used as an overflow dam (Ghodsian. 2004).

When the water level reaches above the side weir crest its divert a certain amount of discharge (May et al. 2003). like all typical weir, side weir can be sharp, broad crested with various geometric and also the flow in the main channel can be sub-critical and supercritical (Subramanya et al. 1972).

Many studies were due on defining the hydraulic behavior of this type of weir, which are often experimental method (Borghei et al. 2011; Emiroglu et al. 2011; Kumar et al. 2012). The flow over a side weir is a typical case of spatially varied flow (SVF) with decreasing discharge (AL-TAEE. 2012). De Marchi with assuming constant energy, obtained equation of the (SVF)and to calculate the outflow discharge form the side, he solved analytically the (SVF) Finally, he proposed an equation for side weir discharge coefficient(CDSW) that today is known as the De Marchi coefficient (Hadadi et al. 2012).

More recently, Laboratory Studies conducted on the various types of this structure to improve the performance of them (Emiroglu et al 2011; Emiroglu et al 2012; Kaya. 2010).

An experimental and Theoretical investigations has done on the flow over labyrinth, Oblique, semi-elliptical, Curved Plan-form and trapezoidal sharp and broad-crested side weir in rectangular channels in the under subcritical and supercritical flow conditions. the results shows that CDSW is related to the Froude number at the upstream of the weir, ratios of weir height to depth of flow, weir length to width of main channel and length of broad-crested weir to width of main channel. The end of all this researches show the effect of each geometric shape of the Side weir on the rising the performances of this structure and for each specific geometric shape of the Side weir experimental formulas are proposed (Emiroglu et al. 2011; Kumar et al. 2012; Cosar et al. 2004, Honar et al. 2007; Kumar et al. 2013; Kumar et al. 2013).The simple Rectangular side weir used very much in water engineering projects because facility in the construction and operation (AL-TAEE. 2012; Rahimi. 2012).

The governing equation on side weir hydraulic characteristics is spatially varied flow (SVF). Computer simulating of flow over side weir included two parts. One- calculating the water surface profile therefore, to this purpose SVF equation must be solved with a suitable numerical and two- estimating the CDSW with empirical formula or Artificial intelligent techniques (Rahimi. 2012) .

In the field of studying the flow characteristics of side weir, predicting the CDSW is more important so, more research conducted on determining this factor in Table (1),some of the empirical equation that proposed for the Sharp crested rectangular side weir was collected (Borghei et al. 2011; Hadadi et al. 2012; Bilhan et al. 2011; Kaya et al. 2011; Parsaie et al. 2013).

To predicting the CDSW, the investigations based on the artificial intelligence techniques have been done also. In Artificial Intelligence Studying a network is develop Instead of a relationships that results from the linear or nonlinear regression. The ANN (Artificial Neural Network), ANFIS (Adaptive Neuro Fuzzy Inference System) and SVM (Support Vector Machine) models in the field of artificial intelligence techniques was used to calculate the CDSW. Based on the reported,

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accuracy of all these methods is much more than empirical equation (Bilhan et al. 2011; Parsaie et al. 2013).

The conclusion that can be drive from a review on literature is that study on hydraulic characteristic of side weir started with Laboratory investigation and to computer simulating of flow over side weir, addition to solve the SVF for determining the water surface profile, the CDSW must predict by a suitable method. The goal of this research is assessing the empirical formula and performance of AI model to calculating and predicting the CDSW in a real laboratory investigation.

Table 1. Some famous empirical formulas to calculation of CDSW

row	Author	Equation
1	Nandesamoorthy et al.	$C_d = 0.432\left(\frac{2-Fr_1^2}{1+2Fr_1^2}\right)^{0.5}$
2	Subramanya et al	$C_d = 0.864\left(\frac{1-Fr_1^2}{2+Fr_1^2}\right)^{0.5}$
3	Yu-Tech	$C_d = 0.623 - 0.222Fr_1$
4	Ranga Raju et al	$C_d = 0.81 - 0.6Fr_1$
5	Hager	$C_d = 0.485\left(\frac{2-Fr_1^2}{2+3Fr_1^2}\right)^{0.5}$
6	Cheong	$C_d = 0.45 - 0.221Fr_1$
7	Singh et al	$C_d = 0.33 - 0.18Fr_1 + 0.49\left(\frac{P}{h_1}\right)$
8	Jalili et al	$C_d = 0.71 - 0.41Fr_1 + 0.22\left(\frac{P}{h_1}\right)$
9	Borghei	$C_d = 0.7 - 0.48Fr_1 + 0.3\left(\frac{P}{h_1}\right) + 0.06\left(\frac{L}{h_1}\right)$

2. Methodology

First dimensionless factors influence in the CD_{SW} was extracted with using dimensional analysis technique then to assessing the empirical equation, some data range published in Articles was collect in table 2. The number of these data is about 140. In the Following the MLP and ANFIS models were developed. Training and testing process of these models has done with the same data. All the process of the assessing and preparing the empirical formula and AI model was programing in Matlab software.

Table 2. Range of data collected

	F1	p/h1	L/b	L/h1	Cd
min	0.09	0.34	0.30	0.35	0.28
max	0.83	0.91	3.00	10.71	1.75
mean	0.41	0.77	1.60	3.99	0.57
stdv	0.20	0.14	1.11	3.10	0.26

2.1. Dimensional analysis

Referring to Fig. 1 the CD_{SW} can be written as a function of width of channel (b), flow depth in the main channel(h1), mean velocity of flow at upstream end of side weir (V1),length of side weir (L), acceleration due to gravity (g), slope of mainchannel bed (So), deviation angle of flow (ψ),

$$C_d = f\left(v_1, L, b, h_1, P, \psi, s_0\right) \tag{1}$$

Using the Buckingham π theorem, nondimensional equations infunctional forms can be obtained as below:

$$C_d = f_1\left(Fr_1 = \frac{v_1}{\sqrt{gh_1}}, \frac{L}{b}, \frac{L}{h_1}, \frac{P}{h_1}, \psi, s_0\right)$$

$$\sin(\psi) = \sqrt{1-\left(\frac{V_1}{V_s}\right)^2} \tag{2}$$

Where Fr is Froude number. El-Khashab also mentioned that the dimensionless length of the side weir (L/b) includes the effect of the deviation angle on the discharge coefficient. Therefore, the deviation angle ψ is not existed in the CD_{SW} equations in the literature. Thus, the CD_{SW} depends on the following dimensionless parameters (Emiroglu et al. 2011, Kaya et al. 2011).

$$C_d = f_2\left(Fr_1, \frac{L}{b}, \frac{L}{h_1}, \frac{P}{h_1}\right) \tag{3}$$

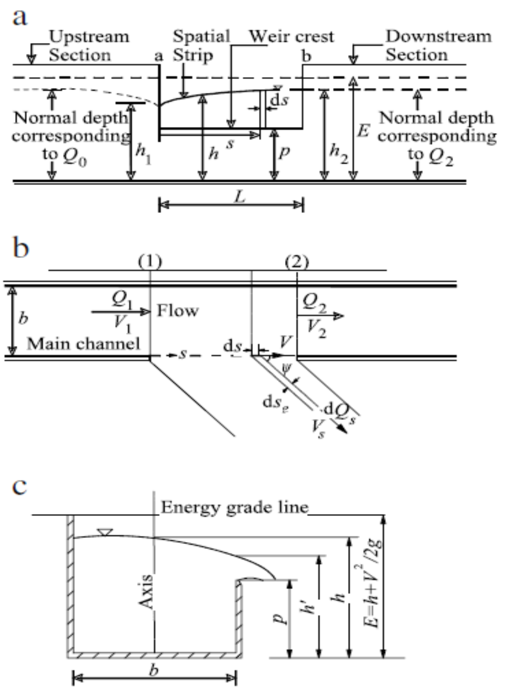

Fig. 1. Definition sketch of subcritical flow over a rectangular side weir

2.2. Artificial neural network (ANN)

The ANN is a nonlinear mathematical model that is able to simulate arbitrarily complex nonlinear processes that relate the inputs and outputs of any system. In many complex mathematical problems that leads to solve complex nonlinear equations, A Multilayer Perceptron network with definition of Appropriate functions, weights and bias can used. Due to the nature of the problem, different Activity functions in neurons can be used. An ANN has one or more hidden layers. Fig. 2 demonstrates a three-layer neural network consisting of inputs layer, hidden layer (layers) and outputs layer. As shown in the fig.2 the w_i is the weights and b_i is the bias for each neuron. Initial assigned weight values will progressively corrected during a training process that compares predicted outputs to known outputs. Such networks are often trained using back propagation algorithm. In the current study, the ANN was trained using Levenberg–Marquardt technique because this technique is more powerful and faster than the conventional gradient descent technique (Aleksander et al. 1995).

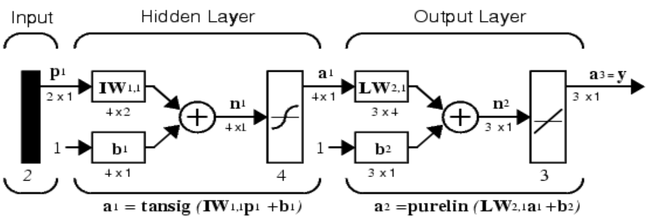

Fig. 2. A three-layer ANN architecture.

2.3. Adaptive neuro fuzzy inference system (ANFIS)

Adaptive Neuro fuzzy Inference Systems (ANFIS) is a powerful tool to modeling of complex system based on input and output data. ANFIS are realized by an appropriate combination of neural and fuzzy systems. This combination enables to use both the numeric power of intelligent systems.

In fuzzy systems, different fuzzification and defuzzificationn strategies with different rule was considering for inputs parameter. For doing the effect of fuzzy logic on the inputs data, selecting of

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membership function can be selected. In this stage maybe considered a Gaussian function for each of inputs variables. Figure (3.a) shows a fuzzy reasoning process. For simplicity illustrating, a fuzzy system with two inputs variable and one output was choiced . Suppose that the rule base containing two fuzzy if-then rules.

$$Rule1: if\ \ x\ is\ A_1\ and\ \ y\ is\ B_1\ then\ f_1 = p_1x + q_1y + r_1$$

$$Rule2: if\ \ x\ is\ A_2\ and\ \ y\ is\ B_2\ then\ f_2 = p_2x + q_2y + r_2$$

Where A_1 ; A_2 and B_1 ; B_2 are the MFs for inputs x and y; respectively; p_1; q_1; r_1 and p_2; q_2; r_2 are the parameters of the output function.ANFIS architecture is presented in Fig. 3(b), in the first layer, all the inputs variable gave the grade membership with membership function. and in layer 2, all the membership grade will be multiplies together and in the layer 3, all the grade of member will be normalized and in the layer 4 contribution of all the rule will be compute. In addition, in the last layer output variable will be compute as weighted average of grade membership.

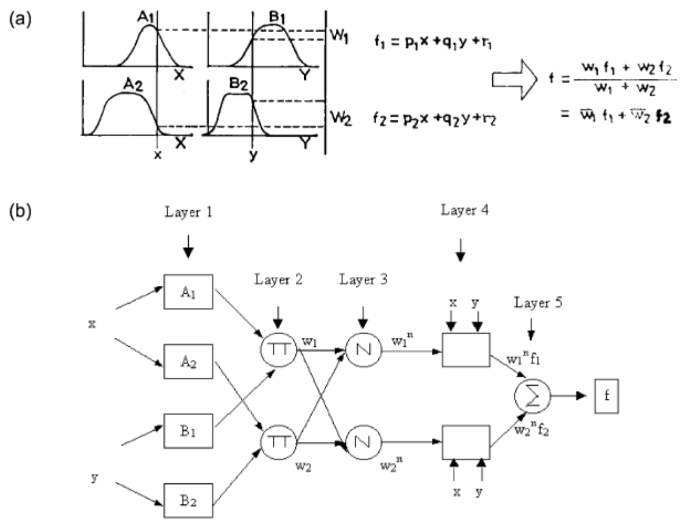

Fig. 3. (a) Fuzzy inference system. (b) Equivalent ANFIS architecture.

3. Result and discussion

Firstly, evaluating the empirical formulas was does with the collected data set. The error indices (eq.11) were calculated and result of them and given in the tables (3). As given in the table (3), the Borghei equation is most accurate among the empirical equation. To much more accuracy of the predicting the CD_{sw}, the AI models (MLP and ANFIS) was developed. Developing the AI models (MLP and ANFIS)does with the same data collected. The performance of the AI models in each stage of preparing such as training, validation and testing was calculated and shows in the Figure (6 to 10).for developing the MLP model, 70% of data was used to training, 15 % used for validation and 15%used for testing of models. For developing the ANFIS model, the 80% of data was used for training 25%used for testing of models. The three-layer has been considered for MLP model structure. The first layer consider as inputs and second as hidden layer and third as outputs. In the hidden layer as shows in the Fig 4, five neurons with tansig transfer function was considered. The levenberge _Marquat technique was used to training this model. In the ANFIS model as shows in the figure (5),the four-membership function is consider for each inputs parameters. A hybrid technique is implementing to training the ANFIS model. To assessing the accuracy of the empirical formulas and AI models in the real engineering problem. These models was used to calculate the CD_{sw} in the experiment laboratory study that did with the Emiroglu et al (2011). The experiment did in a flume with 12m in long, 0.5 m in width, 0.7 m deep and longitudinal slope was equal to 0.001. The result of the Borgei equation and AI model was calculates for two runs of the experiments and give in the table (4).The result of this study showing that using the suitable AI model is much more accuracy in the prediction of the CD_{SW}. This increasing in accuracy in prediction, caused to better operation of this structure.

$$RSME = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_dObs - C_dest)}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}abs(C_dObs - C_dest)$$

$$APE = \frac{1}{N}\sum_{i=1}^{N}abs\left(\frac{C_dObs - C_dest}{C_dObs}\right) \qquad (11)$$

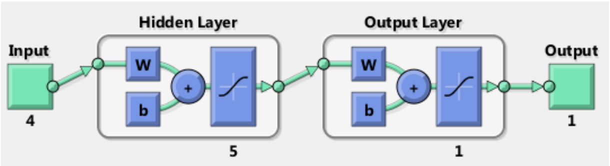

Fig. 4. The structure of the MLP model has been developed

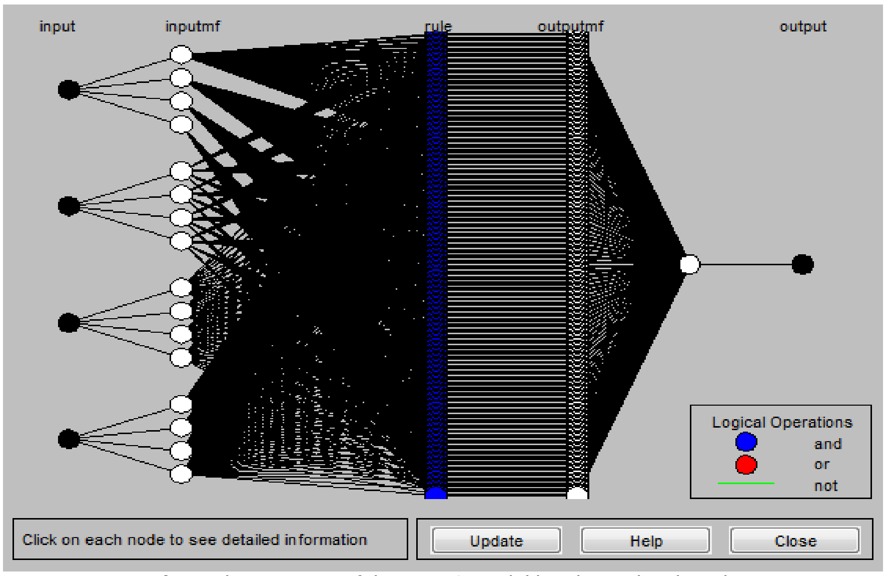

Fig. 5. The structure of the ANFIS model has been developed.

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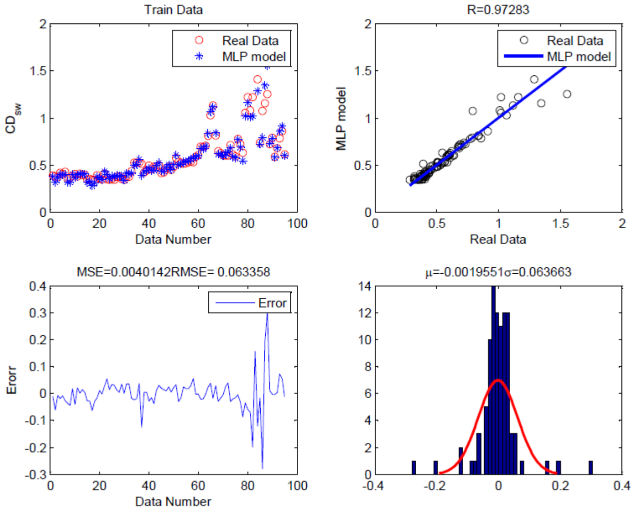


Fig. 6. Performance of MLP models during the training stage.

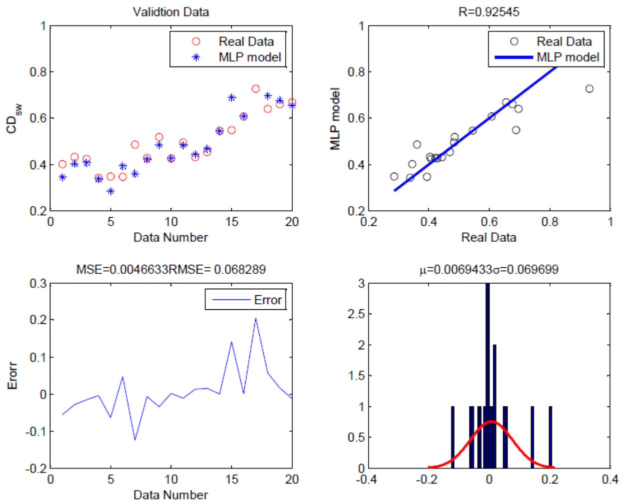


Fig. 7. Performance of MLP models during the Validation Stage

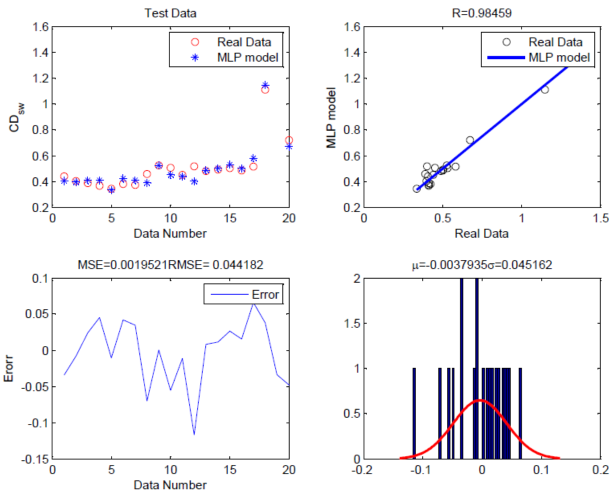


Fig. 8. Performance of MLP models during the test stage.

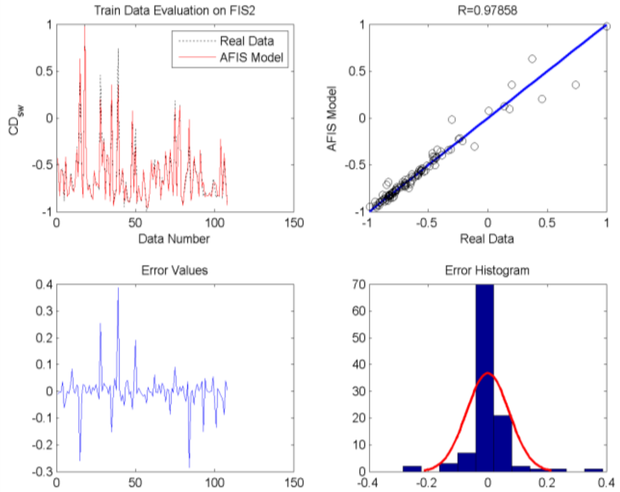


Fig. 9. Performance of ANFIS models during the training stage.

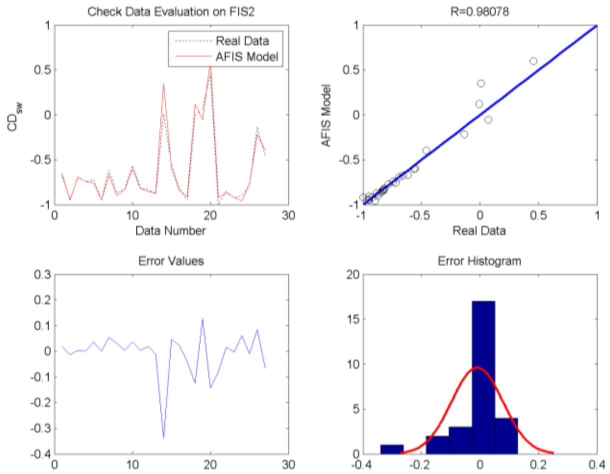
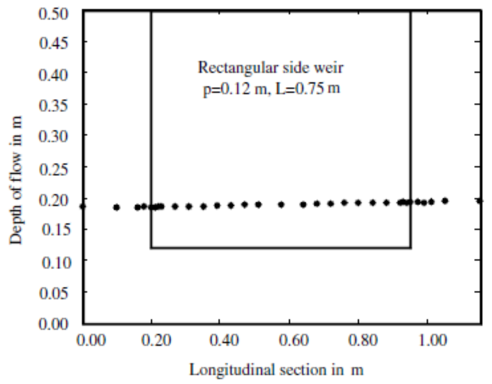


Fig.10. Performance of MLP models during the test stage.

Table 3. The RMSE, MAE, AP and R^2 statistics of the empirical equations

Equation	R^2	RSME	MAE	APE
Nandesamoorthy	0.29	0.315	0.205	32.53
Subramanya	0.34	0.315	0.207	33.88
Yu-Tech	0.277	0.285	0.192	32.23
Ranga Raju	0.277	0.336	0.237	41.72
Hager	0.17	0.312	0.19	25.53
Cheong	0.34	0.325	0.194	25.89
Singh	0	0.273	0.209	40.86
Jalili	0.337	0.372	0.235	32.41
Borghei	0.834	0.288	0.247	51.79



F_1=0.28, Surface profile along the centerline

Fig. 11. Run (1) of the Laboratory experiment of flow over side weir.

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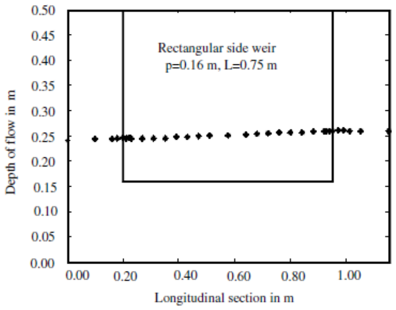

F_1=0.39, Surface profile along the centerline

Fig. 12. Run (2) of the Laboratory experiment of flow over side weir.

Table 4. The parameter that used in computer modeling.

Run Parameter	Fr	P	L	CD_{SW} (ANN)	CD_{SW} (ANFIS)	C_d (borghei)	Measurement
Run -1	0.28	0.12	0.75	0.52	0.54	0.97	0.58
Run -2	0.39	0.16	0.75	0.47	0.46	0.88	0.44

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