5.13. Adaptive Neuro Fuzzy Inference System (ANFIS)

Majority of research papers dealing with WCP forecasting use ANNs, while the use of Adaptive Neuro Fuzzy Inference System (ANFIS) to treat such problems is relatively new. In this part of the thesis, ANFIS is adopted to build general rules on water consumption behavior and patterns in a simplified manner. Following from that, the obtained results helped to build a forecasting model.

5.13.1. Input selection and models construction

For modeling with ANFIS, input combination of 8 scenarios are selected to cover all possible combinations. The reason behind this selection is the limitation of the model (number of inputs). S1, S2, S3 and S4 were conducted in order to evaluate the effect of socio-economic parameters on WCP. On the other hand, the selection of S5 aims to determine the effect of physical characteristics of building units on WCP. As it can be inferred S6, S7 and S8 are the input combination that mixed socio-economic parameters with physical characteristics of building units in order to assess the effect of them on WCP. The selected models and their inputs are represented in table 5.26.

Table 5.26: Classification of neuro fuzzy models for inputs data

Scenarios	HOUS	FEM	INC	AG1	AG3	CARN	PRS	HGS	UNIV	TAR	BAR	ROMN
S1	**X**	**X**	**X**									
S2				**X**	**X**	**X**						
S3							**X**	**X**	**X**			
S4	**X**					**X**			**X**			
S5										**X**	**X**	**X**
S6		**X**	**X**								**X**	
S7	**X**		**X**									**X**
S8					**X**			**X**			**X**	

5.13.2. Training, Testing and Checking of ANFIS models

The input data of ANFIS were divided into three sections : *training, testing* and *checking sections* in the same manner similar to ANNs (for training data size: 50%, 60%, 70% and 80%, for testing data size: 10%, 15%, 20% and 25%, and for validating data size 10%, 15%, 20% and 25%). The selected sections are shown in table 5.27.

ANFIS of MATLAB Fuzzy Logic is not designed to create models in an automated way; rather the trial-and-error approach was used to find the best model. In each time the ANFIS parameters were changed manually, besides the choice of ANFIS structure type, membership function types, training algorithm alternatives of ANFIS were limited compared to ANNs.

Table 5.27: classification of neuro fuzzy models for inputs data

Scenarios	Training inputs	Testing inputs	Checking inputs
S1	50%	25%	25%
S2	60%	20%	20%
S3	70%	15%	15%
S4	80%	10%	10%
S5	50%	25%	25%
S6	70%	15%	15%
S7	60%	20%	20%
S8	50%	25%	25%

To construct fuzzy models the fuzzy toolbox of MATLAB (FIS) is used. ANFIS is able to construct models with both subtractive clustering and grid partition categories. The toolbox grid partition approach is used for model construction and producing fuzzy rules. The topology of the ANFIS model with grid partition including 3 inputs for the eight scenarios S1-S8, where every input has 3 input-membership function, as shown in figure 5.65.

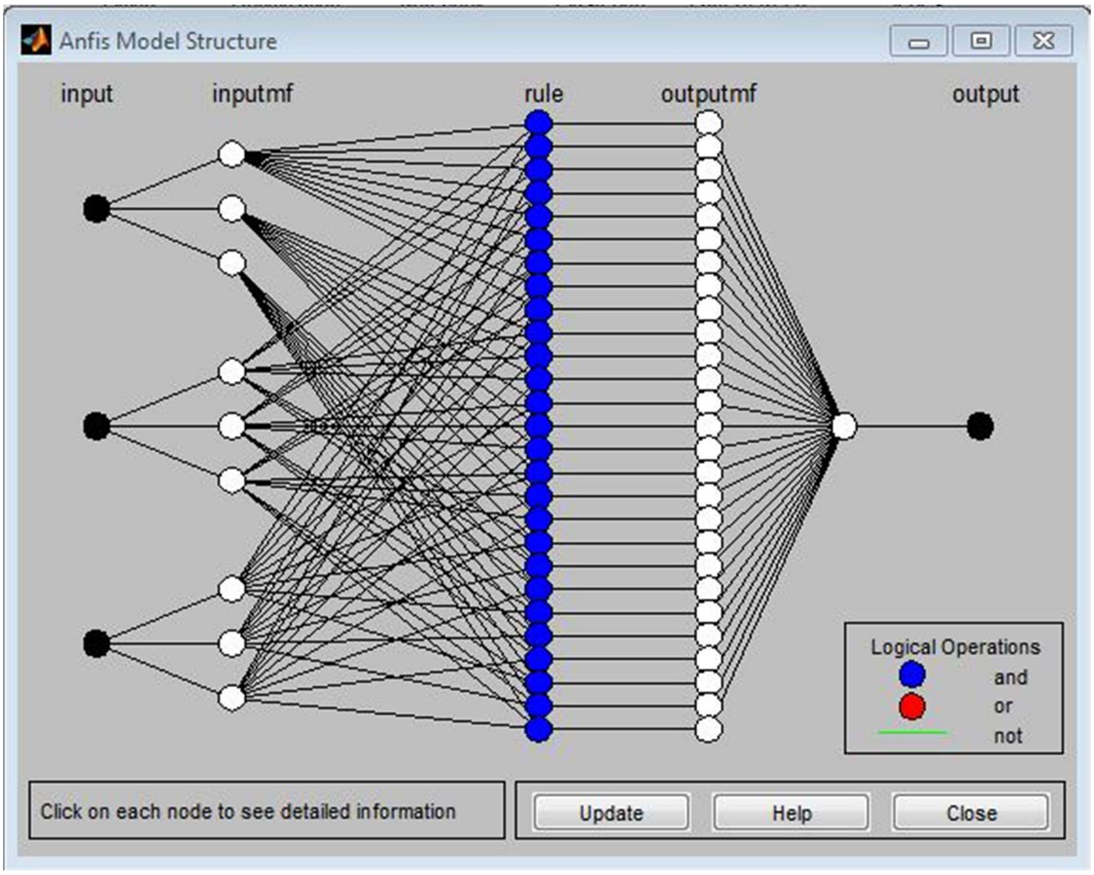

Fig 5.65 Topology of fuzzy and neuro-fuzzy models with grid partition (3 inputs)

The model can be described as follows:

- Layer 1 (input layer): No computation is considered in this layer. Each node, which corresponds to one input variable, only transmits input values to the next layer directly. For example, there are 3 input variables in scenario 4 that are household size (HOUS), university level of residents (UNIV) and car numbers (CARN).
- Layer 2 (fuzzification layer): each node in this layer corresponds one linguistic label to one of the input variables in layer 2. In other words, the output link represents the membership value that specifies the degree to which an input value belongs to a fuzzy set. In the subtractive grid category, a bell-shaped Gaussian function is used for the membership function in the following for (Jang, 1993):

$$\mu_{i,j}\left(X_j\right)=\exp\left(-\frac{\left(X_j-c_{ij}\right)^2}{2\sigma_{ij}^{\;2}}\right) j=1,2 \qquad (5.6)$$

Where, $\mu_{i,j}$ is the membership function or the degree of the membership of variable j in the *i-th* fuzzy implication rule; $\mu_{\,i,j}$ (Xj) indicates membership degree of the *i*-th input variable (X_j); c_{ij} and σ_{ij} represent the center and the half width of the membership function for the *j-th* variable and the *i-th* fuzzy implication rule, respectively.

- Layer 3 (rule antecedent): a node represents the antecedent part of a rule. Normally a T-norm operator is used in this node. Output of the layer 3 represents the firing strength of the corresponding fuzzy rule.
- Layer 4 (combination and defuzzification layer): the single node computes the overall output as a summation of all the incoming signals. The output of N fuzzy implication rules is obtained as follows for grid partition and subtractive clustering:

$$S=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} s_{ij}w_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{m} w_{ij}} \qquad (5.7)$$

In which w_i is the firing strength of the *i-th* fuzzy implication rule, n is the number of the clusters, S_i is the daily water demand estimation value from the *i-th* fuzzy implication rule and S is the estimated daily water demand (Jang, 1993).

Train and validation data are used for constructing neuro fuzzy models, while checking data controls the training error.

Figure 5.66 shows the training, testing and checking data with FIS output and training error for neuro fuzzy in scenario1 with 300 epochs.

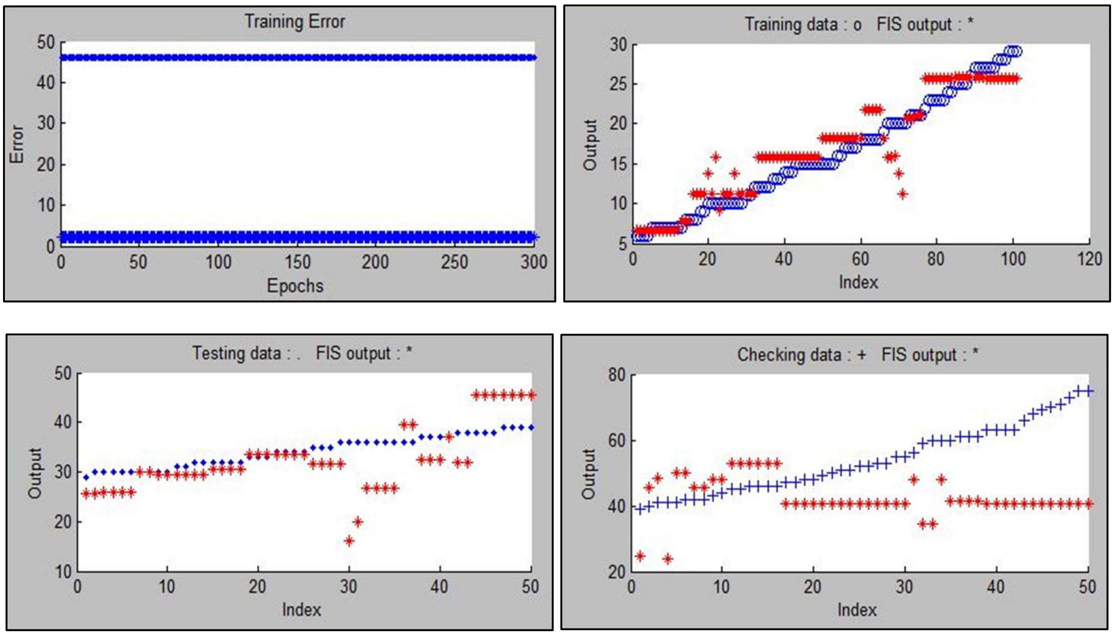

Fig 5.66 Training error and training, testing and checking data with FIS output, scenario 1

The training, testing and checking data with FIS output and training error for neuro fuzzy in scenario 2 are presented in figure 5.67.

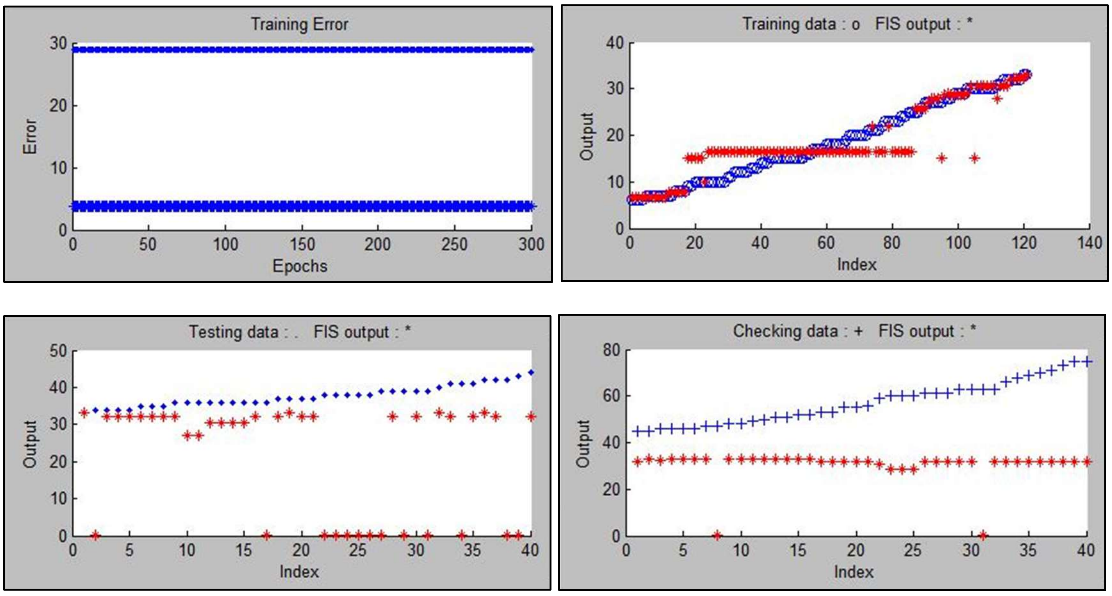

Fig 5.67 Training error and training, testing and checking data with FIS output, scenario 2

The training, testing and checking data with FIS output and training error for neuro fuzzy in scenario 3 are presented in figure 5.68.

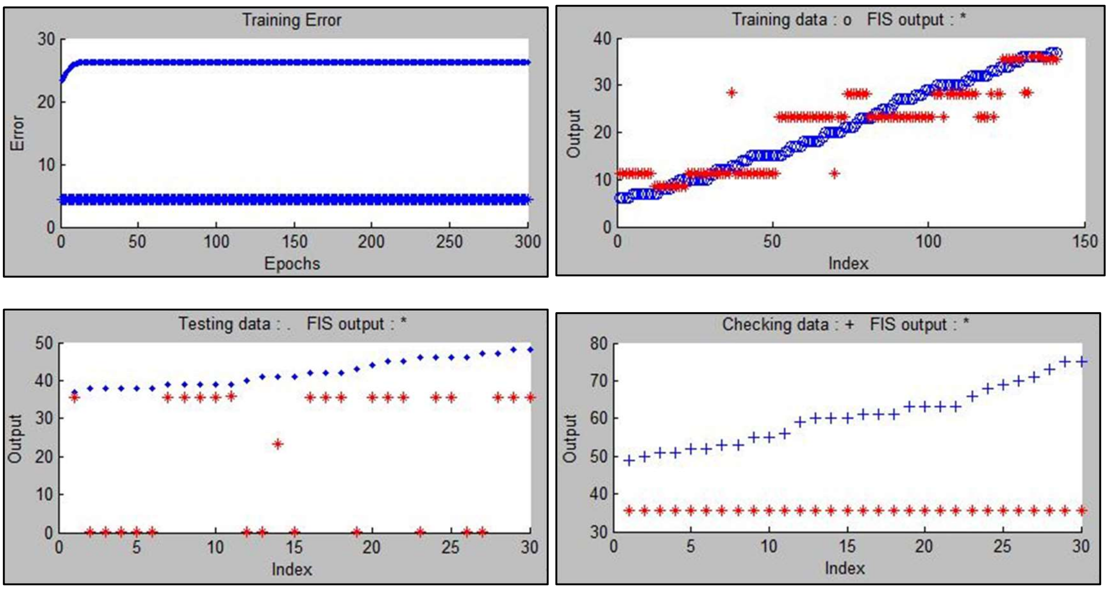

Fig 5.68 Training error and training, testing and checking data with FIS output, scenario 3

The training, testing and checking data with FIS output and training error for neuro fuzzy in scenario 4 are presented in figure 5.69.

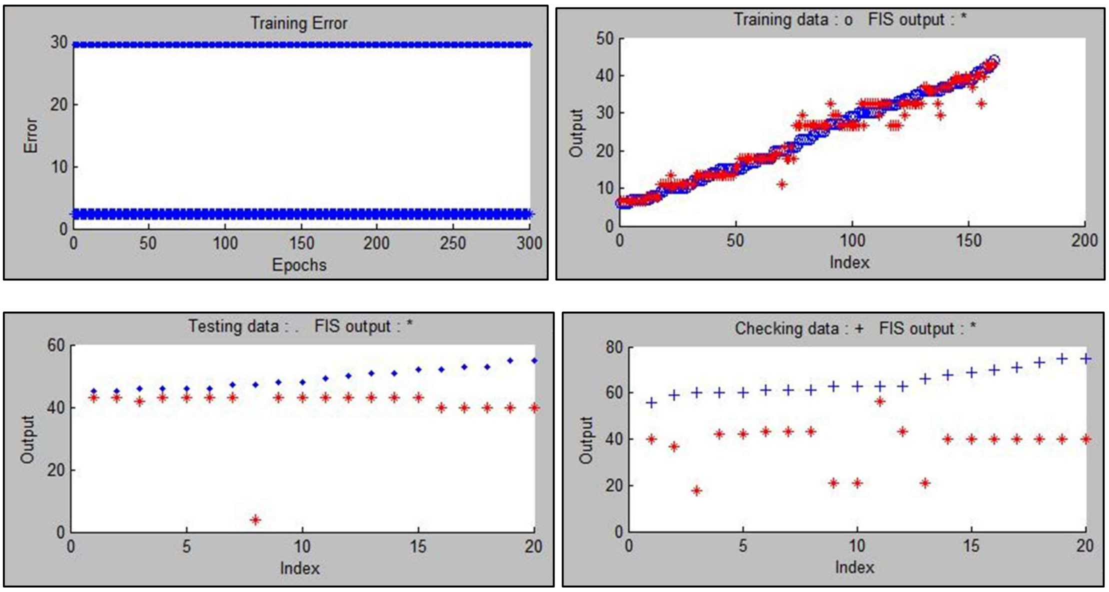

Fig 5.69 Training error and training, testing and checking data with FIS output, scenario 4

Figure 5.70 demonstrates the training, testing and checking data with FIS output. Also, it shows the training error for neuro fuzzy in scenario 5.

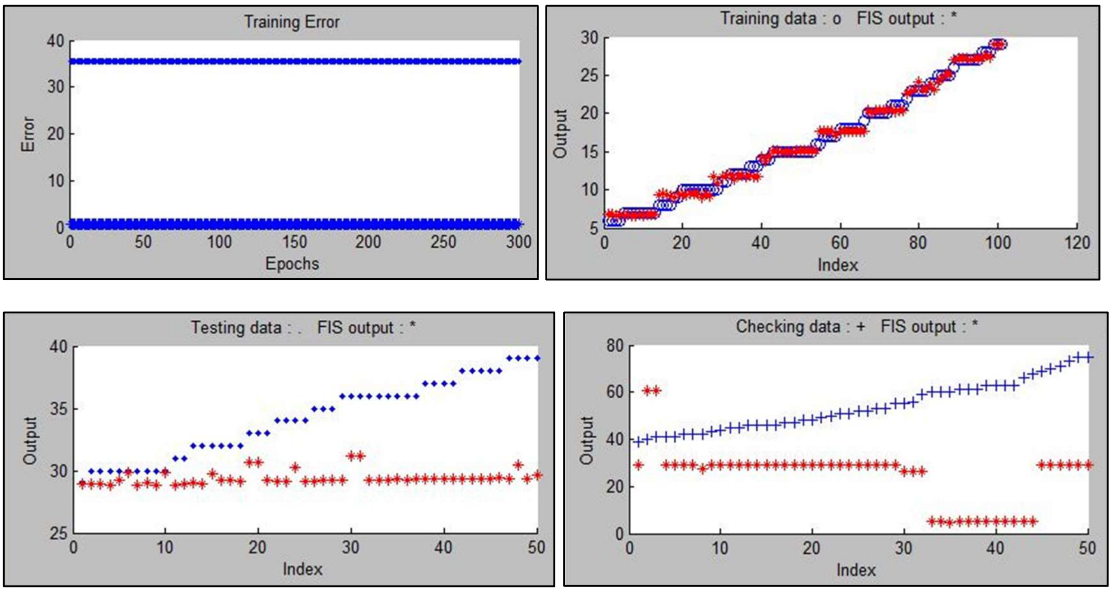

Fig 5.70 Training error and training, testing and checking data with FIS output, scenario 5

Figure 5.71 illustrates the training, testing and checking data with FIS output. In addition, it shows the training error for neuro fuzzy in scenario 6.

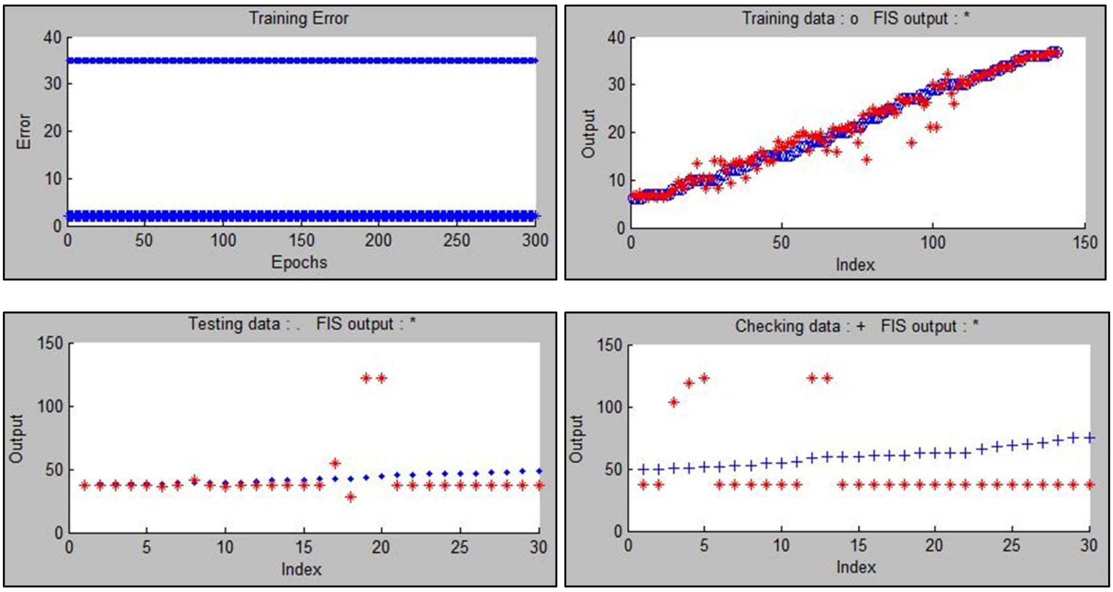

Fig 5.71 Training error and training, testing and checking data with FIS output, scenario 6

Figure 5.72 demonstrates the training, testing and checking data with FIS output. Also, it shows the training error for neuro fuzzy in scenario 7.

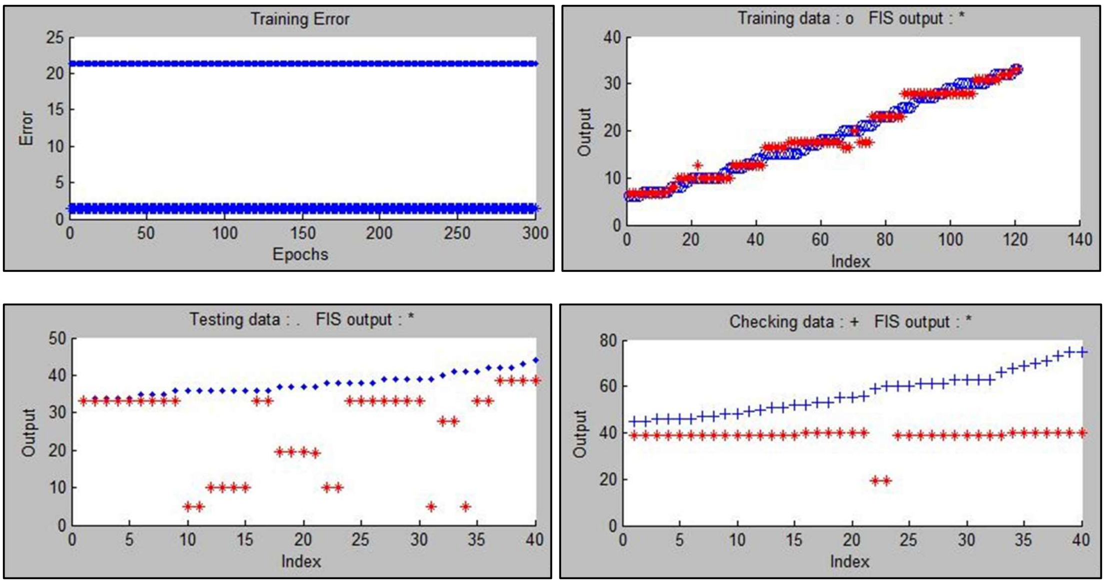

Fig 5.72 Training error and training, testing and checking data with FIS output, scenario 7

Figure 5.73 demonstrates the training, testing and checking data with FIS output. Also, it shows the training error for neuro fuzzy in scenario 8.

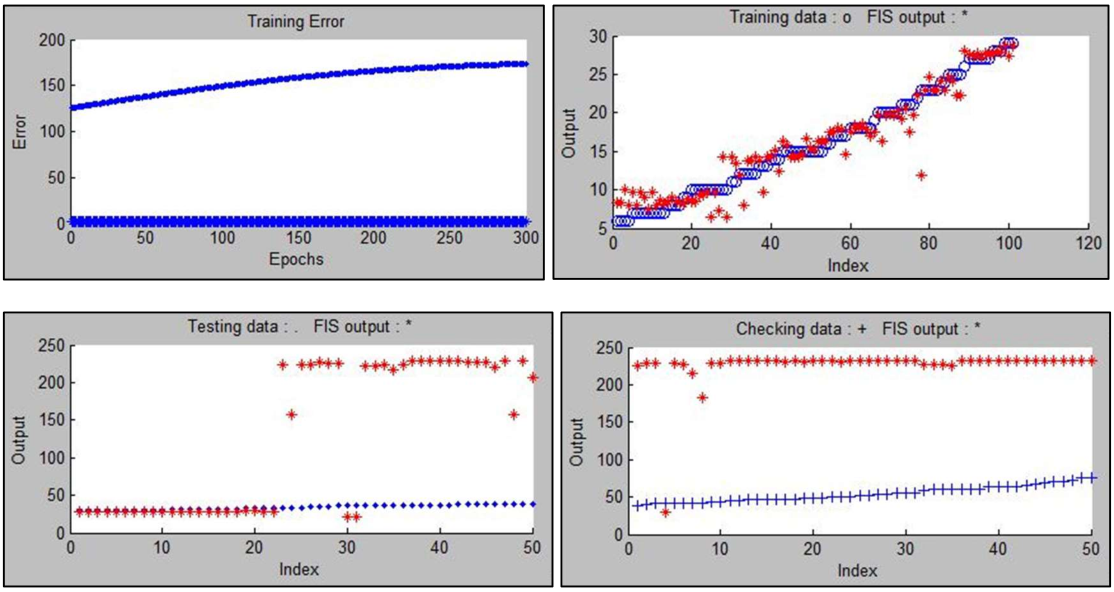

Fig 5.73 Training error and training, testing and checking data with FIS output, scenario 8

In this figures, minimum validation error indicates the optimum number of epochs (300) for construction and testing of the models.

5.13.3. Fuzzy Rule based and Membership functions

The dataset is applied on the Fuzzy logic for the classification purpose. Figures 5.74 shows the modelling of Fuzzy Logic which helps in the classification of the WCP classes.

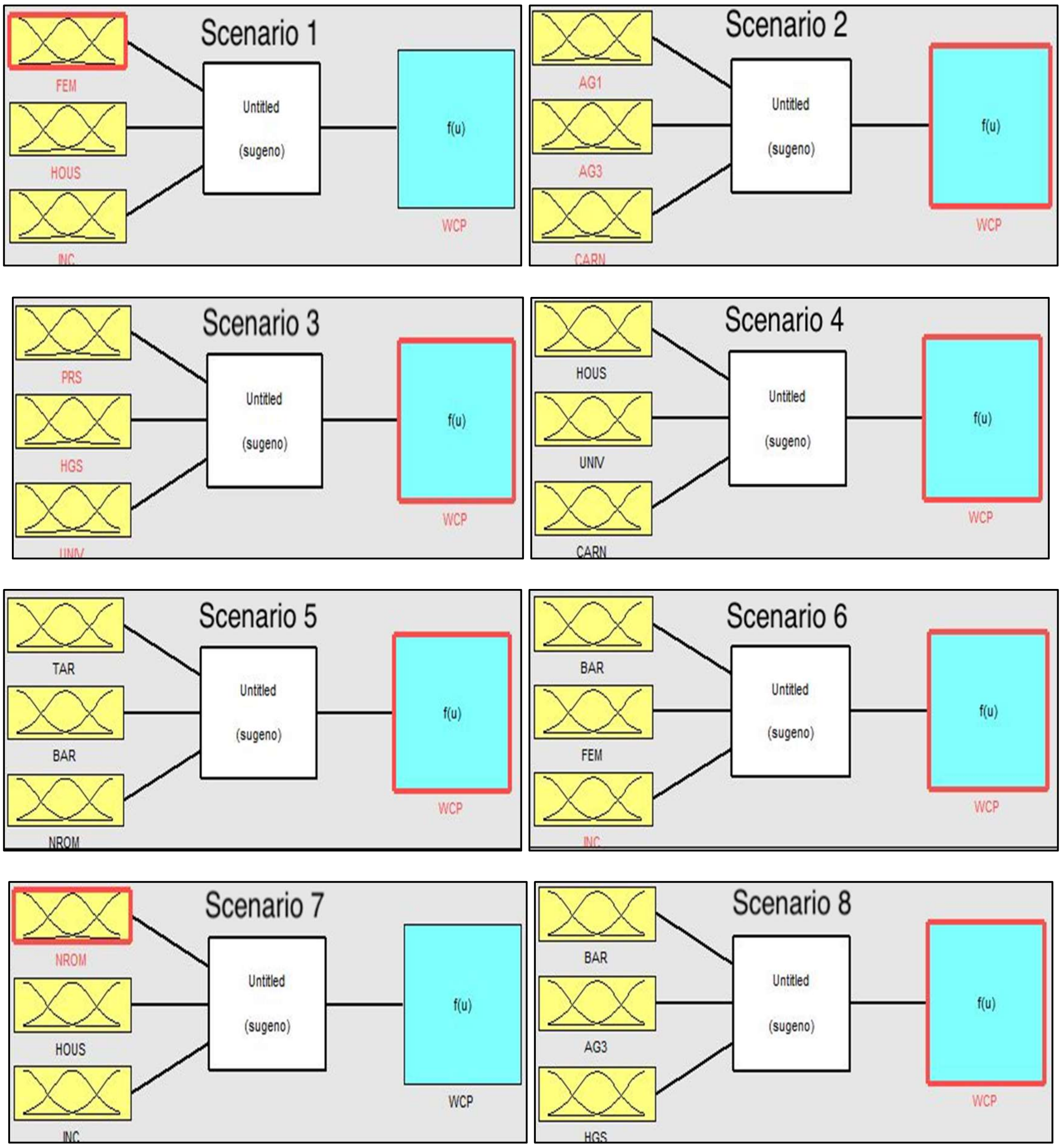

Fig 5.74 Fuzzy rule-based models

The Sugeno model is used in the system. The Sugeno model is computationally efficient, and works well with optimization and adaptive techniques, so it is popular for water problems.

Figures 5.75-5.82 depicted the membership functions for the inputs and the output. Gaussian functions are used for the inputs because of its smoothness.

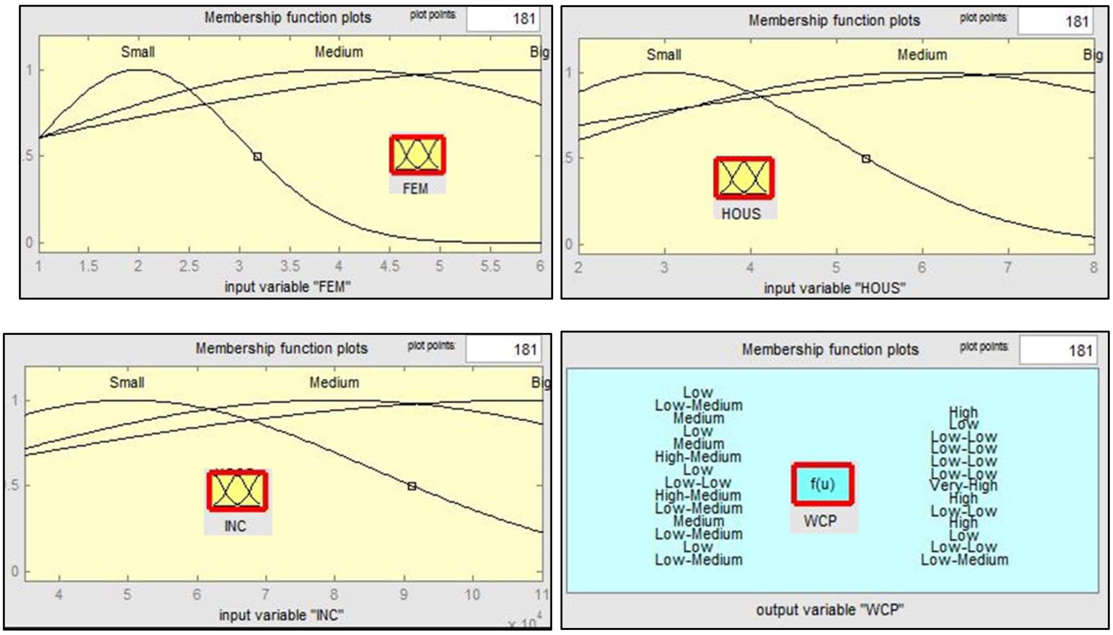

Fig 5.75 Membership functions for inputs and output, scenario 1

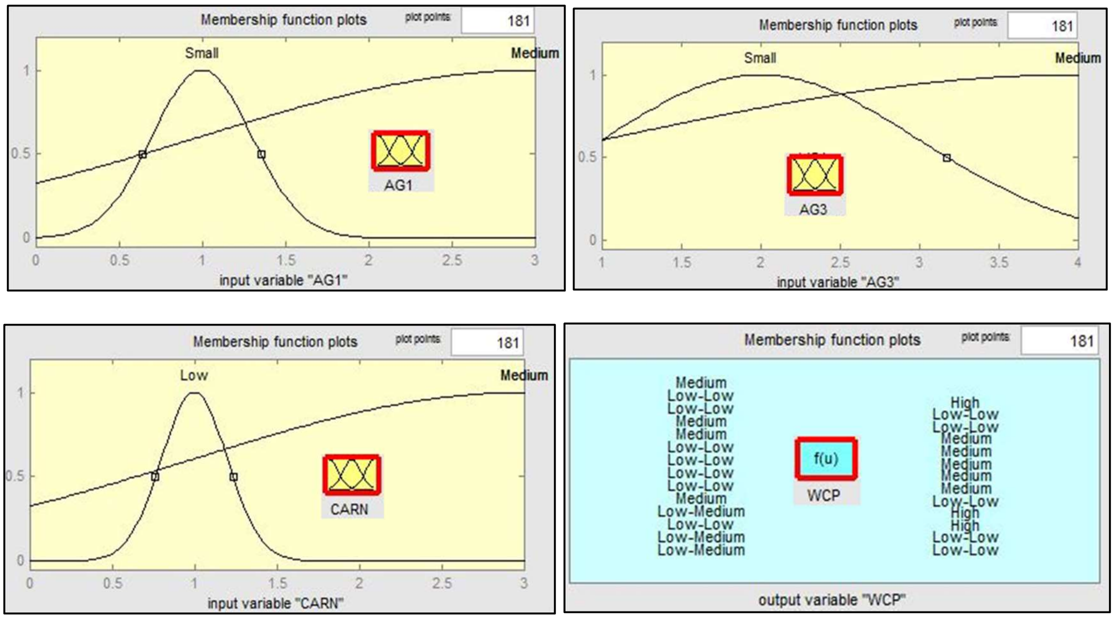

Fig 5.76 Membership functions for inputs and output, scenario 2

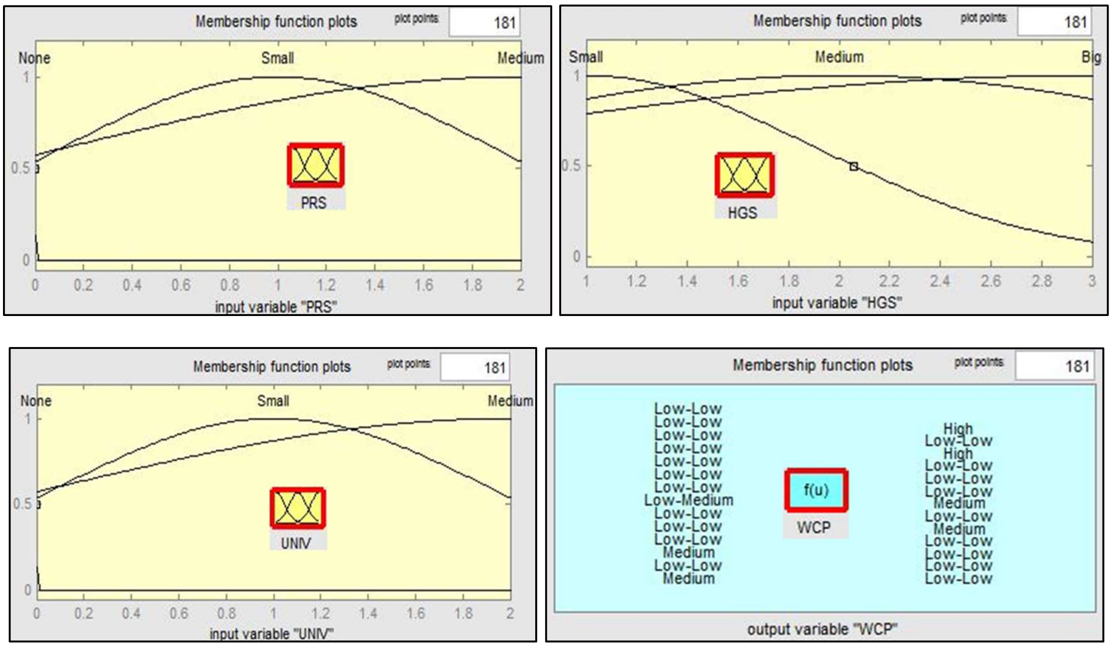

Fig 5.77 Membership functions for inputs and output, scenario 3

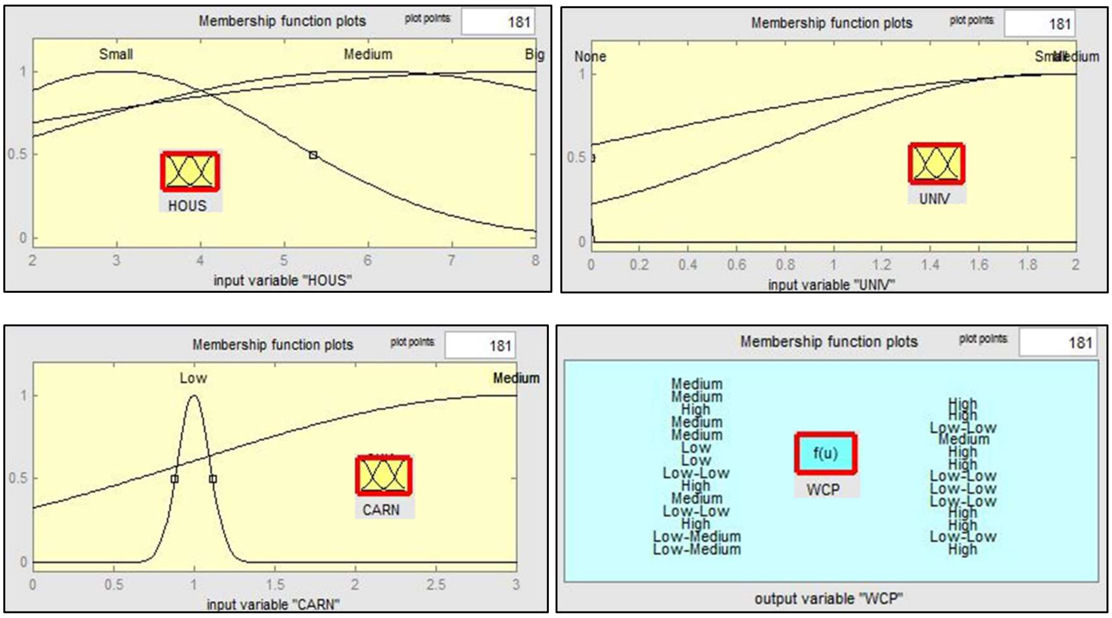

Fig 5.78 Membership functions for inputs and output, scenario 4

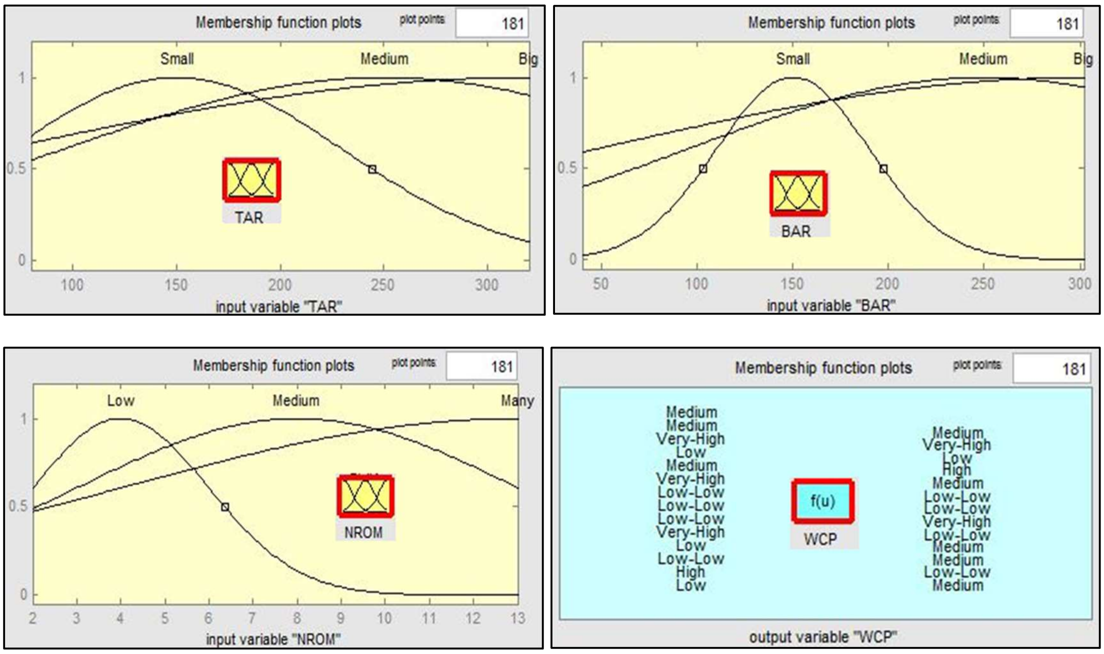

Fig 5.79 Membership functions for inputs and output, scenario 5

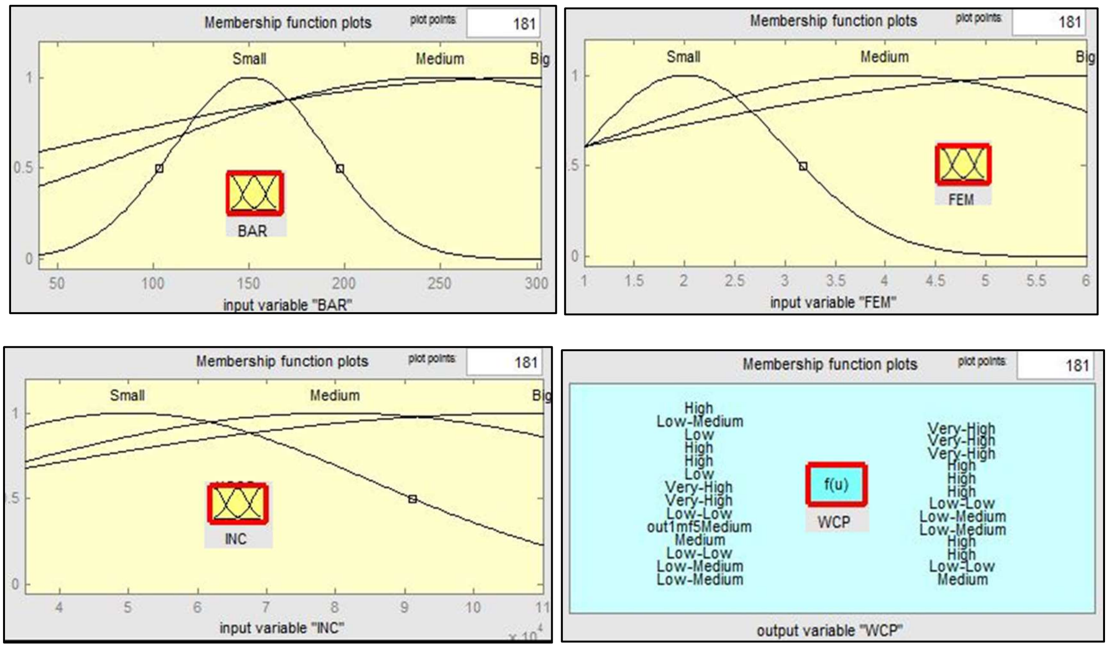

Fig 5.80 Membership functions for inputs and output, scenario 6

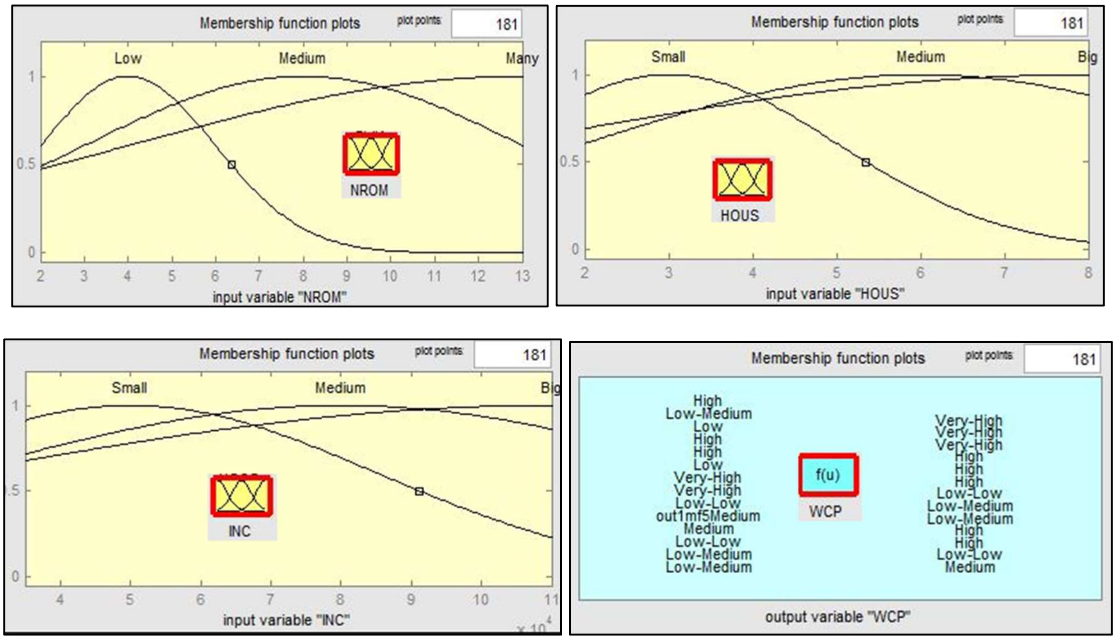

Fig 5.81 Membership functions for inputs and output, scenario 7

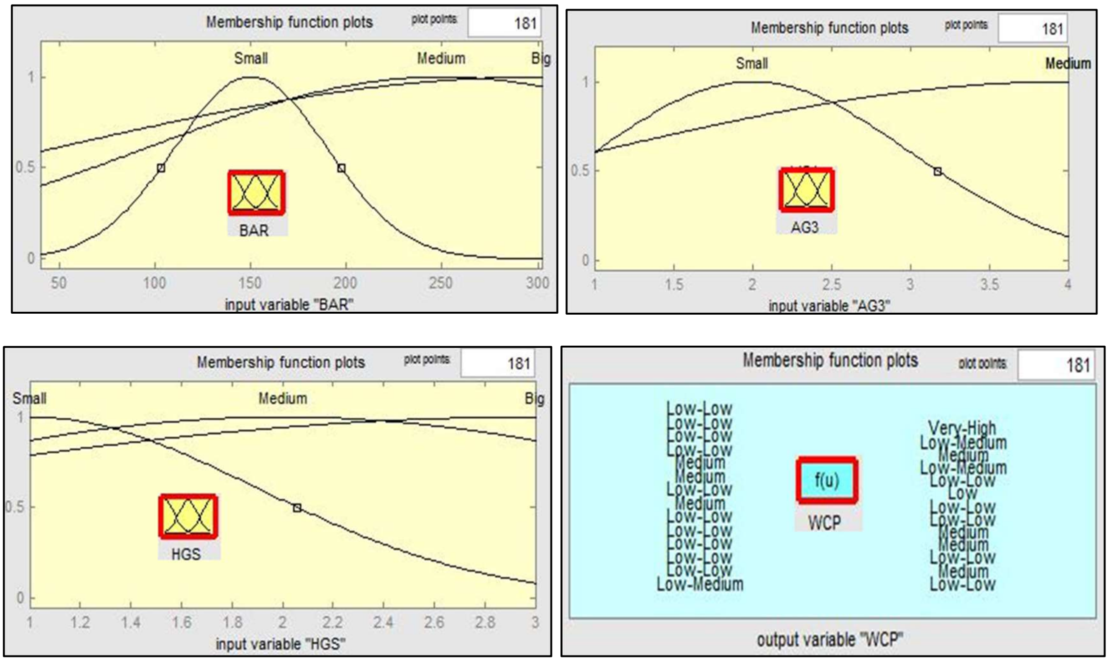

Fig 5.82 Membership functions for inputs and output, scenario 8

5.13.4. Fuzzy Rules

The eight models had 27 rules. Tables 5.28-5.36 demonstrates the fuzzy rules of water consumption. For the inputs, the fuzzy set is divided into small, medium, and big for females, Household size, Income, Age Category 1, Age Category 3, Car Number, Primary School, High School, University, Total Area of the house, Building Area. For Number of Rooms, the fuzzy set is divided into Few, Medium and Many.

As the output factor, the fuzzy sets are divided into following values: low– low, low, low–medium, medium, high–medium, high, and very high.

Table 5.28 Fuzzy rules for water consumption of scenario 1

Rules	Females	Household size	Income	Water Consumption
1	Small	Small	Small	Low-Medium
2	Small	Small	Medium	Low
3	Small	Small	Big	Low-Medium
4	Small	Medium	Small	Medium
5	Small	Medium	Medium	Low-Medium
6	Small	Medium	Big	High-Medium
7	Small	Big	Small	Low-Low
8	Small	Big	Medium	Low
9	Medium	Big	Big	High-Medium
10	Medium	Small	Small	Medium
11	Medium	Small	Medium	Low
12	Medium	Small	Big	Medium
13	Medium	Medium	Small	Low-Medium
14	Medium	Medium	Medium	Low
15	Medium	Medium	Big	Low-Medium
16	Medium	Big	Small	Low-Low
17	Medium	Big	Medium	Low
18	Medium	Big	Big	High
19	Big	Small	Small	Low-Low
20	Big	Small	Medium	High
21	Big	Small	Big	Very-High
22	Big	Medium	Small	Low-Low
23	Big	Medium	Medium	Low-Low
24	Big	Medium	Big	Low-Low
25	Big	Big	Small	Low-Low
26	Big	Big	Medium	Low
27	Big	Big	Big	High

Table 5.29 Fuzzy rules for water consumption of scenario 2

Rules	Age Category 1	Age Category 3	Car Number	Water Consumption
1	Small	Small	Low	Low-Medium
2	Small	Small	Medium	Low-Medium
3	Small	Small	Medium	Low-Medium
4	Small	Medium	Low	Low-Medium
5	Small	Medium	Medium	Medium
6	Small	Medium	Medium	Low-Low
7	Small	Medium	Low	Low-Low
8	Small	Medium	Medium	Low-Low
9	Small	Medium	Medium	Low-Low
10	Medium	Small	Low	Medium
11	Medium	Small	Medium	Medium
12	Medium	Small	Medium	Low-Low
13	Medium	Medium	Low	Low-Low
14	Medium	Medium	Medium	Medium
15	Medium	Medium	Medium	Low-Low
16	Medium	Medium	Low	Low-Low
17	Medium	Medium	Medium	High
18	Medium	Medium	Medium	High
19	Medium	Small	Low	Low-Low
20	Medium	Small	Medium	Medium
21	Medium	Small	Medium	Medium
22	Medium	Medium	Low	Medium
23	Medium	Medium	Medium	Medium
24	Medium	Medium	Medium	Medium
25	Medium	Medium	Low	Low-Low
26	Medium	Medium	Medium	Low-Low
27	Medium	Medium	Medium	High

Table 5.30 Fuzzy rules for water consumption of scenario 3

Rules	Primary School	High School	University	Water Consumption
1	None	Small	None	Medium
2	None	Small	Small	Low-Low
3	None	Small	Medium	Medium
4	None	Medium	None	Low-Low
5	None	Medium	Small	Low-Low
6	None	Medium	Medium	Low-Low
7	None	Big	None	Low-Medium
8	None	Big	Small	Low-Low
9	None	Big	Medium	Low-Low
10	Small	Small	None	Low-Low
11	Small	Small	Small	Low-Low
12	Small	Small	Medium	Low-Low
13	Small	Medium	None	Low-Low
14	Small	Medium	Small	Low-Low
15	Small	Medium	Medium	Low-Low
16	Small	Big	None	Low-Low
17	Small	Big	Small	Low-Low
18	Small	Big	Medium	Low-Low
19	Medium	Small	None	Medium
20	Medium	Small	Small	Low-Low
21	Medium	Small	Medium	Medium
22	Medium	Medium	None	Low-Low
23	Medium	Medium	Small	Low-Low
24	Medium	Medium	Medium	Low-Low
25	Medium	Big	None	High
26	Medium	Big	Small	Low-Low
27	Medium	Big	Medium	High

Table 5.31 Fuzzy rules for water consumption of scenario 4

Rules	Household size	University	Car Number	Water Consumption
1	Small	None	Low	Low-Medium
2	Small	None	Medium	Low-Medium
3	Small	None	High	High
4	Small	Small	Low	Low-Low
5	Small	Small	Medium	Medium
6	Small	Small	Medium	High
7	Small	Medium	Low	Low-Low
8	Small	Medium	Medium	Low
9	Small	Medium	Medium	Low
10	Medium	None	Low	Medium
11	Medium	None	Medium	Medium
12	Medium	None	Medium	High
13	Medium	Small	Low	Medium
14	Medium	Small	Medium	Medium
15	Medium	Small	Medium	High
16	Medium	Medium	Low	Low-Low
17	Medium	Medium	Medium	High
18	Medium	Medium	Medium	High
19	Big	None	Low	Low-Low
20	Big	None	Medium	Low-Low
21	Big	None	Medium	Low-Low
22	Big	Small	Low	High
23	Big	Small	Medium	High
24	Big	Small	Medium	Medium
25	Big	Medium	Low	Low-Low
26	Big	Medium	Medium	High
27	Big	Medium	Medium	High

Table 5.32 Fuzzy rules for water consumption of scenario 5

Rules	Total Area of the house	Building Area	Number of Rooms	Water Consumption
1	Small	Small	Few	Low
2	Small	Small	Medium	High
3	Small	Small	Many	Low-Low
4	Small	Medium	Few	Low
5	Small	Medium	Medium	Very-High
6	Small	Medium	Many	Low-Low
7	Small	Big	Few	Low-Low
8	Small	Big	Medium	Low-Low
9	Small	Big	Many	Very-High
10	Medium	Small	Few	Medium
11	Medium	Small	Medium	Low
12	Medium	Small	Many	Very-High
13	Medium	Medium	Few	Medium
14	Medium	Medium	Medium	Medium
15	Medium	Medium	Many	Medium
16	Medium	Big	Few	Low-Low
17	Medium	Big	Medium	Medium
18	Medium	Big	Many	Medium
19	Big	Small	Few	Low-Low
20	Big	Small	Medium	Very-High
21	Big	Small	Many	Low-Low
22	Big	Medium	Few	Low-Low
23	Big	Medium	Medium	Medium
24	Big	Medium	Many	High
25	Big	Big	Few	Low
26	Big	Big	Medium	Very-High
27	Big	Big	Many	Medium

Table 5.33 Fuzzy rules for water consumption of scenario 6

Rules	Building Area	Females	Income	Water Consumption
1	Small	Small	Small	Low
2	Small	Small	Medium	Low-Medium
3	Small	Small	Big	High
4	Small	Medium	Small	Very-High
5	Small	Medium	Medium	Low-Low
6	Small	Medium	Big	Low-Low
7	Small	Big	Small	Low-Medium
8	Small	Big	Medium	Low-Low
9	Small	Big	Big	Very-High
10	Medium	Small	Small	Low-Medium
11	Medium	Small	Medium	High
12	Medium	Small	Big	High
13	Medium	Medium	Small	Low
14	Medium	Medium	Medium	Very-High
15	Medium	Medium	Big	Low-Low
16	Medium	Big	Small	Medium
17	Medium	Big	Medium	High
18	Medium	Big	Big	Medium
19	Big	Small	Small	Very-High
20	Big	Small	Medium	Low-Medium
21	Big	Small	Big	High
22	Big	Medium	Small	High
23	Big	Medium	Medium	Low-Medium
24	Big	Medium	Big	Very-High
25	Big	Big	Small	Medium
26	Big	Big	Medium	High
27	Big	Big	Big	High

Table 5.34 Fuzzy rules for water consumption of scenario 7

Rules	Number of Rooms	Household size	Income	Water Consumption
1	Few	Small	Small	Low-Medium
2	Few	Small	Medium	Low-Medium
3	Few	Small	Big	Low-Low
4	Few	Medium	Small	Medium
5	Few	Medium	Medium	Medium
6	Few	Medium	Big	Low-Low
7	Few	Big	Small	Very-High
8	Few	Big	Medium	Very-High
9	Few	Big	Big	Low
10	Medium	Small	Small	High
11	Medium	Small	Medium	High
12	Medium	Small	Big	Low
13	Medium	Medium	Small	Low-Medium
14	Medium	Medium	Medium	High
15	Medium	Medium	Big	Medium
16	Medium	Big	Small	Low-Low
17	Medium	Big	Medium	High
18	Medium	Big	Big	High
19	Many	Small	Small	Low-Medium
20	Many	Small	Medium	Low-Medium
21	Many	Small	Big	Low-Low
22	Many	Medium	Small	High
23	Many	Medium	Medium	High
24	Many	Medium	Big	High
25	Many	Big	Small	Very-High
26	Many	Big	Medium	Very-High
27	Many	Big	Big	Very-High

Table 5.35 Fuzzy rules for water consumption of scenario 8

Rules	Building Area	Age Category 3	High School	Water Consumption
1	Small	Small	Small	Low-Medium
2	Small	Small	Medium	Low-Low
3	Small	Small	Big	Low-Low
4	Small	Medium	Small	Low-Low
5	Small	Medium	Medium	Low-Low
6	Small	Medium	Big	Low-Low
7	Small	Medium	Small	Medium
8	Small	Medium	Medium	Low-Low
9	Small	Medium	Big	Medium
10	Medium	Small	Small	Medium
11	Medium	Small	Medium	Low-Low
12	Medium	Small	Big	Low-Low
13	Medium	Medium	Small	Low-Low
14	Medium	Medium	Medium	Low-Low
15	Medium	Medium	Big	Low-Low
16	Medium	Medium	Small	Medium
17	Medium	Medium	Medium	Low-Low
18	Medium	Medium	Big	Medium
19	Big	Small	Small	Medium
20	Big	Small	Medium	Low-Low
21	Big	Small	Big	Low-Low
22	Big	Medium	Small	Low
23	Big	Medium	Medium	Low-Low
24	Big	Medium	Big	Low-Medium
25	Big	Medium	Small	Medium
26	Big	Medium	Medium	Low-Medium
27	Big	Medium	Big	Very-High

Results of the eight fuzzy models are depicted in Table 5.36. The advantages of the models are their simple structure and easy representation. The disadvantages of them, had large error values, different inputs in each scenario and disability to assess the variation of water consumption with all the parameters.

Table 5.36: Results of fuzzy models

Modes	Average Errors		
	Training	Testing	Checking
S1	2.47	5.79	17.38
S2	3.69	22.63	28.97
S3	4.33	27.01	26.21
S4	2.29	12.69	29.39
S5	0.63	5.66	35.53
S6	1.94	21.31	35.07
S7	1.41	16.39	21.38
S8	2.01	132.62	173.55

Model S5 has small training error compared to other models. It can evaluate the variation of water consumption, however, error values for the other scenarios in the three phases are still high. Figures 5.83 below demonstrates the forecasted water consumption from ANFIS for model 6.

As shown in this figure 5.83, the quantity of water consumed is around 38.5 m^3, where the building area equal to 280 m^2, number of females is 4 and monthly income is about 100 000 DA per month. Figures 5.84 illustrates some examples of water consumption predictions.

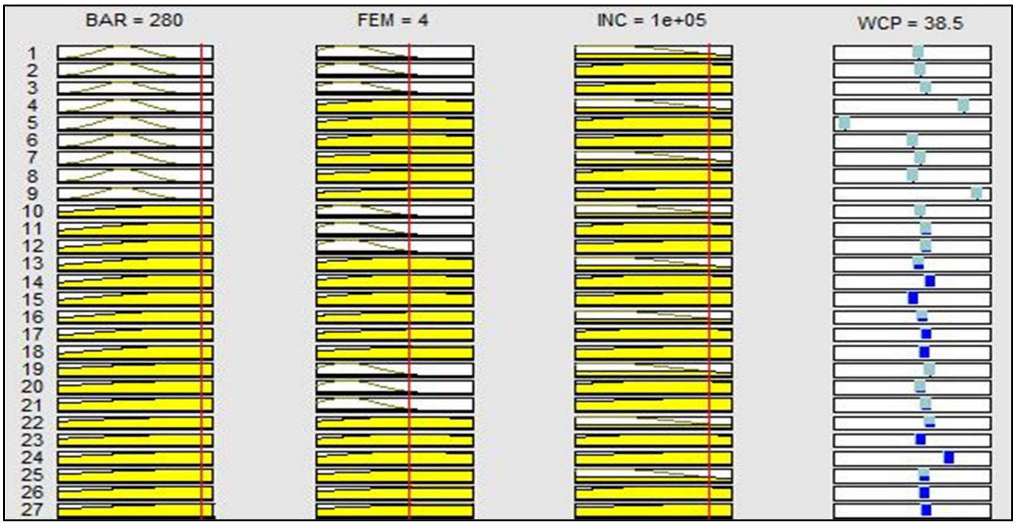

Fig 5.83 Water consumption prediction in scenario 6

Fig 5.84 Water consumption predictions

(ANNEX 06)

The three-dimensional (3D) relationship of females, household size, income and water consumption for scenario 1 is shown in figure 5.85.

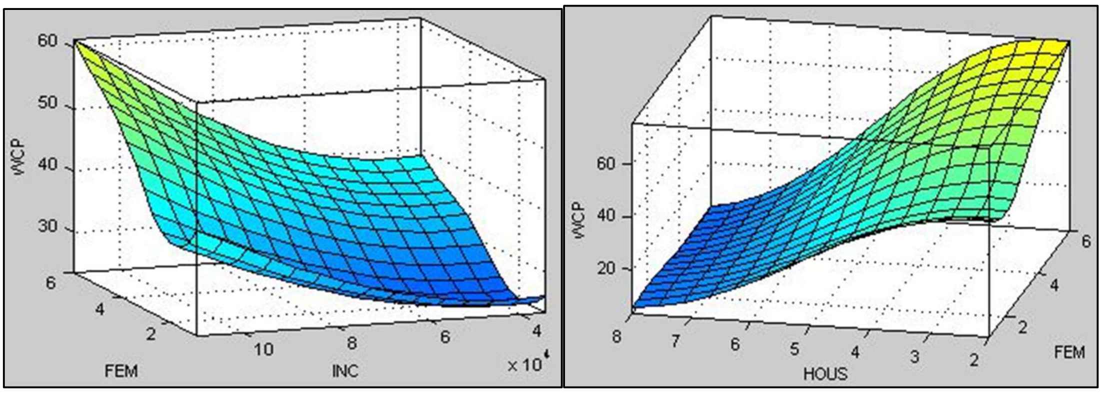

Fig 5.85 Relationship between females, household size, income and water consumption

The three-dimensional (3D) relationship of age category 1, age category 3, car number and water consumption for scenario 2 is shown in figure 5.86.

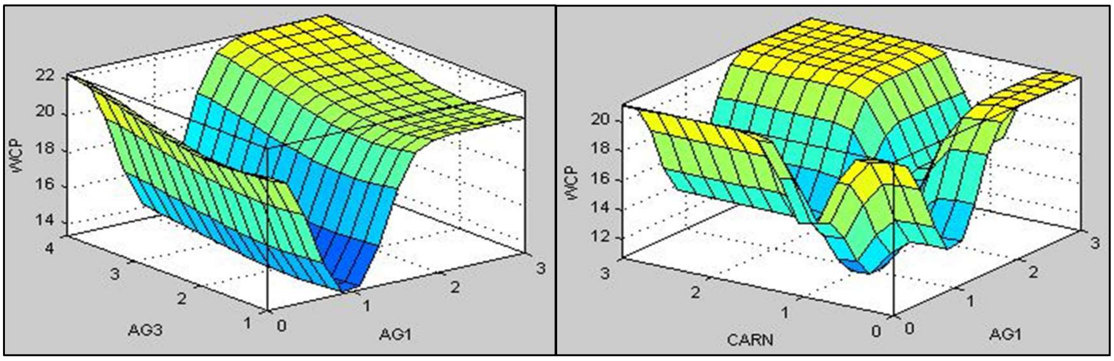

Fig 5.86 Relationship between age category 1, age category 3, car number and water consumption

The three-dimensional (3D) relationship of primary school, high school, university and water consumption for scenario 3 is shown in figure 5.87.

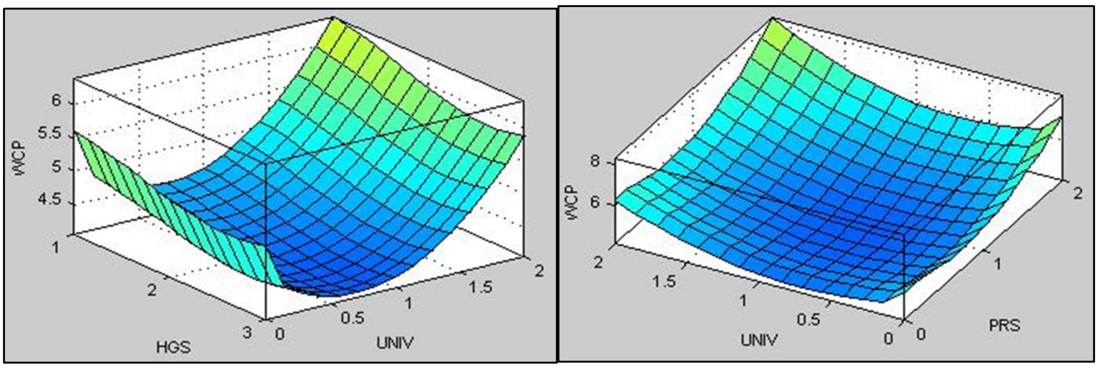

Fig 5.87 Relationship between primary school, high school, university and water consumption

The three-dimensional (3D) relationship of university level, household size, car numbers and water consumption for scenario 4 is shown in figure 5.88.

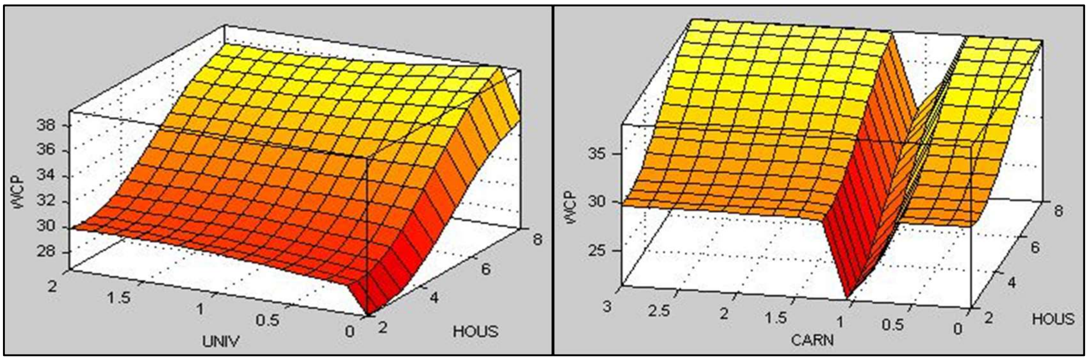

Fig 5.88 Relationship between university level, household size, car numbers and water consumption

The three-dimensional (3d) relationship of total area of the house, building area, number of rooms and water consumption for scenario 5 is shown in figure 5.89.

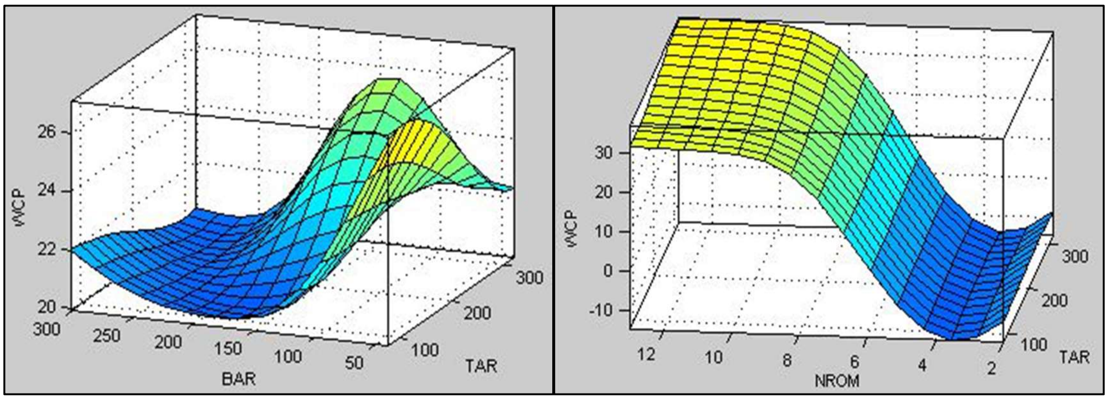

Fig 5.89 Relationship between total area of the house, building area, number of rooms and water consumption

The three-dimensional (3d) relationship of building area, income, females and water consumption for scenario 6 is depicted in figure 5.90.

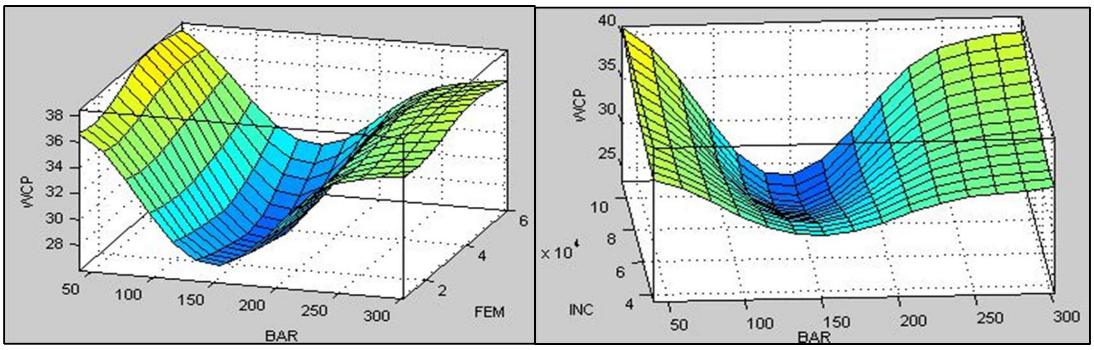

Fig 5.90 Relationship between building area, income, females and water consumption

The three-dimensional (3d) relationship of number of rooms, income, household size and water consumption for scenario 7 is shown in figure 5.91.

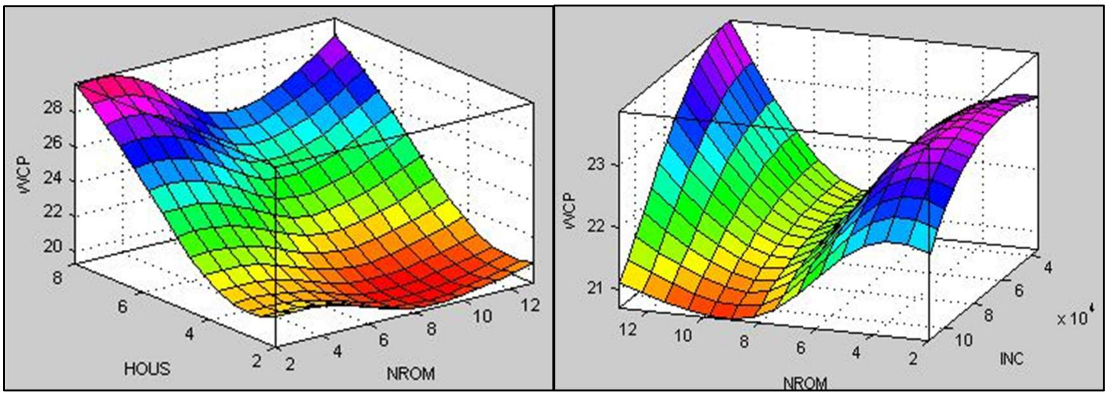

Fig 5.91 Relationship between number of rooms, income, household size and water consumption

The three-dimensional (3d) relationship of building area, high school, age category 3 and water consumption for scenario 8 is shown in figure 5.92.

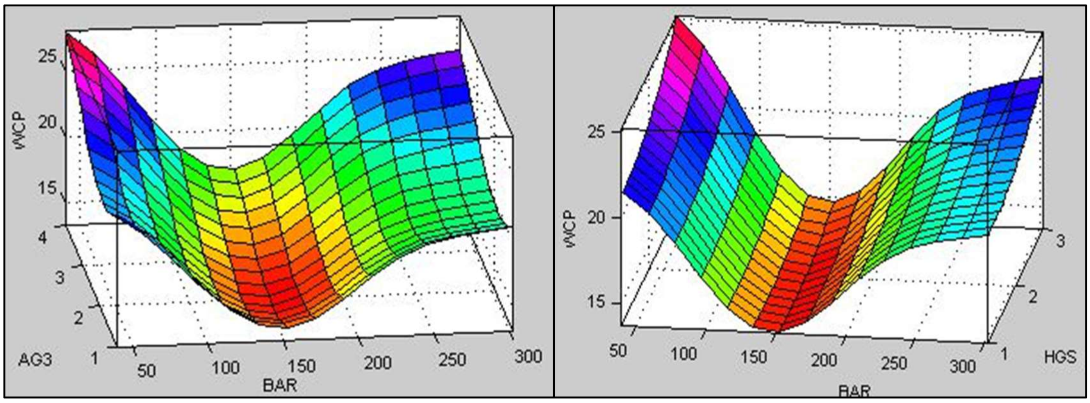

Fig 5.92 Relationship between building area, high school, age category 3 and water consumption

The fuzzy system can deal with uncertain and vague data. The system uses three input factors and develops 27 rules for the eight models to forecast trimester water consumption. To obtain the optimum structure of the model, input data are divided into different sections. This needs several models to be constructed. The results show that the best structure is related to the grid partition of 3-3-3. It is also observed that with increasing the partitions, the model error indicators are higher. The reason may be the fact that with increasing the partitions, the number of required rules is increased exponentially, leading to complexity of the model. For instance, the number of required rules for a model with partition of 3-3-3 are equal to 27. The eight selected models can be used for forecasting Sedrata water consumption without needing to estimate any indoor habits or climatic input parameters. MSE indices is better in model 5 than the other models.

As it can be inferred from the performance parameters that depicted in tables above of ANFIS results in each scenario, the performance of ANFIS was so low in terms of prediction performance of WCP compared to ANNs. The reasons behind pure WCP predictions with ANFIS may be due to software limitations of ANFIS, lack of script that may contain the efforts to develop a successful model and user errors due to low degree of user-friendliness of ANFIS.

5.14. Conclusion 2

The research is conducted through over 50 ANNs models in hope to define the optimum models and architecture. To judge performance of each scenario, indicators like **Mean Square Error** and **Correlation Coefficient** are employed. The inputs in every scenario are selected in way that covers all possible combinations and exclude the non-influential variables for efficiency reasons. In socio-economic scenario, models with architecture (training-testing-validation) of (50 - 25 – 25), (60 -20 -20), (70 -15 -15), (80 -10 -10) and corresponding to hidden layers 7 / 6 / 6 / 5 respectively are the best. For physical characteristics scenario, the best architectures are (50-25-25), (60- 20 -20), (70- 15 -15), (80 -10- 10), (60-30-10) with hidden layers 4, 2, 2, 2, 4 respectively. Another major finding is that when combining all inputs at once, the performance of modelling improves significantly.

As discussed already in literature review, the fuzzy approach can deal better with uncertain and vague data. The obtained results helped to obtain 27 rules for the eight models to forecast trimester water consumption basing on three input factors. To obtain the optimum structure of the model, input data are divided into different sections. This needs several models to be constructed. The results show that the best structure is related to the grid partition of 3-3-3.

Moreover, the usage of adaptive Sugeno fuzzy and neuro-fuzzy inference system (ANFIS) models is preferable thanks to their simple structure and easy representation.

The general conclusion from this line of work is that models developed from neural networks had good perform. This superiority in performance is attributed to the ability of neural networks to efficiently capture non-linearities.