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Estimation of Manning's Roughness Coefficient for Al- Diwaniya River

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Abstract

An accurate estimation of Manning's roughness coefficient is of vital importance in any hydraulic study including open channel flow. There are empirical methods to estimate the values of roughness however these methods are often applicable to a narrow range of river conditions. In the present study, field work, laboratory work and an intelligent method based on Adaptive Neuro- Fuzzy Inference System ANFIS approach model are applied to Al- Diwaniya river as a case study to estimate the values of Manning's coefficient through direct method using discharge, particle size, hydraulic radius, and slope of river. The data are measured in the field (river) for the period from 1/11/2013 to 28/2/2014 and divided randomly into two sets; the first set is for training purposes; the second set is for testing purposes. Statistic measurements are then used to evaluate the performance of the models. Based on the comparison of the results, it is well found that the ANFIS model presented better estimation than the other empirical relationships considered here. Also, a sensitivity analysis showed that d_{90} has greater influence on Manning coefficient than the other independent parameters in ANFIS model.

Keywords: Manning Roughness Coefficient, ANFIS, and Al- Diwaniya River.

تقدير معامل خشونة مانك لنهر الديوانية

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الخلاصة

التخمين الدقيق لمعاملماننك يعتبر من الاهمية الحيوية في أي دراسة هيدروليكية خصوصا في جريان القنوات المفتوحة . على الرغم من ان هنالك طرق وضعية لتخمين قيمة معامل الخشونة الا ان تلك الطرق هي غالبا تنطبق على حالات خاصة لبعض الانهار . في هذه الدراسة تم اجراء قياس حقلي وقياس مختبري و نموذج يستخدم طريقة متطورة و هي تدعى نظام الشريكات العصبية الضبابية المتداخل المكيف ANFIS على نهر الديوانية كحالة دراسية لحساب قيمة معامل خشونة ماننك من خلال استخدام الطريقة المباشرة لحساب التصريف و حجم جزيئة التربة و نصف القطر الهيدروليكي و ميلان قاع النهر . البيانات التي تم قياسها حقليا هي للفترة من 2013/11/1 لغاية 2014/2/28 وقسمت البيانات عشوائيا الى قسمين : القسم الاول لاغراض توليد النموذج والقسم الثاني لاغراض اختبار النموذج. استخدمت الحسابات الاحصائية لتقييم اداء النموذج. من خلال مقارنة النتائج تم التوصل الى ان النموذج الحالي يعطي نتائج افضل من بقية المعادلات الوضعية التي اعتمدت في هذا البحث. وتم ايضا عمل تحليل الحساسية وبينت النتائج ان d_{90} يملك التاثير الاكبر على حساب معامل ماننك باستخدام هذا الموديل مقارنة مع بقية المتغيرات الداخلة بالموديل.

1- Introduction

The procedure for selecting values of Manning *n* is subjective and requires judgment and skill which are developed primarily through experience. Government agencies and private sectors in developed nations such as the USA are still doing research on predicting *n* values for rivers. Various factors affecting the values of roughness coefficients were presented by Chow [4]. The typical value of *n* for natural irrigation channels is 0.025 [6] and for earth channels ranges from 0.022 to 0.033 [8]. Past experience of flow in Iraqi natural rivers indicates that the value of Manning's *n* may vary between 0.025 and 0.033[3].

Manning *n* is often assumed to be a constant that is independent of either flow discharge or depth [7]. However, Chow [4] indicates that the value of *n* is highly variable and depends on a number of factors:1) surface roughness- fine sediment size such as sand resulted in a relatively low value of *n* and coarse sediments such as gravels, for a high value of *n;* 2) vegetation- may also be regarded as a kind of surface roughness depending on the height, density, distribution and types of vegetation; 3) channel irregularity – comprises irregularities in wetted perimeter and variations in cross section, size and shape along the channel length. A gradual and uniform change in cross section, size and shape will not appreciably affect the value of *n*; 4) channel alignment – smooth curvature with large radius will give a relatively low value of *n*; 5)silting and scouring – silting may change a very irregular channel into a comparatively uniform one and decrease *n*, whereas scouring may do the reverse and increase *n*; 6) obstruction – the presence of log jams, bridge piers, and the like tends to increase *n*; 7) size and shape of channel – an increase in hydraulic radius may either increase or decrease *n* depending on the condition of the channel; and 8) stage and discharge – *n* value in most streams decreases with increase in stage and discharge. However, the *n* value may be large at high stages if the banks are rough and grassy [7].Moharana S., and Khatua K.K, in 2014 used an laboratory experimental model and ANFIS model to estimate Manning coefficient *n* in meandering channel [14]. It is believed that the variation of roughness coefficient for a straight reach of a channel due to slope, geometry and flow depth is not significant as compared to that for meandering channels [11]. Lai SaiHin et.al, (2008) expressed that estimation of discharge capacity in river channels was complicated by variations in geometry and boundary roughness [12]. Important applications of ANFIS in the related field are calculation of the entrance length for low Reynolds number flow in pipe by Shau and Khatua [13], and prediction of friction coefficient in open channel flow by Samandar [1].So, and due to these factors the objectives of this research can be summarized as in the following paragraph.

2- The objectives of the research

The main objectives of this research are as follows:-

1- To measure Manning coefficient for Al- Diwaniya River which is variable due to the variability of river characteristics.
2- Make a model using ANFIS for estimating Manning *n* coefficient.

3- Experimental work

In the present study a field work and laboratory work are used for Al- Diwaniya river as a case study for 25 sections per month during the period from 1/11/2014 to 28/2/2014 (i.e. there were 100 sections during that period). Field data in the river were measured using velocity – area method for each section to calculate discharge, hydraulic radius, and slope of channel using current – meter device for measuring velocity, and the direct method to calculate Manning roughness *n* as shown later, while laboratory sieve analysis data was used to measure effective size of particle (d_{50}, d_{75}, and d_{90}).Figure (1) shows the plane of Al- Diwaniya river and its branches. The velocity – area and direct method were illustrated in the next paragraph.

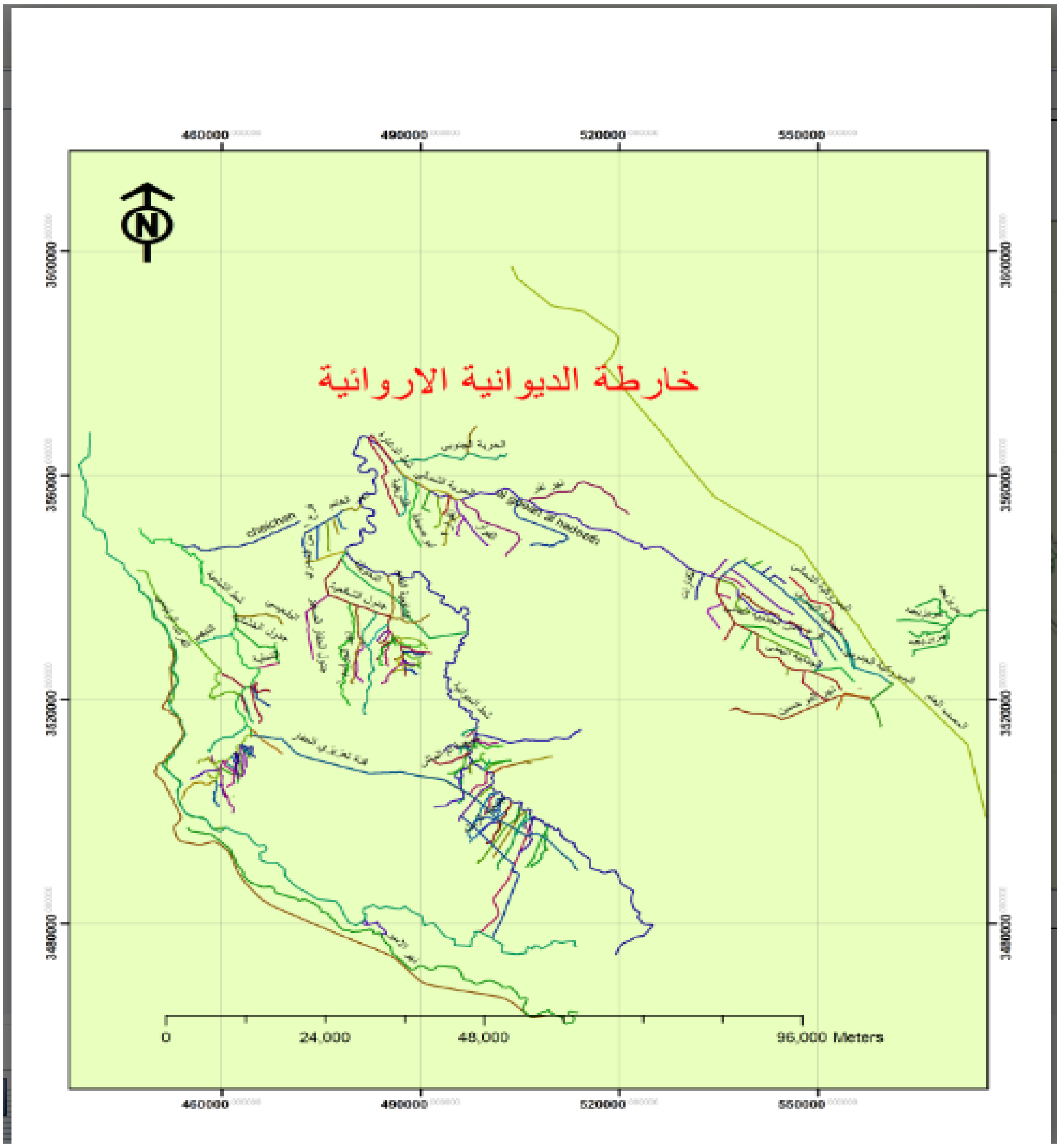

Fig.(1): Plans of Al-Diwaniya river and its branches[5].

2.1- Velocity – Area method

Velocity – area method was used to calculate discharge by using current - meter and M9 Doppler device which used to measure velocity in the river in several verticals at 0.2 and 0.8 times the depth every 2 m of the width of the river and these devices from water resources official. Level device was used to measure depths, area, and slope of the channel. Figure (2) and Figure (3) show the current – meter device (the current – meter was used from the water resources office at Al- Diwaniya city and the maximum revolution and the velocity that can be measured are 99 and 1.232 m/s, respectively) and the application of velocity area method to Al- Diwaniya river, respectively.

Fig.(2): Current - meter device

a) b)

Fig(3): Application of velocity – area method for Al- Diwaniya river (a) and (b).

Table (1) shows the relation between velocity and the number of revolution of the current – meter.

Table (1): relation between velocity (m/sec) and revolution of current – meter[5]

revolution	0	1	2	3	4	5	6	7	8	9
0	0.0	0.023	0.034	0.045	0.056	0.076	0.078	0.084	0.1	0.111
10	0.123	0.134	0.146	0.157	0.168	0.179	0.19	0.201	0.213	0.224
20	0.235	0.246	0.257	0.264	0.28	0.291	0.302	0.313	0.325	0.336
30	0.347	0.358	0.369	0.381	0.392	0.403	0.414	0.425	0.437	0.447
40	0.459	0.47	0.481	0.493	0.504	0.505	0.526	0.537	0.549	0.672
50	0.571	0.582	0.593	0.603	0.616	0.627	0.638	0.649	0.661	0.784
60	0.683	0.694	0.705	0.717	0.728	0.739	0.638	0.767	0.773	0.896
70	0.795	0.806	0.817	0.82	0.84	0.851	0.862	0.878	0.885	1.003
80	0.927	0.448	0.424	0.447	0.952	0.963	0.974	0.958	0.995	1.22
90	1.092	1.03	1.041	1.053	1.064	1.075	1.086	1.097	1.104	1.232

2.2- Direct Method

The roughness values were calculated using the same method described in Barnes (1967) and Hicks and Mason (1991) which was considered to give the most accurate roughness values of the channels [15]:-

$$n = \frac{1}{Q}\left(\frac{(h_m - h_1)+(h_{vm} - h_{v1}) - \sum_{i=2}^{m}(K_{(i-1)},\Delta h_{vi-1,i})}{\sum_{i=2}^{m} \frac{L_{i-1,i}}{Z_{i-1}Z_i}}\right)^{1/2} \qquad \ldots(1)$$

Where:-
Q: is the water discharge (m^3/s),
m: is the number of cross – sections,
Z_{i-1}: equal to $A_{i-1}*R_{i-1}^{(2/3)}$(A_{i-1}: area of cross section (m^2), R_{i-1}: hydraulic radius (m)) at section *i-1*,
Z_i: equal to $A_i*R_i^{(2/3)}$ (A_i: area of cross section (m^2), R_i: hydraulic radius (m)) at section *i*,
$L_{i-1,i}$: is the reach length between section *i-1* and section *i*(m),
h_i: is the water surface elevation at *i* cross section,
h_v: is the velocity head at *i* cross section,
$\Delta h_{vi-1,i}$: is the change in velocity head between the upstream (section $_{i-1}$) and downstream cross sections (section $_i$),
$K_{(i-1)}(\Delta h_{vi-1,i})$: approximates the energy loss due to acceleration or deceleration in a contracting or expanding reach, $K_{(i-1)}$ is assumed equal to zero for contracting reaches and 0.5 for expanding reaches [15].

Using velocity – area for finding discharge Q, hydraulic radius R, area A and slope of reach S, which was applied at Al- Diwaniya river and collect samples from bed river to find sieve analysis (d_{50}, d_{75}, d_{90}) at the laboratory. Then Direct method used and the data that were measured for 100 sections are shown in Table (2) by dividing randomly data into two sets, training and testing data for modeling:-

Table (2): Field and laboratory data range for Al- Diwaniya River

Notations	Training data	Testing data
Number of data	80	20
Q (m^3/sec)	13.84-324	12.78-322
d_{50} (mm)	0.1-0.4	0.12-0.22
d_{75} (mm)	0.15-1.0	0.19-0.45
d_{90} (mm)	0.28-1.8	0.35-1.4
R (m)	0.98- 4.2	0.82 – 4.1
S (-)	0.0001-0.0002	0.0001-0.0002
n	0.022- 0.033	0.022- 0.026

4- Adaptive Neuro- Fuzzy Inference System (ANFIS) model

ANFIS, first introduced by Jang [10] which is the abbreviated of Adaptive Neuro – Fuzzy Inference System, is a universal approximate and, as such, is capable of approximating any real continuous function on a compact set to any degree of accuracy [9]. Actually, this method is like a fuzzy inference system with this different that here a backpropagation is used which tries to minimize the error [2]. The performance of this method is like both ANN and FL. In both ANN and FL case, the input pass through the input layer (by input membership function) and the output could be seen in output layer (by output membership functions). Since, in this type of advanced fuzzy logic, neural network has been used, therefore, by using a learning algorithm the parameters are changed until the optimal solution is reached. Actually, in this type the FL tries by using the neural network advantages to adjust its parameters. Therefore, ANFIS uses either backpropagation or combination of least squares estimation and backpropagation (hybrid) for membership function parameter estimation [9].

Membership function: is a function through which it would be possible to present the input. The aim of using this function is by using the weights which is with the inputs, the functional overlap between the inputs would be defined and lead to output determination [2].

Rules: is some instruction which through them it would be possible for input that by using the membership values and their definitions, give the final output [2].

5- ANFIS application for estimating *n*

From the group of training data sets used in this study, 80% were used for preparing the model (chosen randomly), while the remaining patterns 20% were used for verification the ANFIS model. The method involves the training of ANFIS with discharge Q, size of bed particles d_{50}, d_{75}, d_{90}, hydraulic radius R, and channel slope S as input and the Manning coefficient *n* as output.

One of the most important steps in neuro- fuzzy modeling is the fuzzy membership values definition. Some membership functions specified by three parameters were used as an input data in the present model. There are six membership functions, Generalized Bell, Gaussian, Gaussian combined, pi curves, Difference of two sigmoid, and Product of two sigmoid as shown in Figure (4). MSE (Mean Square Error) is used to determine how much the network has reached the desired output values. Results show that network with Gaussian membership function with size of particle diameter d_{90}can estimates Manning coefficient of Al- Diwaniya river better than other functions as shown in Table (3).

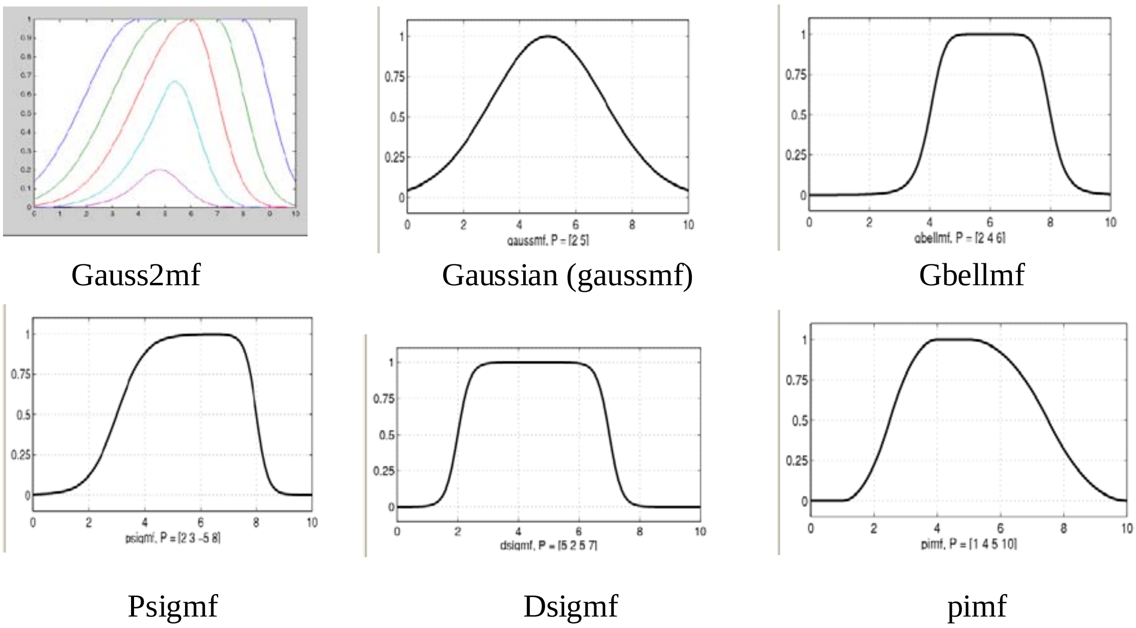

Fig. (4): Membership functions types (from MATLAB help)

Table (3): Performance membership functions for training and testing data.

Membership function	Performance in training with d_{50}	Performance in training with d_{75}	Performance in training with d_{90}
	MSE*10$^{(-3)}$	MSE*10$^{(-3)}$	MSE*10$^{(-3)}$
gbellmf	1.6362	1.2743	1.2375
gaussmf	1.5229	1.1778	1.1437
Gauss2mf	1.6989	1.5448	1.3634
pimf	2.1261	2.0553	1.9991
dsigmf	1.7031	1.5541	1.3843
psigmf	1.7031	1.5541	1.3843

Figure (5) and Figure (6) represent the variables with shape function and FIS editor, respectively, for the ANFIS model using MATLAB R2011b.

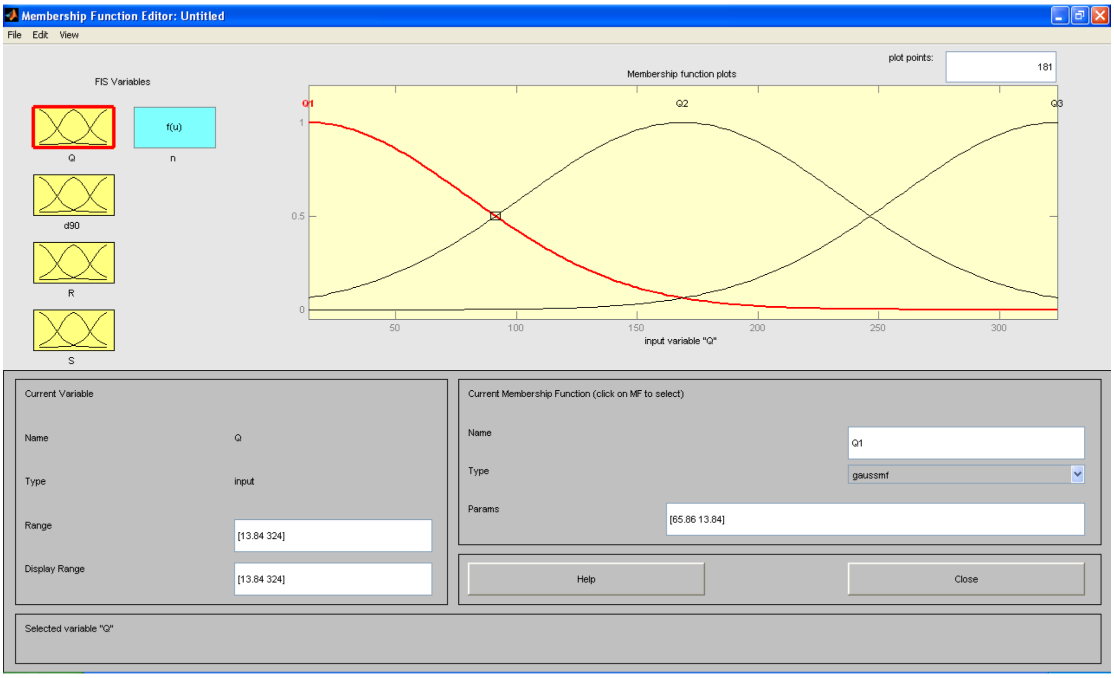

Fig.(5): Variables using Gaussian membership function

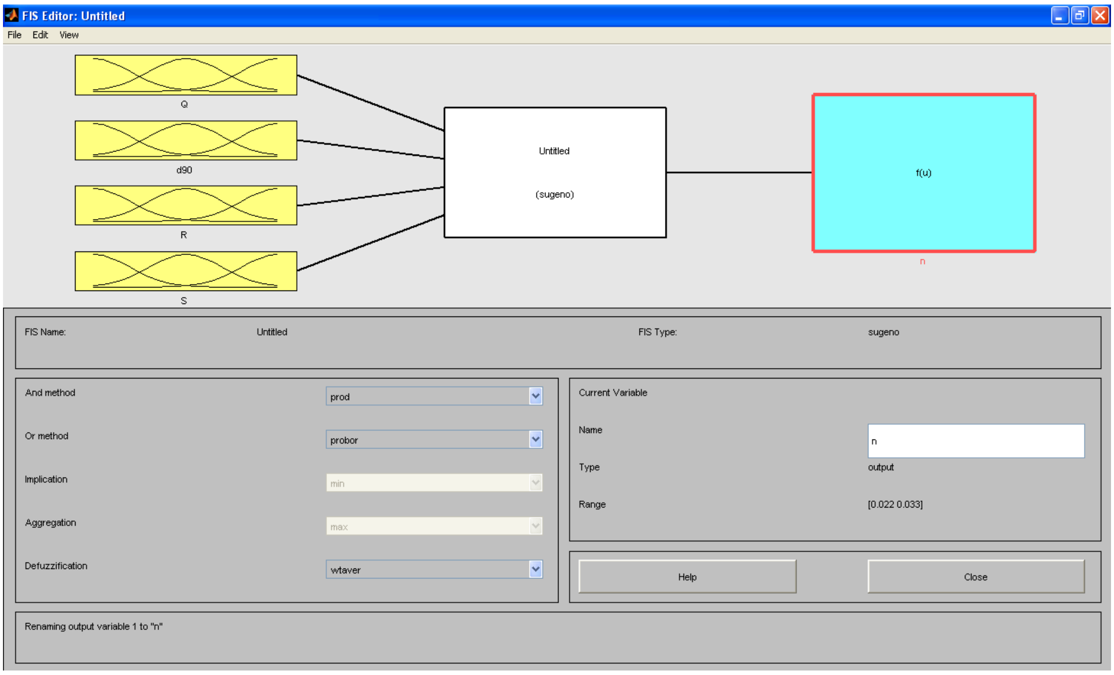

Fig. (6): FIS editor for the ANFIS model.

ANFIS model was applied to the experimental data which were mentioned in Table (2) and the results were shown in Figure (7) with MSE = 0.0011437 when using Gaussian membership function for Q, d_{90}, R, S as an input data and n as an output.

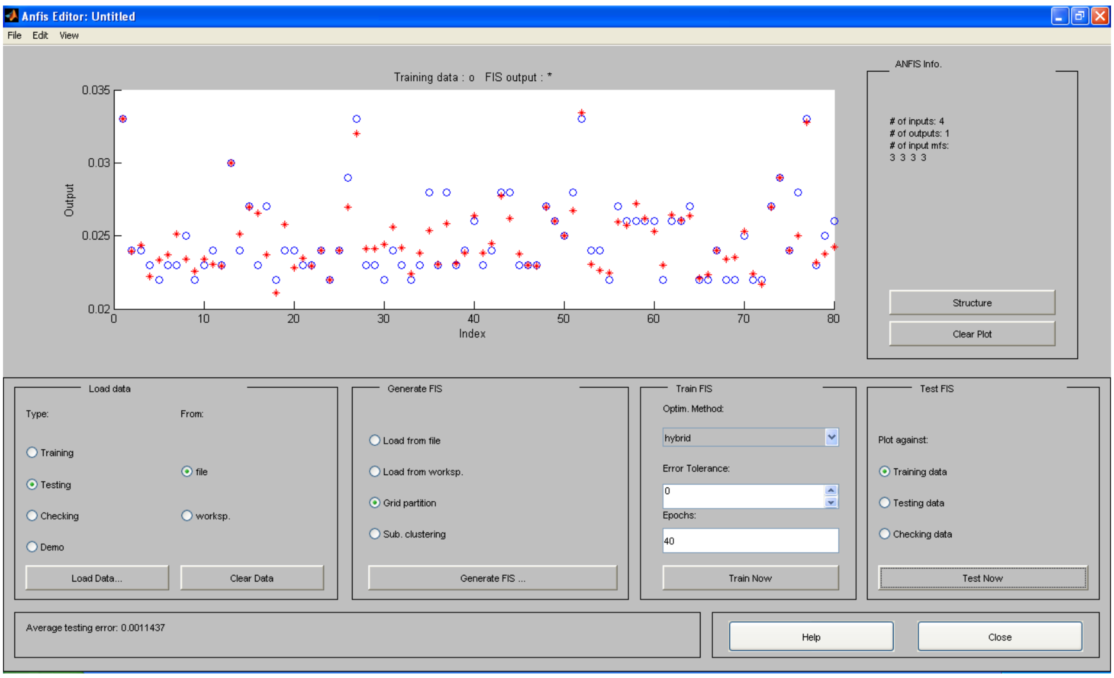

Fig.(7): ANFIS model editor for the measured data

Figure (8) shows the Rules of the ANFIS model for Al- Diwaniya River. By changing the input data Q, d_{90}, R, and S the output data *n* can be obtained.

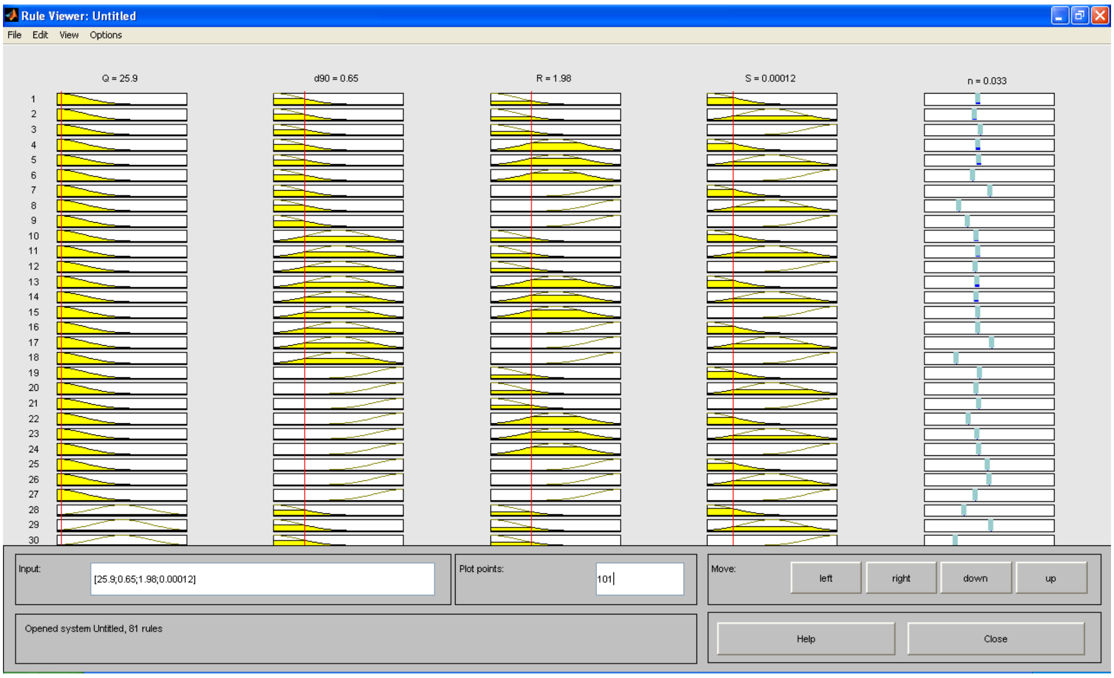

Fig.(8): Rules for ANFIS model for Al- Diwaniya River

Figures (9),(10), and(11) represent the structure of the ANFIS model, surface of ANFIS model between Q,R, and *n*, surface of ANFIS model between Q,d_{90}, and *n*, respectively.

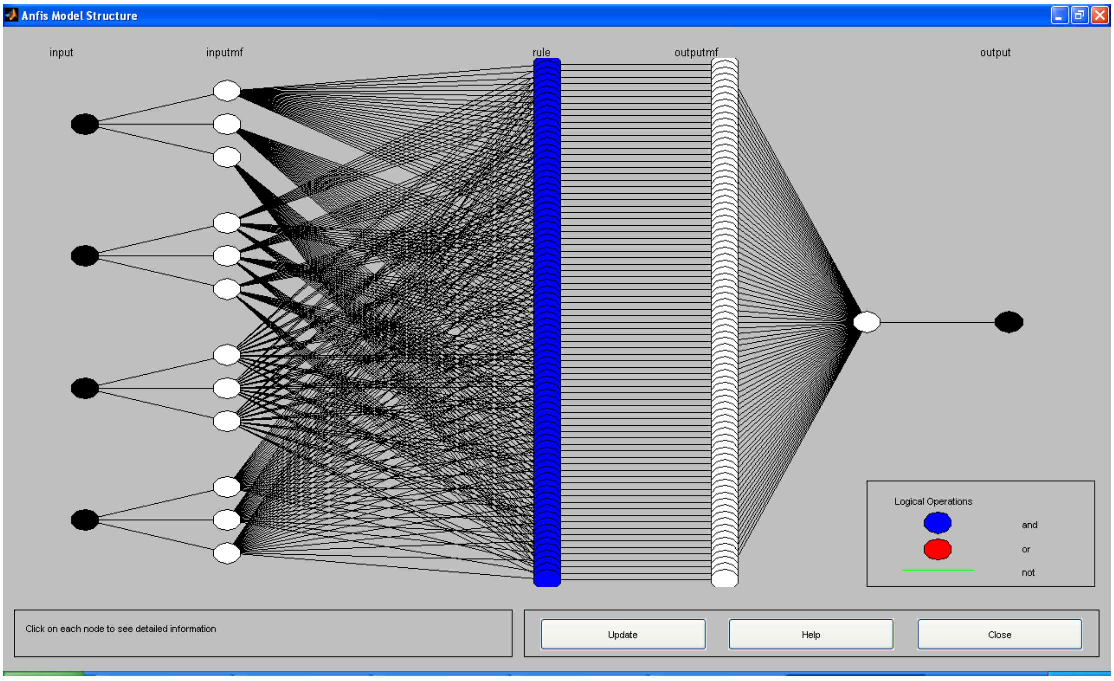

Fig.(9): The structure of ANFIS model for Al- Diwaniya river.

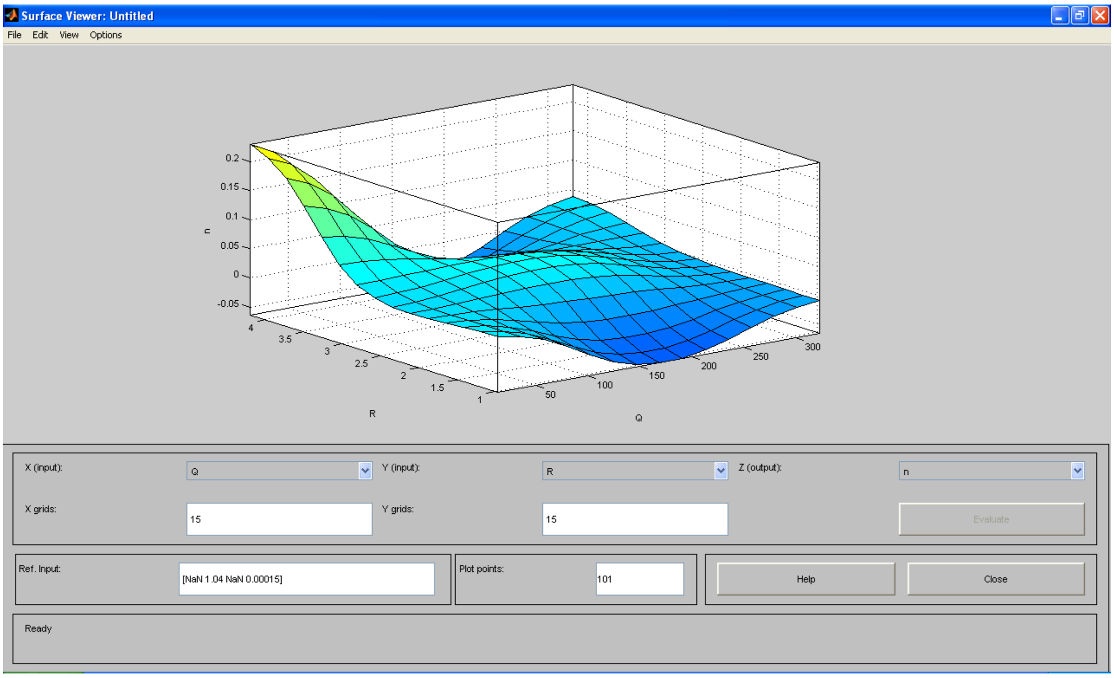

Fig.(10): Surface of the ANFIS model between Q,R, and *n*.

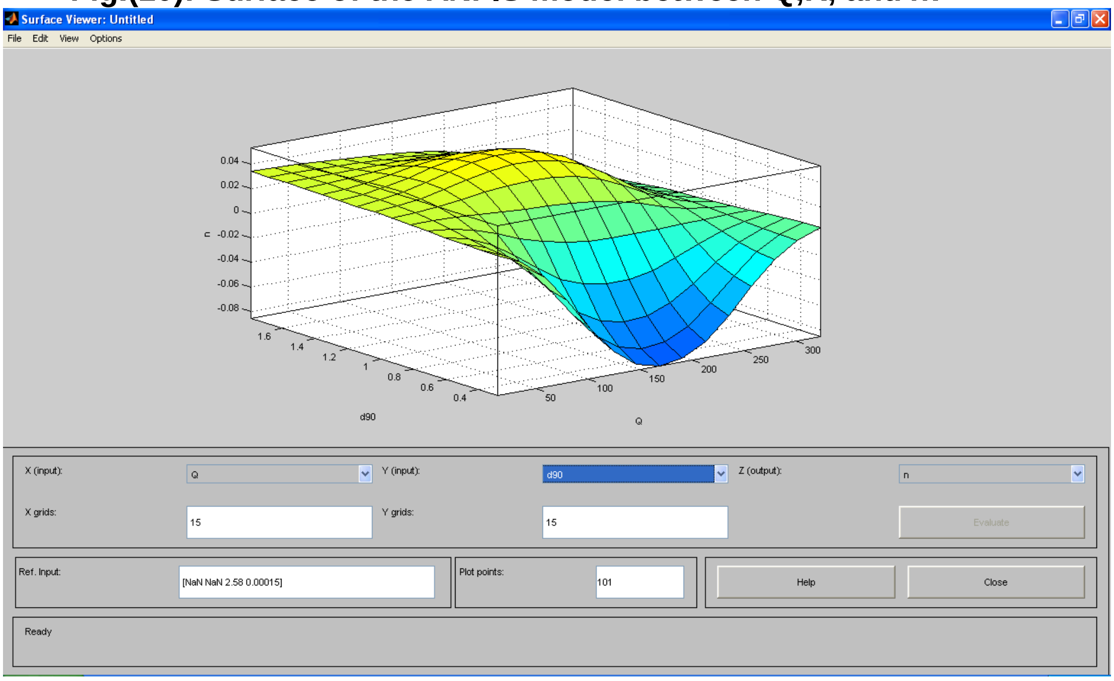

Fig.(11): Surface of ANFIS model between d_{90}, Q, and *n*.

From Figures (10) and (11) when increasing R, and d90, n will be increase. While in the first any increasing in Q, *n* will be decrease and latter will be increase due to presence of grass and bed roughness.

6- Existing equations for evaluation Manning's coefficient

Several available equations to predict values of *n* for rivers can be found in Simons and Senturk (1992), Yang (1996) and Lang et al. (2004) [7]. These equations can be categorized as: 1- equations that are based on bed sediment size; 2- equations that are based on the ratio of flow depth or hydraulic radius over sediment size; and 3- equations that include water – surface slope besides bed sediment size and hydraulic radius or flow depth. In the present study, four equations were evaluated as follows [7].

Category 1: Equations based on bed sediment size:-

Meyar- Peter &Muller (1948): $n = \frac{1}{26} d_{90}^{(\frac{1}{6})}$ …(2)

Category 2: Equations based on ratio of R or y_o over sediment size:-

Limerinos (1970): $n = \frac{0.113\ R^{(\frac{1}{6})}}{0.35+2.0\ log_{10}\ (\frac{R}{d_{50}})}$ …(3)

Category 3: Equations based on S, R, and d_{50}:-

Brownlie (1983) : $n = [\ 1.893*(\frac{R}{d_{50}})^{0.1374} * S^{0.1112}\ ] *0.034*d_{50}^{0.167}$ …(4)

Bruschin (1985): $n = \frac{d_{50}^{(\frac{1}{6})}}{12.38} * (\frac{\mathrm{R}}{\mathrm{d}_{50}} * \mathrm{S})^{(\frac{1}{7.3})}$ …(5)

Herein d is the representative sediment size in meters, R the hydraulic radius in meters, and S the water surface slope.

ANFIS model was compared with equations 2, 3, 4, and 5 for verification. Figures (12) and (13) show the comparison between measured data, ANFIS model, and the other equations (equations 2 through 5).

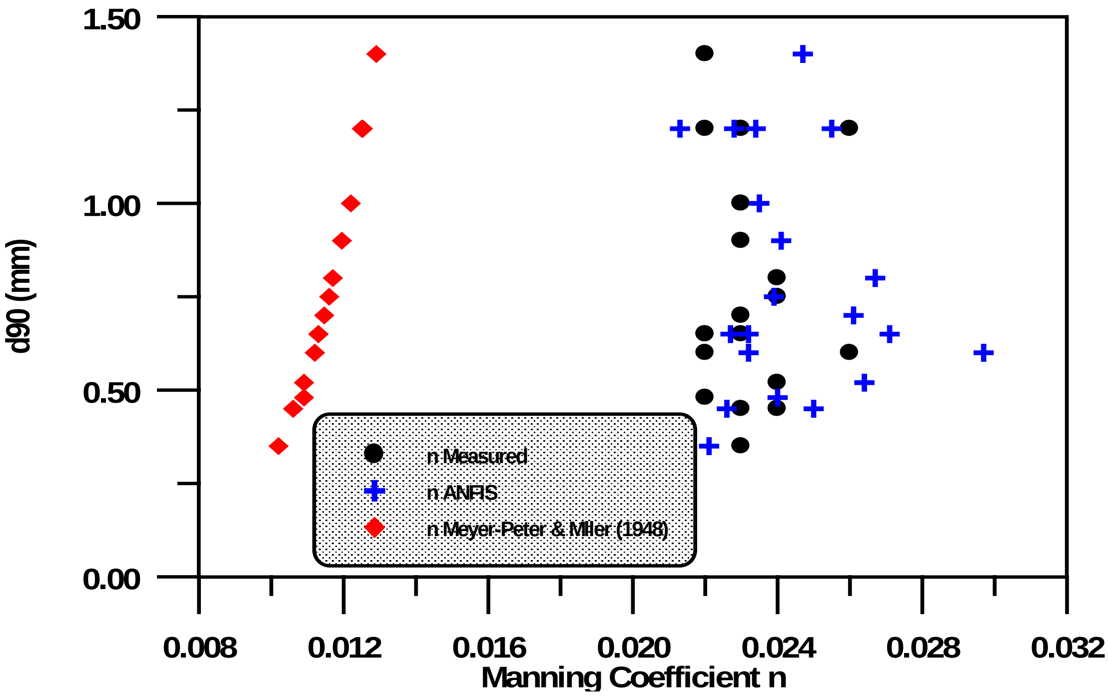

Fig.(12): Comparison between measured data, ANFIS model and Meyer-Peter & Muller equation for *n* by testing data.

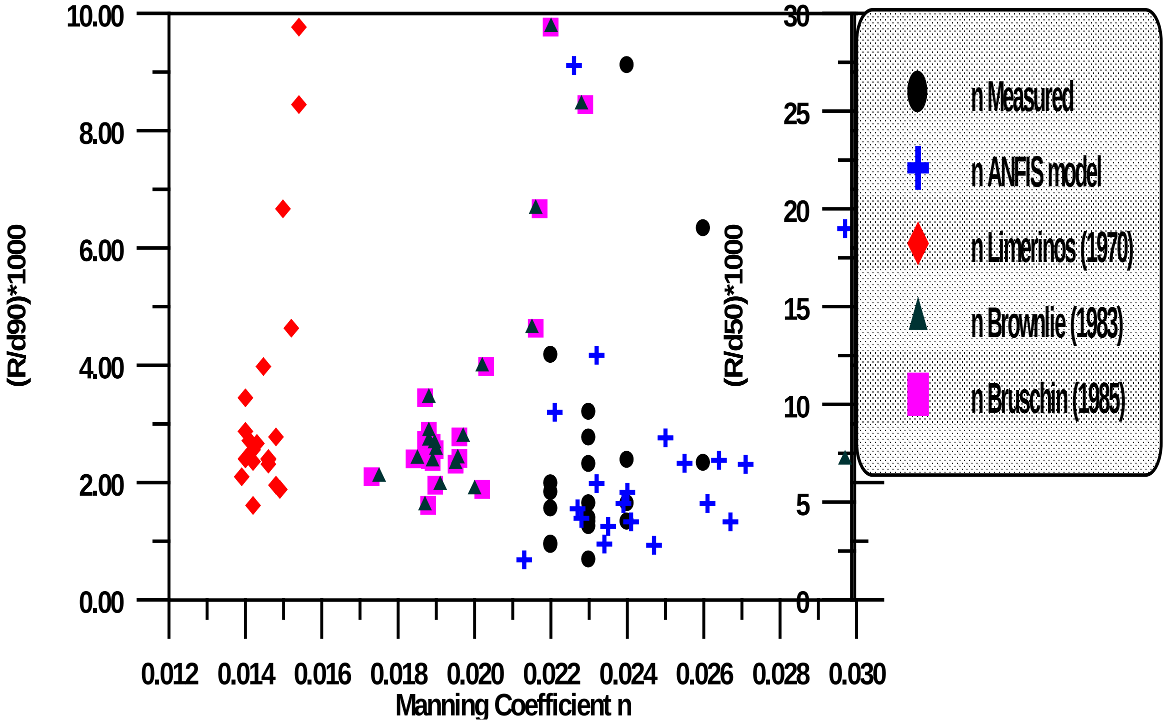

Fig.(13): Comparison between measured data, ANFIS model, Brownlie, and Bruschin equations for *n* by testing data.

A comparison of ANFIS model with empirical equations has been carried out to assess the accuracy of the intelligent models over the regression methods in the prediction of the Manning's coefficient at Al- Diwaniya river using the testing data. Based on the comparison of the results, it is well found that the ANFIS model presented here gives better estimates than the other empirical relationships based on MSE.

7- Sensitivity analysis

The sensitivity tests are commonly carried out to ascertain the relative significance of each independent parameter. The results of sensitivity analysis for the Manning coefficient parameters are shown in Table (4). This Table provides a comparison between the ANFIS model (with Gaussian membership function and d_{90}) of all independent parameters and ANFIS model having one of the independent variables removed in each case.

Table (4): Sensitivity analysis of the ANFIS model

Parameter	Performance in training process ($MSE*10^{(-3)}$)
All	1.1437
No d_{90}	2.7023
No Q	2.5183
No R	2.1437
No S	2.0974

Table (4) indicates that Sand d_{90} have the least and the largest effect on the Manning coefficient n, respectively.

8- Conclusion

In this study an attempt were made to derive new model from experimental data for computing Manning for application to sand bed streams in Iraq specially for Al-Diwania river based on 100 sections along this river (80 % for training data and 20% for testing data).This paper measured experimentally the Manning Roughness coefficient n directly and indicates the ability of adaptive neuro – fuzzy inference system (ANFIS) model to predict the Manning coefficient of Al- Diwaniya river. The ANFIS model performs better than the empirical formulas in estimating of Manning's coefficient in open channels. The ANFIS with Gaussian membership function, d_{90}, Q, R, and S were selected as optimum model to predict Manning coefficient *n*. Also, sensitivity analysis of ANFIS model demonstrated that S and d_{90} have the least and the largest effect on the Manning coefficient *n*, respectively. The study present a field work, laboratory works, and used these data for deriving ANFIS model to estimate Manning coefficient in Al- Diwaniya river.

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