Enhancement of forecasting discharge coefficient of the elliptical side orifice by adaptive Neuro-Fuzzy inference system and nonlinear regression

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Abstract :
The characteristics of flow through orifice are taken into account to determine the discharge coefficient for subcritical flow condition under the assumption of constant – specific energy . the discharge in man channel, opening size of side orifice, and sill height of the orifice are treated as the controlled variables. in this study, the discharge coefficient of elliptical side orifice is predictive by using Adaptive - Neuro Fuzzy Inference System (ANFIS) and Nonlinear Regression (NLR). 588 laboratory test results are used for determine coefficient of discharge of elliptical side orifice. Take the affect parameters wereratio of the orifice crest height to the vertical semi- axes (W:b), ratio of the main channel to the horizontal semi-axes(B:a), ratio of the main channel to the vertical semi- axes(B:b), ratio of the vertical semi- axes to the upstream flow depth in the main channel(b:y1) and, the Froude number Fr at main channel. Finally, the compassion between the result of laboratory and (ANFIS, NLR) found the accuracy of ANFIS result for case 1and case 7 were greater than the other cases R^2 = 0.909 -0.88 and error percent = 83%-93% of results are small than 2%, another hand the R^2 =0.814-0.816 for case 1and 7 is greater than other cases for NLR the error percent = 63%-93% are small than 2%.Therefore, the analyzing results of ANFIS method could be successfully employed in modeling coefficient of discharge.

Keywords : Coefficient of discharge , Elliptical side orifice, AdaptivNeuro-Fuzzy- Inference system (ANFIS) , Nonlinear Regression (NLR)

1. Introduction

Side orifice have been extensively used in environmental and hydraulic engineering applications. They are usually installed on the side wall of a main channel to distribution the flow in irrigation systems and treatment units. Measurement of the flow rate of water in an important procedure in the organization of technological processes of extraction, storage ,transportation and distribution of water resource.So that has the researchers studied the hydraulic properties for different shapes of the side orifice in several sections from the open channels. Ramamurthy et al.[1986]. were the first to study the characteristics of flow in a rectangular side orifice. They derived an equation for the discharge coefficient of the side orifice using a theory of two-dimensional flow. This equation calculates the discharge coefficient as a function of the length of the orifice, width of the main channel, and the ratio of the average velocity in the main channel to the orifice jet velocity. Gill (1987) studied the square side orifice as a special case of spatially varied flow in the open channels and neglecting the frictional head loss. Hussain et al. (2010) using rectangular main channels at laboratorywith circular side orifices. They presentedan equation of discharge coefficient for circular side orifices as a function of the Froude number and the ratio of the orifice diameter to the width of main channel. Their discharge equation predicts the values of the side orifice discharge with an accuracy of _5%.Hussain et al. (2011) also conducted an experimental investigation of the characteristics of the flow in the main channels with rectangular side orifices anddiscussed the effect of variables for orifice flow discharge. Vatankhah and Bijankhan (2013) applied the energy equation to obtain a theoretical discharge equation which is useful for both small and large circular orifices. Hussain et al. (2014) studied the passing discharge through rectangular lateral orifice using analytical relations and compared it with the experimental data. Hussain et al. (2016) also conducted study the flow through a side circular orifice under free and submerged flow conditions.Vatankhah (2016) also presented a unified discharge relation for both circular weirs and orifices. Eghbalzadeh et al. (2016) studied the discharge coefficient for both square and circular sharp-crested lateral orifices by used artificial neural network models (ANN).Khoshbinet al. (2016) modeled the conduit capacity of rectangular side weirsin subcritical flow conditions by combining the adaptive neurofuzzyinference system (ANFIS), a genetic algorithm (GA), andsingular value decomposition methods.Vatankhah and Rafeifar (2020) conducted an analytical and experimental study of flow through elliptical sharp-crested lateral orifices. they study the effect of variable on discharge coefficient.

In this study predicts the discharge coefficient of elliptical side orifice using the Nonlinear Regression method by SPSS program to analysis this method . and Adaptive - Neuro Fuzzy Inference System models MATLAB program to this analysis , according to the values from laboratory test . the dimension lessvariables used in the current study are, ratio of the orifice crest height to the vertical semi- axes (W:b), ratio of the main channel to the horizontal semi-axes(B:a), ratio of the main channel to the vertical semi- axes(B:b), ratio of the vertical semi- axes to the upstream flow depth in the main channel(b:y1) and, the Froude number Fr at main channel. Then, the result of ANFIS method and NLR are compared with experimental result. finally, the best method for providing the discharge coefficient of elliptical side orifices is introduced.

list of symbols

Cd = discharge coefficient	$y_{1,2}$ = upstream and downstream flow depth
W= orifice crest height	Fr1 = Froude number at main channel
B= main channel width	Qu = discharge in main channel
b = vertical semi- axes	Qs = discharge passing through the side orifice,

Materials and method

1.1 Experimental model

The experimental measurements conducted by Vatankhah (2020) are used to verify numerical model results . their experimental model consisted of an open rectangular channel 12m long, 25cm wide and 50 cm deep was used for laboratory tests. To adjust the flow depth in mentioned channel, a slide gate installed at the end of the system was used .elliptical side orifices were placed on the main channel side walls . the experimental value ranges measured by Vatankhah (2020) are given in Table 1. in this table, Q_u, Q_s, a, b, W,yc,F1,$y_1$andy_2 are the total discharge upstream of the orifice Qu, the discharge passing through the side orifice, orifice length a, orifice heights b, crest height W, flow depth at center of orifice length yc, upstream Froude number and flow depth upstream and downstream of the orifice (y1 &y2). Fig.1 show the laboratory model used by Vatankhah (2020).

Table 1. Laboratory values Range measured by Vatankhah (2020)

Parameters	Range
$Q_u(l/s)$	13.8-39.61
$Q_s(l/s)$	3.66-21.41
a cm	15-20
b cm	2-4
W	5-10
F1	0.22-0.77
y_1	10.86- 25.56
y_2	11.33-28

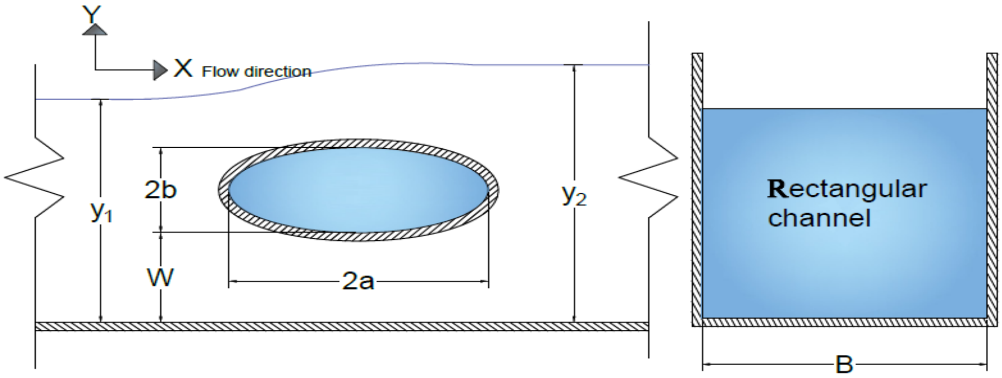


Figure 1 . Schematic of elliptical side orifice model

1.2 Discharge coefficient of elliptical side orifices

Vatankhah (2020) studied the relationship between the discharge coefficient C_d and other effective variables . variables that are possible are: the horizontal semi –axes, a, the vertical semi –axes,b, the orifice crest height w, the upstream velocity in the main in the main channel V_1, the upstream flow depth in the main channel y_1, the main channel width B, water density ρ, water viscosity μ, water surface tension σ, and gravitational acceleration .

$$C_d = K_1(a, b, W, B, y_1, V_1, g, \sigma, \mu, \rho) \quad \dots\dots\dots\dots. 1$$

And by using dimensional analysis for variables affect Cd , the Eq. (1) Neglecting the effects of the Reynolds$R_e = \frac{\rho V_1 a}{\mu}$ and weber number$W_e = \frac{\sigma}{\rho g a^2}$can be written in the form

$$C_d = z\left(\frac{W}{b}, \frac{B}{a}, \frac{B}{b}, \frac{y_1}{b}, F_1 = \frac{V_1}{\sqrt{g y_1}}\right)$$

They provided nonlinear regression NLR form was considered for the discharge coefficient Cd of the elliptical lateral orifice .

$$C_d = m_0 + m_1 \left(\frac{W}{b}\right)^{m_2} \left(\frac{B}{a}\right)^{m_3} \left(\frac{B}{b}\right)^{m_4} \left(\frac{b}{y_1}\right)^{m_5} F_1^{m_6} \quad \dots\dots\dots\dots..2$$

Where $m_{1 to\ 6}$ are empirical coefficients are estimation by using statistical program (SPSS).

In this paper is studying the effect of dimensionless parameters of Eq.2 on the discharge coefficient of elliptical lateral orifices. in orderto determine the accuracy of the lateral orifice discharge coefficient modeling results using numerical models, (MAPE) is the mean absolute percentage error, (RMSE) is the root-mean-square-error, (SI) is the scatter index, BIAS, and (R) is the correlation coefficient. statistical indices are used

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{\left|(C_d)_{P_i} - (C_d)_{O_i}\right|}{(C_d)_{O_i}}\right] \times 100 \quad \dots\dots 3$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[(C_d)_{P_i} - (C_d)_{O_i}\right]^2} \quad \dots\dots\dots 4$$

$$SI = \frac{RMSE}{\overline{(C_d)_O}} \quad \dots\dots\dots 5$$

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}\left[(C_d)_{P_i} - (C_d)_{O_i}\right] \quad \dots\dots\dots\dots 6$$

$$R = \frac{\sum_{i=1}^{n}\left[(C_d)_{O_i} - \overline{(C_d)_O}\right]\left[(C_d)_{P_i} - \overline{(C_d)_P}\right]}{\sqrt{\sum_{i=1}^{n}\left[(C_d)_{O_i} - \overline{(C_d)_O}\right]^2 \sum_{i=1}^{n}\left[(C_d)_{P_i} - \overline{(C_d)_P}\right]^2}} \quad \dots\dots\dots\dots 7$$

Where$(C_d)_{O_i}$ = Observed discharge coefficient of the experimental model;$(C_d)_{P_i}$ = Predicted discharge coefficient predicted by the numerical model; $\overline{(C_d)_O}$ = average discharge coefficient of the experimental model; $\overline{(C_d)_P}$= average discharge coefficient of the numerical model; and n= number of experimental measurement.

1.3 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Jang(1993) proposed the Fuzzy Logic approach to describe complicated systems. (FIS) Fuzzy inference system is a rule based system consisting of three main components:

(i) a rule-database , containing fuzzy if-then

(ii) a data-base, defining the Membership Functions (MF) and

(iii) Reasoning mechanism that combines the fuzzy rules and produces the system results (Firat et al., 2009).

In the fuzzy logic (FI) no systematic procedure to selecting the membership function parameters, that there is main problem. further, an ANN has the ability to learn from input and output couple and adapt to it in an interactive method. In recent years, the ANFIS method, Integrating ANN and FI strategies, has been developed.In a single setting, ANFIS has the potential advantages of all these strategies. ANFIS removes the fundamental problem in the design of the fuzzy system, determines the parameters of the membership function and design of fuzzy if-then rules by effectively using ANN's learning capacity for automatic generation of fuzzy rules and optimization of parameters(Sanikhani and Kisi 2012; Kisi et al. 2013; Ebtehaj and Bonakdari2014),The ANFIS methodology is therefore proposed in this paper to self-organize the model structure and to adjust parameters of the fuzzy system for discharge coefficient estimation in elliptical side weirs.A database of fuzzy-rules consists of rules IF-THEN. For example, “if the value of x is low, then the value of y is lowered” could be a fuzzy rule, so that low and high in this rule are linguistic variables. The database performs the membership functions used in fuzzy rules. The reasoning mechaniifsm performs the output deduction procedure from the input variables. It is assumed that the fuzzy system has two variables (x and y) and an output (z). In addition, the rules database consists of two fuzzy IF-THEN rules in the first-grade Takagi-Sugeno fuzzy system as follows:

$$Rule\ 1 : IF\ x = A_1 \&\ y = B_1\ , then\ z_1 = f_1 = p_1 * x + q_1 * y + r_1$$

$$Rule\ 2 : IF\ x = A_2 \&\ y = B_2\ , then\ z_2 = f_2 = p_2 * x + q_2 * y + r_2$$

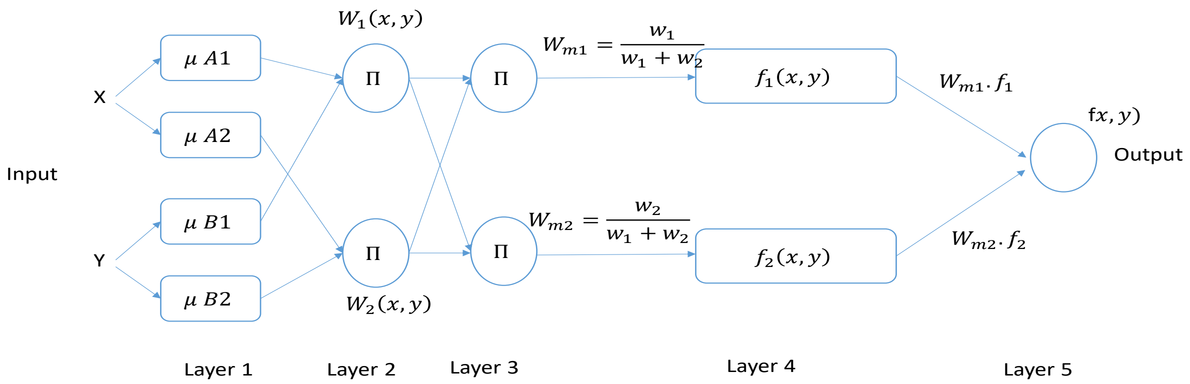


Fig. 2 ANFIS structures

The ANFIS structure consists of five varied layers , as shown below

Layer 1 : in this layer nodes are adaptive nodes and node's output is calculated as follows

$$O^1_{i=1,2} = \mu_{A_i}(x) \quad ; \quad O^1_{i=3,4} = \mu_{B_{i-2}}(y)$$

Where Ai , Bi = linguistic labels , (pi ,qi ,ri) = consequent parameters , μ_{A_i} and μ_{B_i} = membership functions for Ai and Bi linguistic labels , respectively .

The mathematical detail of the membership function can be given as (Ebtehaj and Bonakdari 2014)

$$\mu_{A_i}(x) = \frac{1}{1 + \left|\frac{x-c_i}{a_i}\right|^{2b_i}}$$

Layer 2 : In this layer, the value of each node represents the output of each node.The intensity or the firing strength. The output of this layer is production by multiplying all input signals is calculated by :

$$O^2_{i=1,2} = w_i = \mu_{A_i}(x) * \mu_{B_i}(y)$$

Layer 3 : In this layer, the value of each node is constant and it’s calculated as follows

$$O^3_{i=1,2} = \overline{w}_i = \frac{w_i}{\sum_i w_i}$$

Layer 4 : In this layer, nodes are the output operators for each rule

$$O^4_{i=1,2} = \overline{w}_i f_i = \overline{w}_i * (p_i x + q_i y + r_i)$$

Layer 5: In this layer, one node and shows the final value of the overall output by summing all incoming signals :

$$O^5_{i=1,2} = f(x,y) = \sum_i \overline{w}_i * f_i = \overline{w}_i * f_1 + \overline{w}_i * f_2 = \frac{\sum_i w_i * f_i}{\sum_i w_i}$$

The details and mathematical background for these algorithms can be found in Jang et al. (1997) and in Nayak et al. (2004).

The discharge coefficient of rectangular side orifices is used to model 588 experimental measurementwere used using the ANFIS models. 75% for simplesmodel training and the other 25% for simulation testing.Next, for each of the ANFIS andNLR 7 different cases were described and, as shown in Fig. 3.

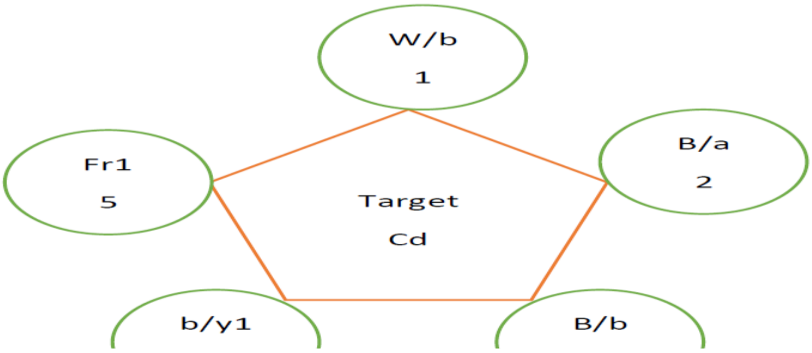


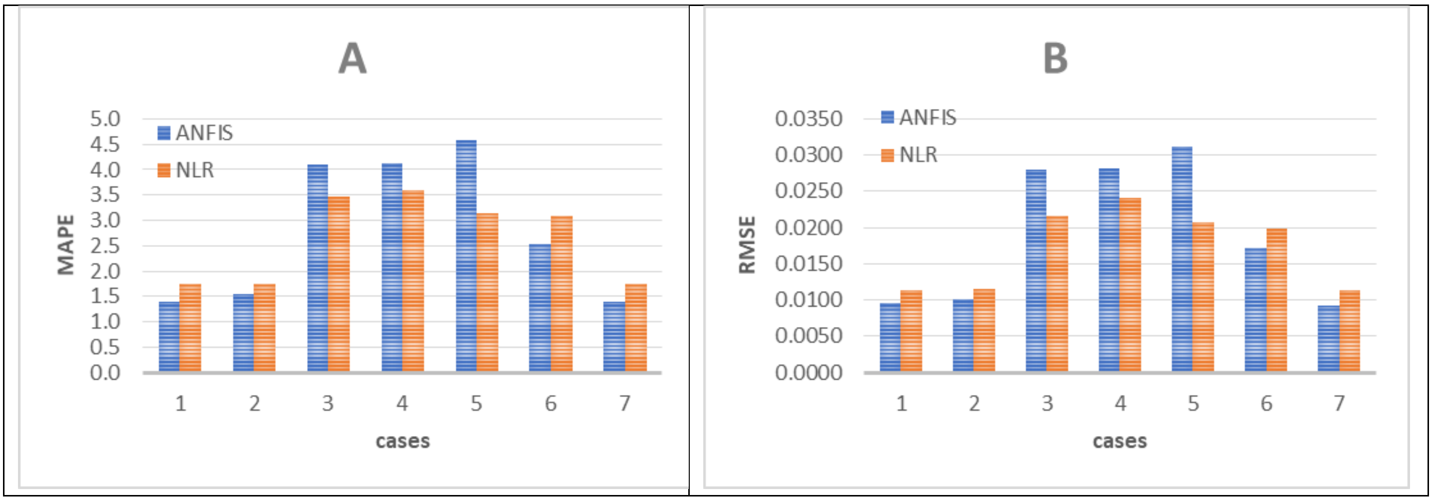
Figure. 3 Target and combination of variables

2. Result and discussion

The calculated results of a statistical index Eq.8 to 8 are used to a comparison between experimental and (ANFIS model and NLR) of cases 1 to 7.Depending on the statistical analysis (MAPE, RMSE, SI, BIAS, R) as shown in figure. 4 . MAX. and MIN. results of methods (ANFIS and NLR) for all cases as shown in table 2. the ANFIS method is best from NLR to estimation coefficient of discharge in side elliptical orifice .

Table 2. max. and min. values of statistical analysis for ANFIS and NLR

	MAPE		RMSE		SI		BIAS		R	
	MAX	MIN	MAX	MIN	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.
ANFIS	4.5115	1.396	0.031	0.009	0.06	0.0176	0.023	0.0071	0.91	0.005
NLR	3.595	1.741	0.024	0.011	0.046	0.022	0.018	0.009	0.81	0.186



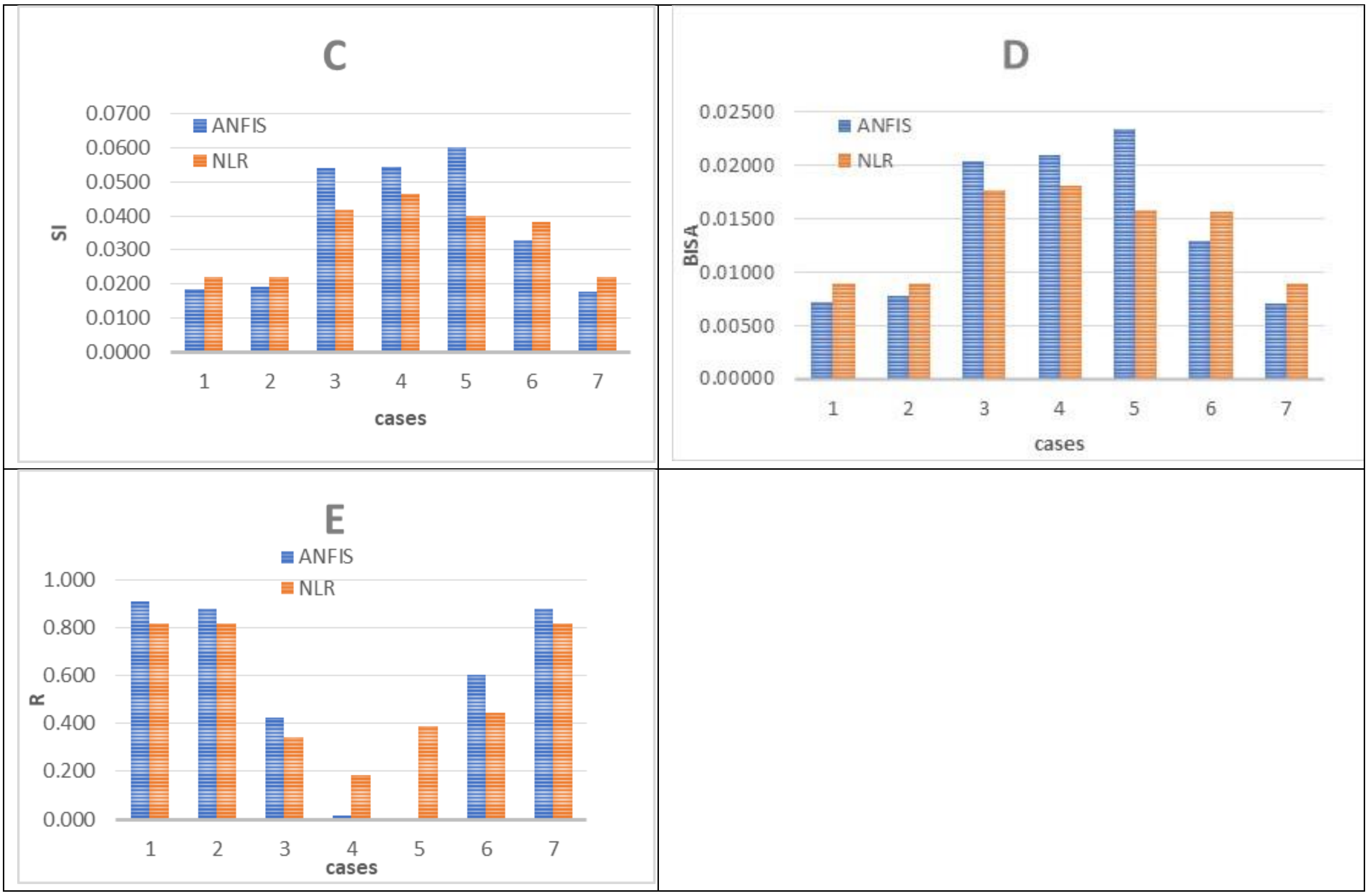


Figure. 4 Comparison of A-MAPE , B-RMSE , C-SI , D-BISA ,and E- R for cases 1 to 7 (ANFIS and NLR method)

In case 1 all variables are affecting on estimation the discharge coefficient for the side elliptical orifice. those variables are(W:b) ratio of the orifice crest height to the vertical semi- axes, (B:a) ratio of the main channel to the horizontal semi-axes, (B:b)ratio of the main channel to the vertical semi- axes, (b,y_1) ratio of the vertical semi- axes to the upstream flow depth in the main channel, and the Froude number Fr at main channel.used those variable in (NLR method was prediction parameters as shown in Eq. 8), and (ANFIS method). Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 5. the value of the R parameter for this case was (0.91 and 0.85) respectively.

$$C_d = 0.619 - 0.069 * \left(\frac{W}{b}\right)^{0.656} * \left(\frac{B}{a}\right)^{1.515} * \left(\frac{B}{b}\right)^{0.141} * \left(\frac{b}{y_1}\right)^{0.227} * (Fr_1)^{0.914} \ldots \ldots 8$$

In figure. 6,Approximately (83, 63)% of the results had an error smaller than (2%), and (100%) of the results had an error smaller than 10 % .

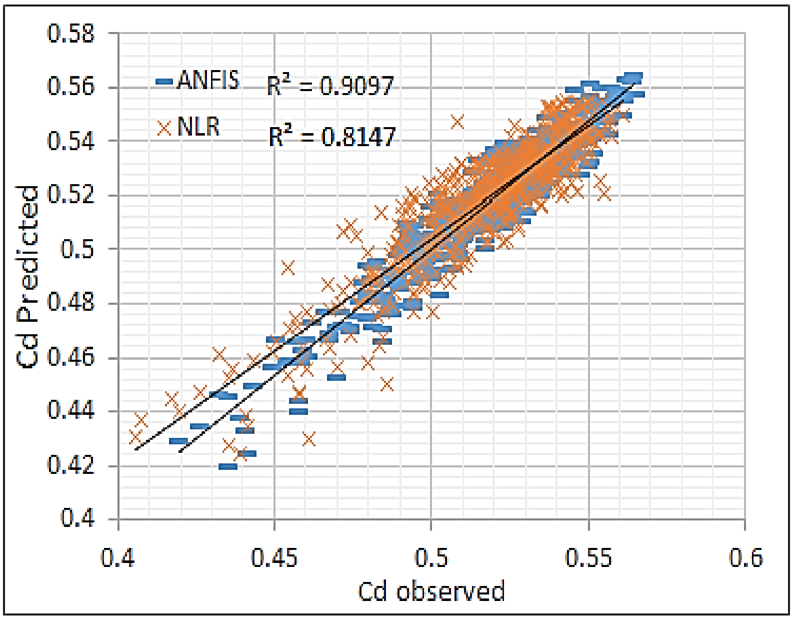
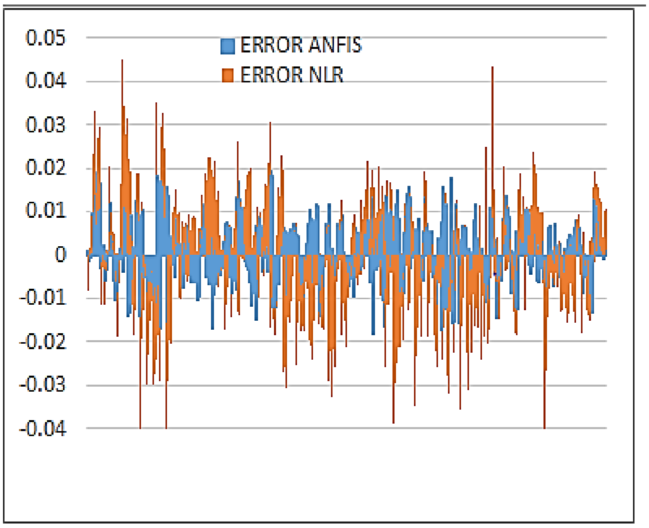


Figure. 5 Comparison between Cd observed and Cd predicted for case 1



To predict the discharge coefficient of the elliptical side orifice for Case 2 used terms (W:b), (B:a), and the Froude number Fr. used those variable in (NLR method was prediction parameters as shown in Eq. 9), and (ANFIS method).

$$C_d = 0.642 - 0.09 * \left(\frac{w}{b}\right)^{0.532} * \left(\frac{B}{a}\right)^{1.316} * (Fr_1)^{0.87} \ldots \ldots 9$$

Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 7. the value of the R parameter for this case was (0.88 and 0.81) respectively. In figure. 8, Approximately (75,64%) of the results had an error smaller than (2%), and (100%) of the results had an error smaller than 10 %.

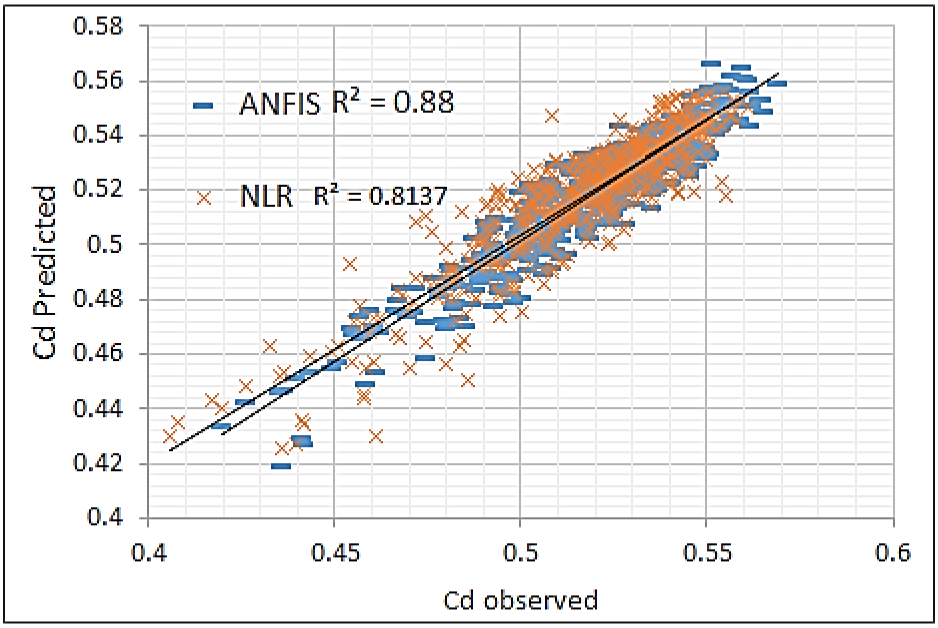
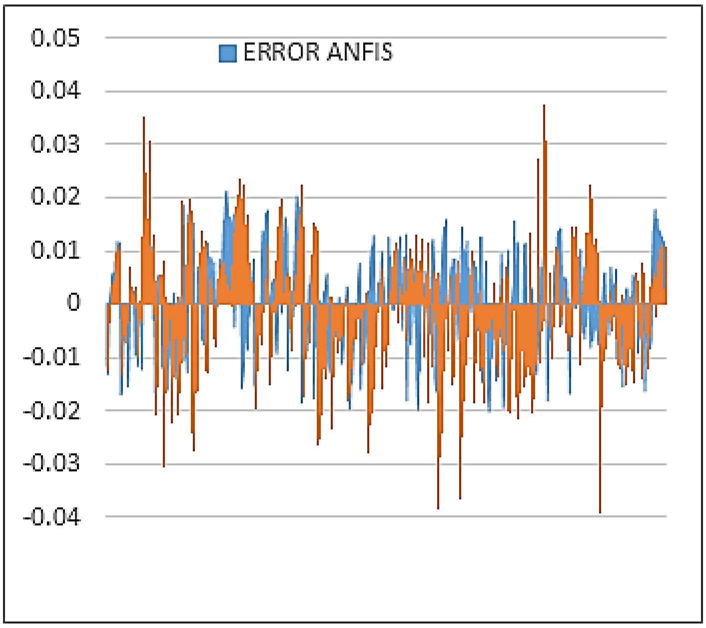


Figure. 7 Comparison between Cd observed and Cd predicted for case 2



For Case 3, the Cd value was calculated by combining (W:b), (B:a),and Fr_1. used those variable in (NLR method was prediction parameters as shown in Eq. 10), and (ANFIS method).Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 9. the value of the R parameter for this case was (0.425 and 0.34) respectively. In figure. 10

$$C_d = 0.534 - 0.005 * \left(\frac{w}{b}\right)^{2.67} * (Fr_1)^{2.236} \dots \dots 10$$

, Approximately (40,32%) of the results had an error smaller than (2%), and (97%) of the results had an error smaller than 10 % .

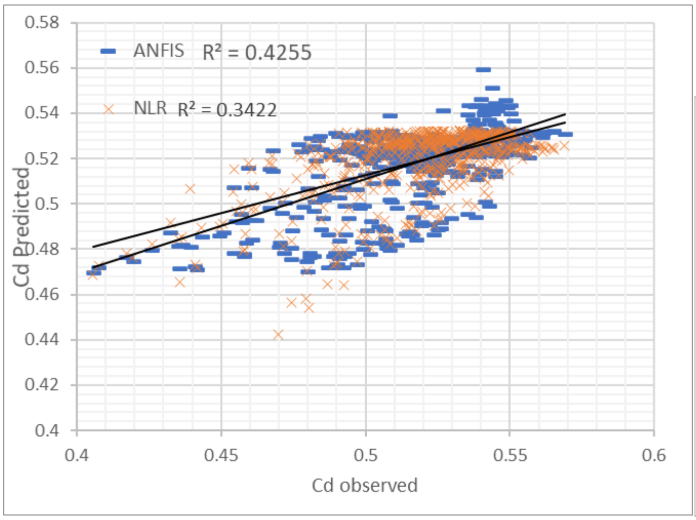


Figure. 9 Comparison between Cd observed and Cd predicted for case 3

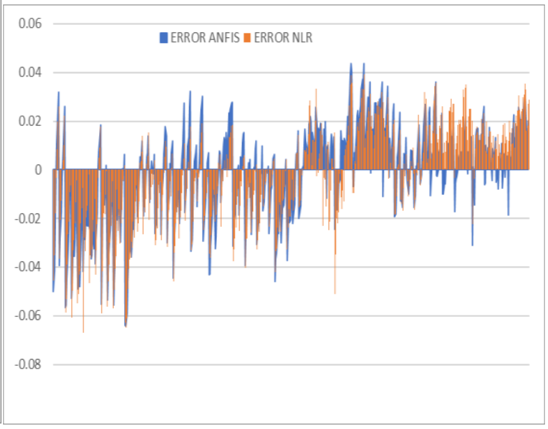


Figure. 10 Error distributions for case 3

(0.016,0.18) shown in fig. this case depending on two parameters (B:a),and Fr_1. used those variable in (NLR method was prediction parameters as shown in Eq.11), and (ANFIS method).Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 11. the value of the R parameter for this case was (0.016 and 0.18) respectively. In figure. 12

$$C_d = 0.596 - 0.055 * \left(\frac{B}{a}\right)^{1.11} * (Fr_1)^{0.114} \; \dots \dots 11$$

Approximately (34, 37%) of the results had an error smaller than (2%), and (89,94%) of the results had an error smaller than 10 %
.

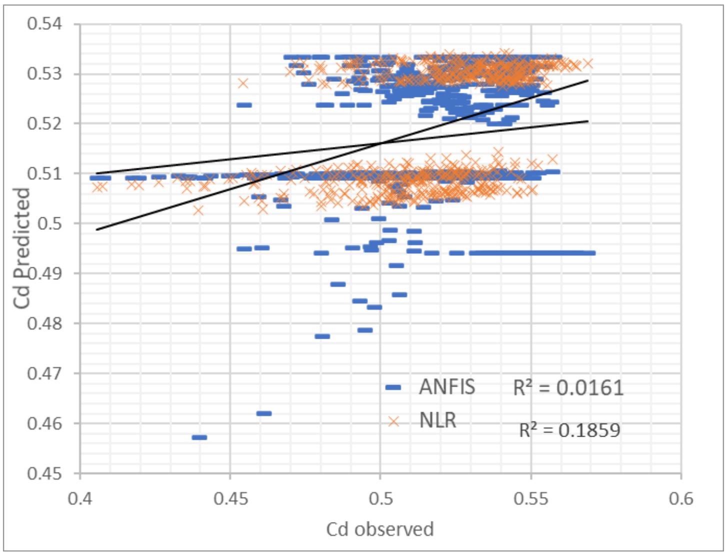


Figure. 11 Comparison between Cd observed and Cd predicted for case 4

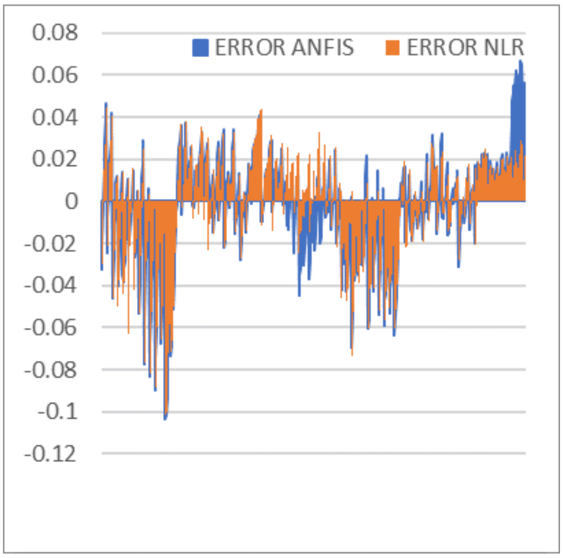


Figure. 12 Error distributions for case 4

Case 5 predict the discharge coefficient of the elliptical side orifice as a function of (W:b), (B:a). used those variable in (NLR method was prediction parameters as shown in Eq. 12), and (ANFIS method). Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 13. the value of the R parameter for this case was (0.005 and 0.18) respectively. In figure. 14

$$C_d = 0.6 - 0.042 * \left(\frac{w}{b}\right)^{0.307} * \left(\frac{B}{a}\right)^{0.994} \; \dots \dots 12$$

Approximately (31,44%) of the results had an error smaller than (2%), and (88,96%) of the results had an error smaller than 10 %
.

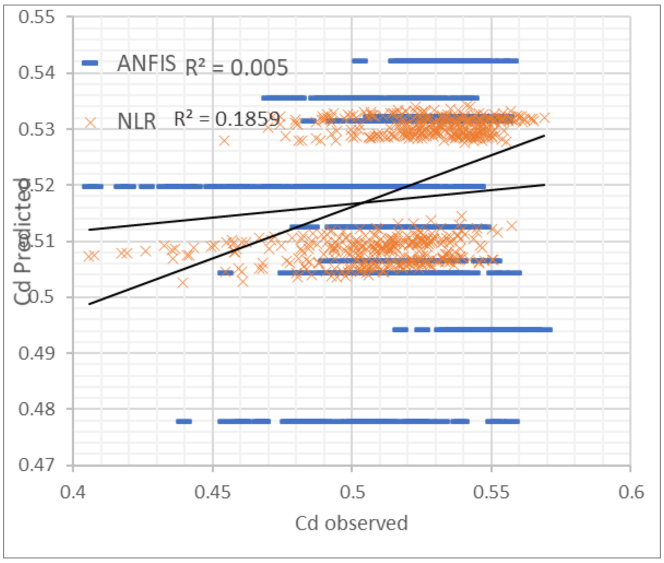


Figure. 13 Comparison between Cd observed and Cd predicted for case 5

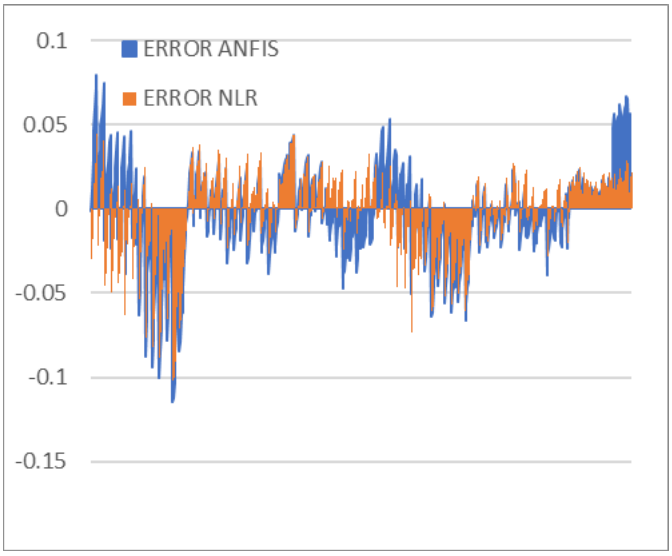


Figure. 14 Error distributions for case 5

Case 6 considered the Cd value as a function of (W:b),(B:a),(b,y1). used those variable in (NLR method was prediction parameters as shown in Eq. 13), and (ANFIS method). Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 15. the value of the R parameter for this case was (0.6 and 0.44) respectively. In figure. 16

$$C_d = 0.54 - 0.061 * \left(\frac{w}{b}\right)^{2.296} * \left(\frac{B}{a}\right)^{3.7} * \left(\frac{b}{y_1}\right)^{1.924} \quad \ldots\ldots 13$$

Approximately (93%) of the results had an error smaller than (2%), and (100%) of the results had an error smaller than 10 % .

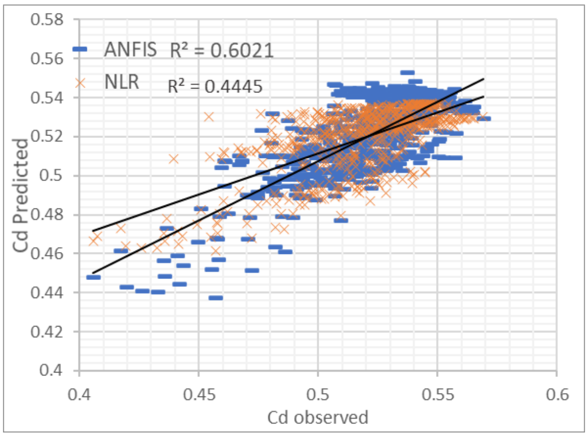


Figure. 15 Comparison between Cd observed and Cd predicted for case 6

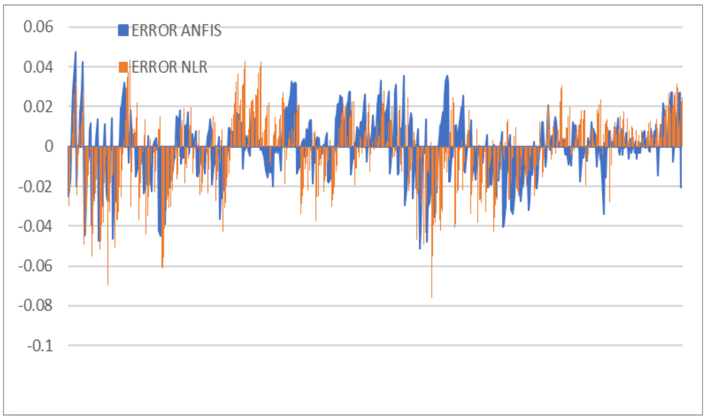


Figure. 16 Error distributions for case 6

ForCase 7 considered the Cd value as a function of (W: b),(B:a),(b,y1), Fr1. used those variables in (NLR method was prediction parameters as shown in Eq. 14),

$$C_d = 0.641 - 0.091 * \left(\frac{w}{b}\right)^{0.54} * \left(\frac{B}{a}\right)^{1.323} * \left(\frac{b}{y_1}\right)^{0.012} * (Fr_1)^{0.873} \ldots\ldots 14$$

and (ANFIS method). Cd Predicted results for (ANFIS and NLR) were comparison with Cd observed results as shown in figure. 17. the value of the R parameter for this case was (0.88 and 0.82) respectively. In figure. 18

Approximately (93%) of the results had an error smaller than (2%), and (100%) of the results had an error smaller than 10 %.

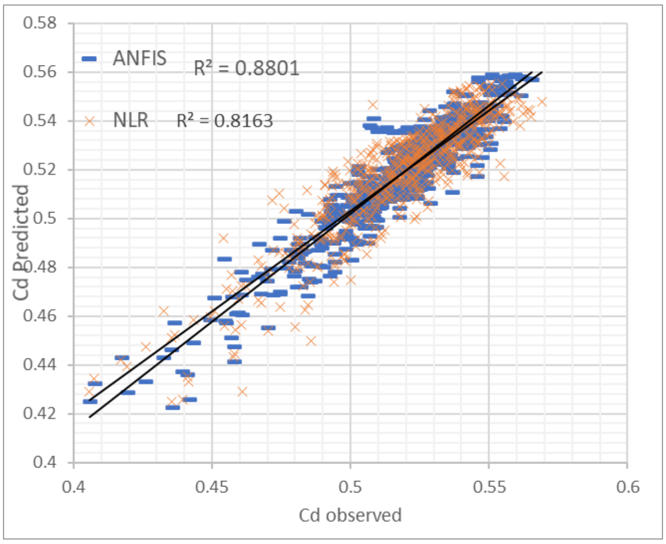


Figure.17 Comparison between Cd observed and Cd predicted for case 7

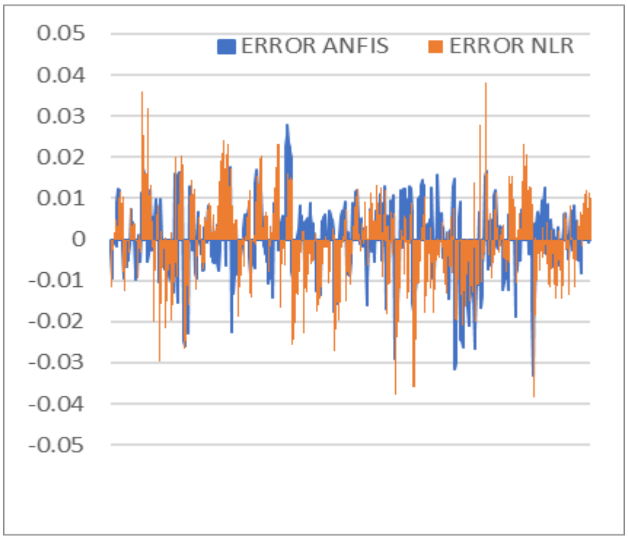


Figure.18 Error distributions for case

3. Conclusions

The following findings were obtained in this studyusing (ANFIS and NLR) models for estimating the coefficient of discharge. The following findings were obtained in this study:

1. Finding (ANFIS model and NLR method) were very us full to estimating the coefficient of dischargein weirs
2. Correlation coefficient for the best ANFISmodelsand NLRwere 0.91 and 0.816 , respectively . also,(93% and 63%) for Results had an error small than 2%
3. High correlation coefficients and low errors for the ANFIS modelobtained from the proposed model are generally more acceptable than the NLR method ..
4. On the basis of the sensitivity analysis results, it was observed that Froude number isthe most significant parameter, followed by *B/a*and *W/b*. But *b/y* was little significant parameter on the coefficient of discharge .
5. It was found that the value of Cd decreases when there values w/b, B/a, and Fr1 are increases ; and it's increases when there values b/y1 decreases.
6. NLR method can be potentially used by the researchers to measure the flow passing through side orifice for open channel.

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