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IDENTIFICATION OF OPTIMAL WASTEWATER SYSTEM PARAMETERS AIMED AT MAXIMIZING ECONOMIC PERFORMANCE

Marija Stevanović[1], Miloš Milovančević[2*]

[1]The higher health and sanitary school of vocational studies „Visan", Belgrade, Serbia,
[2]Faculty of Mechanical Engineering, University of Niš, Niš, Serbia,
***Corresponding author: milos.milovancevic@gmail.com**

Abstract: In this article, a selection procedure for identifying the most influential parameters of a wastewater treatment system with respect to maximizing economic profit is presented. Optimal wastewater treatment configurations require the adjustment of numerous system parameters to obtain economically efficient solutions. Such optimal solutions are commonly defined in terms of maximizing economic performance, typically expressed through minimizing the total cost of the wastewater treatment system. However, applying classical analytical optimization methods to this problem is time-consuming and computationally demanding due to the system's high degree of nonlinearity. Accordingly, the primary objective of this study was to determine which parameters of the wastewater treatment system exert the greatest influence on overall economic profit. To support this selection process, an Adaptive Neuro-Fuzzy Inference System (ANFIS) was employed, as this method is well-suited for handling nonlinear relationships and redundant datasets. The results indicate that system size is the dominant factor affecting economic outcomes. The obtained findings have practical significance, as they provide guidance for selecting the most economically favorable configuration for a given wastewater treatment system.

Keywords: Wastewater, Economic profit, Optimal solution, ANFIS.

INTRODUCTION

Wastewater treatment systems are inherently complex, comprising numerous interdependent parameters that influence overall process performance. To achieve substantial economic benefits in rural wastewater treatment applications, it is essential to identify those parameters that exert the greatest impact on economic profit. These key parameters simultaneously represent the primary contributors to the total costs of the wastewater treatment system. Consequently, economic profit is typically evaluated through the minimization of total system costs.

The selection of an optimal solution is of critical importance when applying economic criteria to wastewater treatment system design and operation (Abdelf-Fatah, 2018). Research on the sustainable development of wastewater systems consistently highlights the necessity of integrating environmental, social, and economic dimensions within the decision-making process (Ansari et al., 2019). Various technological configurations have been investigated to enhance wastewater treatment performance. For example, two technological setups were analyzed in (Jokanović et al., 2017), forming the basis for four alternative wastewater reclamation scenarios. In another study, a sequential approach to hydrogen and methane production from dairy industry wastewater was explored using Enterobacter aerogens and methanogenic bacteria derived from cow dung, demonstrating simultaneous pollutant reduction and biofuel generation (Novković-Cvetković et al., 2019). A thermo-economic analysis of hybrid solar conventional energy supply in a zero-liquid-discharge plant was presented in (Elreedy et al., 2019), while biogas production through anaerobic digestion of organic waste and manure has shown potential to reduce greenhouse gas emissions across multiple sectors, including waste management, transportation, energy, and agriculture (Deneva et al., 2017).

Further investigations include the development of a wastewater metabolism input–output model aimed at providing a novel framework for sustainable industrial wastewater flow assessment among economic sectors (Kothari et al., 2017). Advances in nanofiltration membrane (NF) technologies continue to represent a crucial component within modern wastewater treatment processes (Lyng et al., 2018). Additionally, independent hydrogen production from petrochemical wastewater containing mono-ethylene glycol (MEG) has been comprehensively evaluated under psychrophilic conditions using an anaerobic sequencing batch reactor (ASBR) (Mladenovic et al., 2016). Domestic wastewater, owing to its high nutrient content, also offers substantial potential for nutrient recovery through dedicated wastewater treatment technologies (Nikolić et al., 2018).

Classical analytical optimization approaches applied to wastewater treatment systems require considerable time and computational effort due to the pronounced nonlinearity of the governing equations. Therefore, the principal objective of this study is to identify the parameters of a wastewater treatment system that have the most significant influence on its economic profitability. To facilitate this selection process, an Adaptive Neuro-Fuzzy Inference System (ANFIS) was employed (Murashko et al., 2018; Najafi et al., 2019; Padilla-Rivera and Güereca, 2019; Nikolić et al., 2018; Zheng et al., 2019), as this method is particularly suitable for handling nonlinear, redundant, and complex datasets.

MATERIAL AND METHODS

Database of Wastewater System

To implement the ANFIS model, it was necessary to prepare a comprehensive database consisting of input-output data samples. Table 1 presents all variables used in the study. The input parameters include: system size; elongation factor (i.e., the length-to-width ratio of the settlement); dispersion factor (defined as the ratio between the number of households and the sewer network length); vertical terrain uniformity; proximity to the urban centre (distance between the settlement and the nearest urban node); degree of settlement clustering (distance between neighboring settlements); and distance between the wastewater treatment plant and the settlement. The total construction cost of the wastewater treatment system was used as the output variable.

Table 1. Input and output parameters of the wastewater system

Input 1 Size	Input 2 Elongation	Input 3 Dispersion	Input 4 Uniformity	Input 5 Vicinity	Input 6 Grouping	Input 7 Distance	Output Total costs
284.9	3	0.02	4.96	6.01	1.17	0.96	1039705.4

ANFIS Methodology

ANFIS network has five layers as it shown in Figure 1. The main core of the ANFIS network is fuzzy inference system. Layer 1 receives the inputs and convert them in the fuzzy value by membership functions. In this study bell shaped membership function is used since the function has the highest capability for the regression of the nonlinear data.

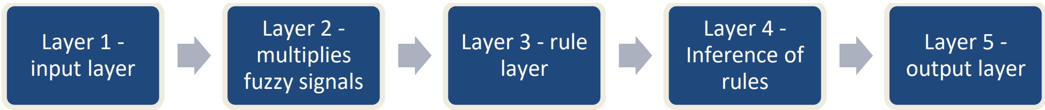


Figure 1. ANFIS layers

Bell-shaped membership functios is defined as follows:

$$\mu(x) = bell(x; a_i, b_i, c_i) = \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}} \tag{1}$$

where $\{a_i, b_i, c_i\}$ is the parameters set and x is input.

Second layer multiplies the fuzzy signals from the first layer and provides the firing strength of as rule. The third layer is the rule layers where all signals from the second layer are normalized. The fourth layer provides the inference of rules, and all signals are converted in crisp values. The final layers summarized all signals and provided the output crisp value.

RESULTS AND DISCUSSION

Accuracy Indices

Performances of the proposed models are presented as root means square error (RMSE), Coefficient of determination (R^2) and Pearson coefficient (r) as follows:

1) RMSE

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}\ , \tag{2}$$

2) Pearson correlation coefficient (r)

$$r = \frac{n\left(\sum_{i=1}^{n} O_i \cdot P_i\right) - \left(\sum_{i=1}^{n} O_i\right)\cdot\left(\sum_{i=1}^{n} P_i\right)}{\sqrt{\left(n\sum_{i=1}^{n} O_i^2 - \left(\sum_{i=1}^{n} O_i\right)^2\right)\cdot\left(n\sum_{i=1}^{n} P_i^2 - \left(\sum_{i=1}^{n} P_i\right)^2\right)}} \tag{3}$$

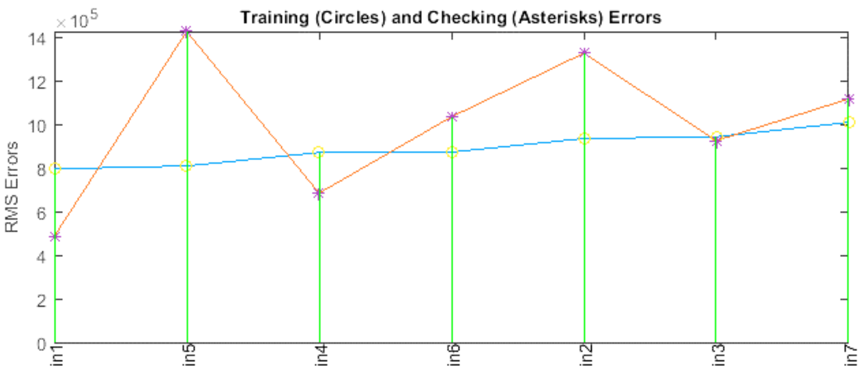
3) Coefficient of determination (R^2)

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(O_i - \overline{O_i}\right)\cdot\left(P_i - \overline{P_i}\right)\right]^2}{\sum_{i=1}^{n}\left(O_i - \overline{O_i}\right)\cdot\sum_{i=1}^{n}\left(P_i - \overline{P_i}\right)} \tag{4}$$

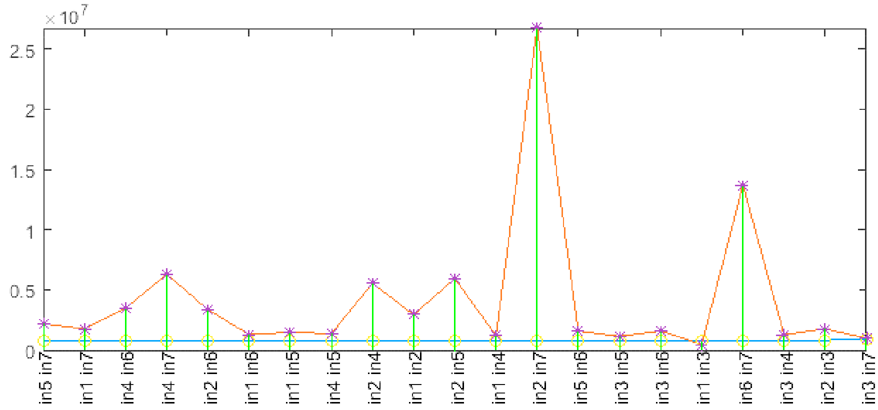
where P_i and O_i are known as the experimental and forecast values, respectively, and n is the total number of datasets.

ANFIS Results

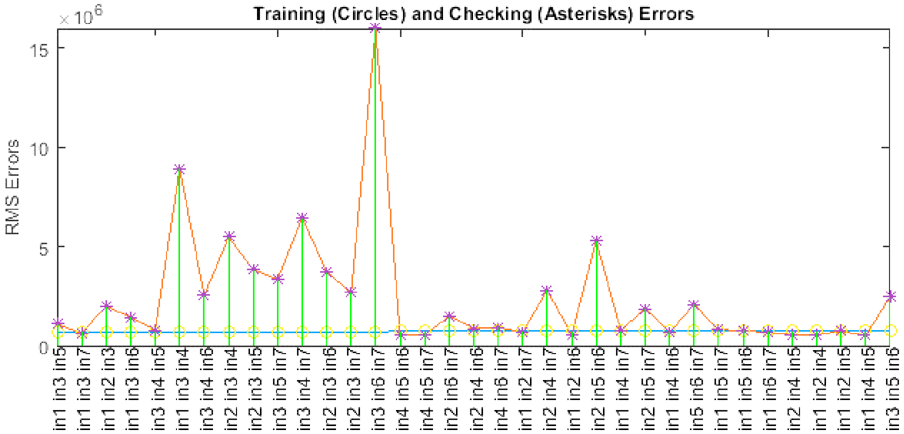
Table 3 shows the prediction errors for the total costs or economic profit of the wastewater system for single, two and three input parameters. Training RMSE shows influence of the inputs for the wastewater total costs. Smaller training errors have more influence on the wastewater total costs. Checking RMSE is used for overfitting tracking between training and checking data. Here one can see there is small overfitting for two and three input combinations since checking errors do not track training errors very well. As can be seen for single input parameters influence in Figure 2a the input parameters system size has the smallest training error therefore largest influence on the total costs of the wastewater system. Figure 2b shows two parameters' combinations and their corresponding training and checking errors for the total costs prediction of the wastewater system where combination of vicinity and distance has the smallest training error, hence the largest impact on the economic profit of the wastewater system. Finally Figure 2c shows three input combinations where one can see that the parameter system size, dispersion and vicinity form the optimal combination of three parameters for the total costs prediction of the wastewater system. Tables 2-4 show the numerical training and checking errors for all inputs combinations of the total costs prediction of the wastewater system where bolded values represent the optimal combinations.



(a)



(b)



(c)

Figure 2. Inputs' influence on the output: (a) single inputs, (b) two inputs, (c) three inputs

Table 2. Single inputs' influence on the output

ANFIS model 1: in1 --> trn=795052.3800	**chk=486121.6677**
ANFIS model 2: in2 --> trn=934493.0105	chk=1325577.0070
ANFIS model 3: in3 --> trn=942358.2941	chk=924852.5804
ANFIS model 4: in4 --> trn=870057.7917	chk=684031.8942
ANFIS model 5: in5 --> trn=809001.7197	chk=1425160.2330
ANFIS model 6: in6 --> trn=872226.5836	chk=1033930.6644
ANFIS model 7: in7 --> trn=1008353.1837	chk=1116116.8827

Table 3. Two inputs' influence on the output

ANFIS model 1: in1 in2 --> trn=724825.7907	chk=2931102.1642
ANFIS model 2: in1 in3 --> trn=774927.9722	chk=462781.9739
ANFIS model 3: in1 in4 --> trn=724825.9920	chk=1199555.0113
ANFIS model 4: in1 in5 --> trn=724825.7715	chk=1471737.5135
ANFIS model 5: in1 in6 --> trn=721190.5829	chk=1284921.6765
ANFIS model 6: in1 in7 --> trn=721190.0175	chk=1756868.7562
ANFIS model 7: in2 in3 --> trn=813386.0264	chk=1746867.8528
ANFIS model 8: in2 in4 --> trn=724825.7716	chk=5531286.3668
ANFIS model 9: in2 in5 --> trn=724825.8296	chk=5920287.0186
ANFIS model 10: in2 in6 --> trn=721190.1054	chk=3351655.9556

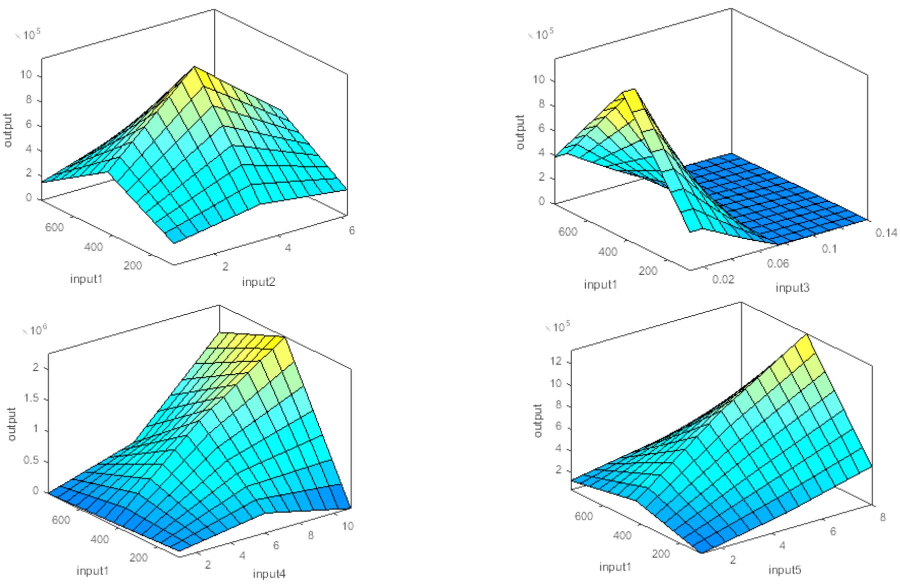
ANFIS model 11:	in2 in7 --> trn=732752.1817	chk=26719811.3762
ANFIS model 12:	in3 in4 --> trn=791683.6982	chk=1265159.0159
ANFIS model 13:	in3 in5 --> trn=762214.7836	chk=1137596.5035
ANFIS model 14:	in3 in6 --> trn=772622.1657	chk=1570964.2008
ANFIS model 15:	in3 in7 --> trn=873703.5481	chk=975834.5975
ANFIS model 16:	in4 in5 --> trn=724825.7715	chk=1362411.5779
ANFIS model 17:	in4 in6 --> trn=721190.0175	chk=3462676.9435
ANFIS model 18:	in4 in7 --> trn=721190.1050	chk=6293597.5250
ANFIS model 19:	in5 in6 --> trn=756651.3649	chk=1562383.1620
ANFIS model 20:	**in5 in7 --> trn=721190.0066**	**chk=2184588.3894**
ANFIS model 21:	in6 in7 --> trn=788304.2828	chk=13688525.4462

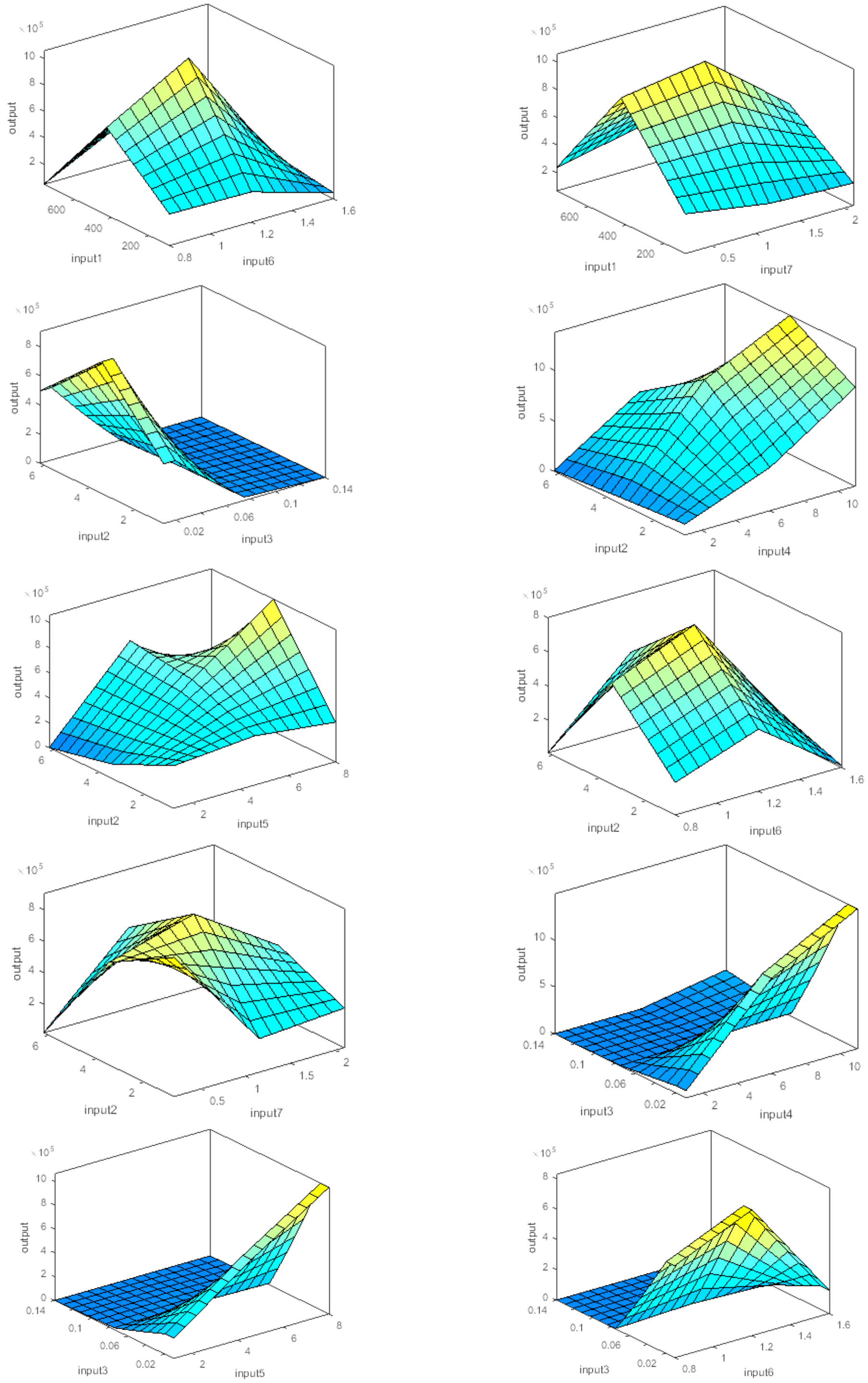
Table 4. Three inputs' influence on the output

ANFIS model 1:	in1 in2 in3 --> trn=717062.3526,	chk=1991830.1402
ANFIS model 2:	in1 in2 in4 --> trn=724825.7715	chk=541577.8279
ANFIS model 3:	in1 in2 in5 --> trn=724825.7719	chk=727232.1725
ANFIS model 4:	in1 in2 in6 --> trn=721190.0012	chk=550695.9397
ANFIS model 5:	in1 in2 in7 --> trn=721190.0012	chk=676052.4503
ANFIS model 6:	in1 in3 in4 --> trn=717062.3621	chk=8919082.8974
ANFIS model 7:	**in1 in3 in5 --> trn=717062.3524**	**chk=1080947.4127**
ANFIS model 8:	in1 in3 in6 --> trn=717062.3528	chk=1437260.3746
ANFIS model 9:	in1 in3 in7 --> trn=717062.3526	chk=642086.9245
ANFIS model 10:	in1 in4 in5 --> trn=724825.7729	chk=515033.0225
ANFIS model 11:	in1 in4 in6 --> trn=721190.0012	chk=673446.7701
ANFIS model 12:	in1 in4 in7 --> trn=721190.0012	chk=774892.2500
ANFIS model 13:	in1 in5 in6 --> trn=721190.0068	chk=780201.7730
ANFIS model 14:	in1 in5 in7 --> trn=721190.0028	chk=799408.8123
ANFIS model 15:	in1 in6 in7 --> trn=721190.0161	chk=667044.1730
ANFIS model 16:	in2 in3 in4 --> trn=717062.3679	chk=5470009.1720
ANFIS model 17:	in2 in3 in5 --> trn=717062.3735	chk=3823271.6177
ANFIS model 18:	in2 in3 in6 --> trn=717062.5549	chk=3718324.6971
ANFIS model 19:	in2 in3 in7 --> trn=717063.6139	chk=2667008.2019
ANFIS model 20:	in2 in4 in5 --> trn=724825.7714	chk=563687.6772
ANFIS model 21:	in2 in4 in6 --> trn=721190.0012	chk=861955.0153
ANFIS model 22:	in2 in4 in7 --> trn=721190.0012	chk=2797595.2049
ANFIS model 23:	in2 in5 in6 --> trn=721190.0012	chk=5292965.2192
ANFIS model 24:	in2 in5 in7 --> trn=721190.0012	chk=1869850.4545
ANFIS model 25:	in2 in6 in7 --> trn=721190.0012	chk=1486697.1116
ANFIS model 26:	in3 in4 in5 --> trn=717062.3536	chk=779282.7756
ANFIS model 27:	in3 in4 in6 --> trn=717062.3626	chk=2528292.0317
ANFIS model 28:	in3 in4 in7 --> trn=717062.4691	chk=6453906.4347
ANFIS model 29:	in3 in5 in6 --> trn=730327.4828	chk=2471711.0046
ANFIS model 30:	in3 in5 in7 --> trn=717062.3805	chk=3332526.6893
ANFIS model 31:	in3 in6 in7 --> trn=717679.4983	chk=15975926.5099
ANFIS model 32:	in4 in5 in6 --> trn=721190.0012	chk=539168.0373
ANFIS model 33:	in4 in5 in7 --> trn=721190.0012	chk=548010.1157
ANFIS model 34:	in4 in6 in7 --> trn=721190.0012	chk=925331.3952
ANFIS model 35:	in5 in6 in7 --> trn=721190.0023	chk=2079240.9627

Figure 3 shows the ANFIS decision surfaces for the economic profit of wastewater treatment system based on different combinations of inputs. The combinations created based on mean values of the inputs and can be listed as follows:

1.	*Input 1*	*Input 2*	0.02616	4.964	6.015	1.178	0.9673
2.	*Input 1*	3.008	*Input 3*	4.964	6.015	1.178	0.9673
3.	*Input 1*	3.008	0.02616	*Input 4*	6.015	1.178	0.9673
4.	*Input 1*	3.008	0.02616	4.964	*Input 5*	1.178	0.9673
5.	*Input 1*	3.008	0.02616	4.964	6.015	*Input 6*	0.9673
6.	*Input 1*	3.008	0.02616	4.964	6.015	1.178	*Input 7*
7.	284.9	*Input 2*	*Input 3*	4.964	6.015	1.178	0.9673
8.	284.9	*Input 2*	0.02616	*Input 4*	6.015	1.178	0.9673
9.	284.9	*Input 2*	0.02616	4.964	*Input 5*	1.178	0.9673
10.	284.9	*Input 2*	0.02616	4.964	6.015	*Input 6*	0.9673
11.	284.9	*Input 2*	0.02616	4.964	6.015	1.178	*Input 7*
12.	284.9	3.008	*Input 3*	*Input 4*	6.015	1.178	0.9673
13.	284.9	3.008	*Input 3*	4.964	*Input 5*	1.178	0.9673
14.	284.9	3.008	*Input 3*	4.964	6.015	*Input 6*	0.9673
15.	284.9	3.008	*Input 3*	4.964	6.015	1.178	*Input 7*
16.	284.9	3.008	0.02616	*Input 4*	*Input 5*	1.178	0.9673
17.	284.9	3.008	0.02616	*Input 4*	6.015	*Input 6*	0.9673
18.	284.9	3.008	0.02616	*Input 4*	6.015	1.178	*Input 7*
19.	284.9	3.008	0.02616	4.964	*Input 5*	*Input 6*	0.9673
20.	284.9	3.008	0.02616	4.964	*Input 5*	1.178	*Input 7*
21.	284.9	3.008	0.02616	4.964	6.015	*Input 6*	*Input 7*

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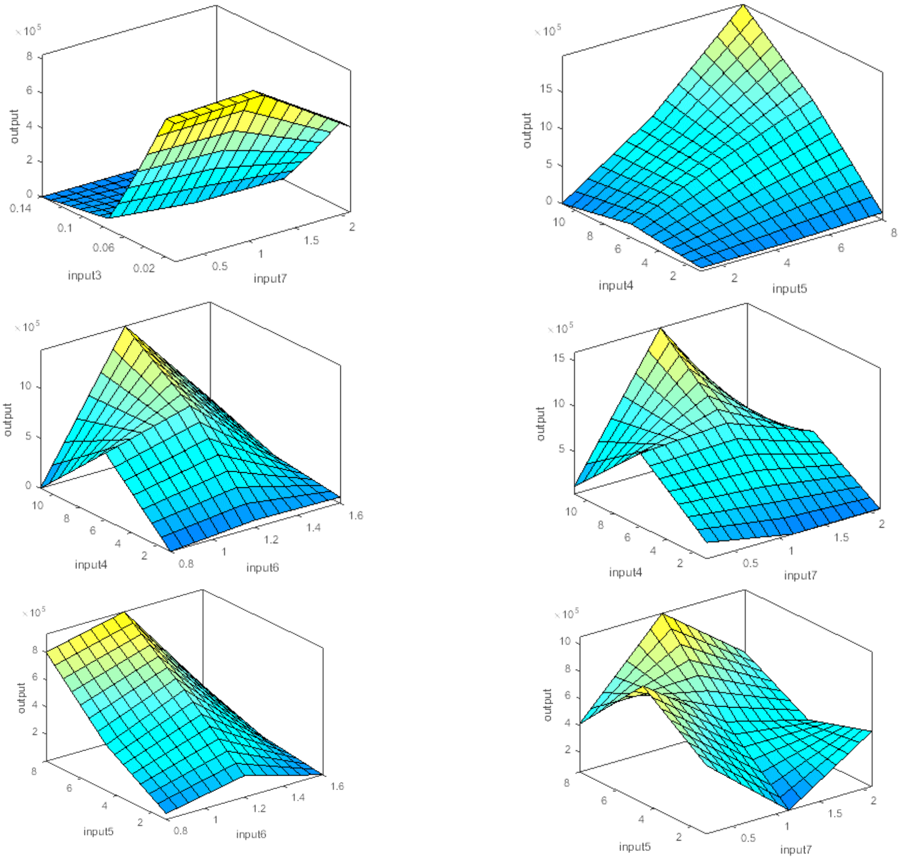

Figure 3. ANFIS decision surfaces for the economic profit of wastewater treatment system based on different combinations of inputs

CONCLUSION

In this article, adaptive neuro fuzzy inference system (ANFIS) is used for selection procedures in order to identify the most influential parameters of wastewater treatment system based on economic profit. Results revealed that the size of the system has the most influence on economic profit. Furthermore, obtained solutions could be of practical importance since one could select which solutions are the most suitable for particular wastewater treatment system.

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