As stated in the Chapter 4, the modeling is conducted by two phases: Artificial Neural works (ANNs) Phase and Adaptive Neuro Fuzzy Inference System (ANFIS) Phase.

5.12. Artificial Neural Networks (ANNs)

In this part of thesis, the ANNs models are used for characterizing and prioritizing the effective parameters affecting water consumption (WCP) in the three scenarios. The applied methodology is illustrated in figure 5.28.

The neural network for identifier is designed as a three-layer neural network (input/ hidden/output layers). The neuron numbers in the hidden layers can be chosen depending on the practical training result. The training model adaptive neural network approach based on Back propagation algorithm is applied to assess household water consumption determinants.

Dataset	
Input parameters: The three scenarios of parameters	**Output parameter:** Water consumption

Input parameters: Scenarios	
• **Scenario1 (S1):** Socio-economic parameters • **Scenario2 (S2):** Physical characteristics of housing units	• **Scenario3 (S1+S2):** Socio-economic parameters + Physical characteristics of housing units

Data selection in Matlab Software		
Training data size: **(50%; 60%; 70% and 80%)**	Testing data size: **(10%; 15%; 20% 25%)**	Validation Data size: **(10%; 15%; 20% 25%)**

Preparation for training the neural network		
Network type: Multilayer perceptron (**MLP)**	Rising the number of network training: **50**	Select the best network result based on **5** performance criteria for each scenario

Results obtained	
MES (mean square error)	**R** (Correlation coefficient)

Fig 5.28 The applied methodology for ANNs approach

5.12.1. Input parameters

It is expected that the sensitivity of WCP differs accordingly to the considered input parameters, and this mainly because the variation of correlation strength between WCP and each parameter (Part 01 of Chapter 05).

- **Data initialization**

Before creating the input vectors and output vector, the data must be in normalized form. This step in modelling aims to convert the input and output values into representative range of values for the computation using ANNs. It was applied already in the previous Chapter 03. As mentioned in part I of this chapter, the total selected variables (explanatory variables) are 12 that are categorized into three scenarios. in the current work, the back-propagation feed-forward MLP with sigmoidal-type activation function (equation 5.1) thanks to its popularity and mostly high performance compared to other networks (Lippmann, 1987).

$$f(z) = \frac{1}{1+\exp^{-z}} \qquad \textbf{(5.1)}$$

Performance function are one of the important factors affects the learning performance. For feed forward network, **"Mean Square Error (MSE)"** is commonly used performance function. This last calculate the cumulative values between the target outputs values and created outputs by the network.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left[e(t)^2\right] \qquad \textbf{(5.2)}$$

Where; *e (t)* is forecast error at period *t*, *n* is number of periods (Agami et al., 2009)

a. Scenario1 (S1)

The target output Water Consumption (WCP) can be considered as a function of: household size (HOUS), number of female (FEM), monthly income (INC), two age categories (AG1 and AG3), three categories of education level (PRS, HGS & UNIV) and car numbers (CARN). The MLP network can be expressed by:

WCP= f (HOUS, FEM, INC, AG1, AG3, PRS, HGS, UNIV, CARN) **(5.3)**

AG2 AG4 MAL MDS are removed from further analysis because of their week correlation to WCP. Removing such inputs would improve the process and reduces the time.

b. Scenario2 (S2)

Scenario 2 represents the explanatory variables of physical characteristics of housing units. In this scenario, WCP is considered a function of the following parameters: total area of the house (TAR), building area (BAR) and number of rooms (NROM). The MLP network can be expressed by:

WCP= *f* (TAR, BAR, NROM) **(5.4)**

Also, because of their week impact on WCP, Garden area (GAR) and watering frequency (GWAT) are no more taken into consideration.

c. Scenario3 (S1+S2)

To confirm the sensibility of WCP to number of inputs, all the factors are considered in this scenario.

This scenario is a combination between the first and the second scenarios where the total explanatory variables are 12 parameters. The MLP network can be expressed by the following function:

WCP= *f* (HOUS, FEM, INC, AG1, AG3, PRS, HGS, UNIV, CARN, TAR, BAR, NROM) **(5.5)**

5.12.2. Training, testing and validating the neural networks

The neural network models are trained to learn the forward dynamics of water consumption. 12 inputs and one output (WCP) are selected as the identifier model.

5.12.2.1. Scenario1: Models architectures and their performances

Results in table 5.23 shows the four selected models for the first scenario. Also, the training, testing and validation **"MSE"** and the training, testing and validation **"R"**.

Table 5.23: Summary of the architectures and the performance of the Scenario1 models

Models	**M1**	**M2**	**M3**	**M4**
Input layer	S1	S1	S1	S1
Training size	50 %	60 %	70 %	80 %
Testing size	25 %	20 %	15 %	10 %
Validation size	25 %	20 %	15 %	10 %
Structure	(9 : 7 :1)	(9 : 6 : 1)	(9 : 6 : 1)	(9 : 5 : 1)
Hidden layer	7	6	6	5
Training MSE	0.576	0.240	0.165	0.199
Validation MSE	1.186	0.401	0.199	0.539
Testing MSE	1.384	0.732	0.441	0.175
All MSE	**0.928**	**0.370**	**0.211**	**0.230**
Training R	0.99	0.99	0.99	0.99
Validation R	0.98	0.99	0.99	0.99
Testing R	0.98	0.99	0.99	0.99
All R	**0.98**	**0.99**	**0.99**	**0.99**

Results from the above table 5.23 shows that the four models have a good correlation coefficient (> 0.97) between WCP and the selected socio-economic parameters.

Figure 5.29 represents the architecture of model 1. The model has nine inputs, seven hidden layers and one output (WCP).

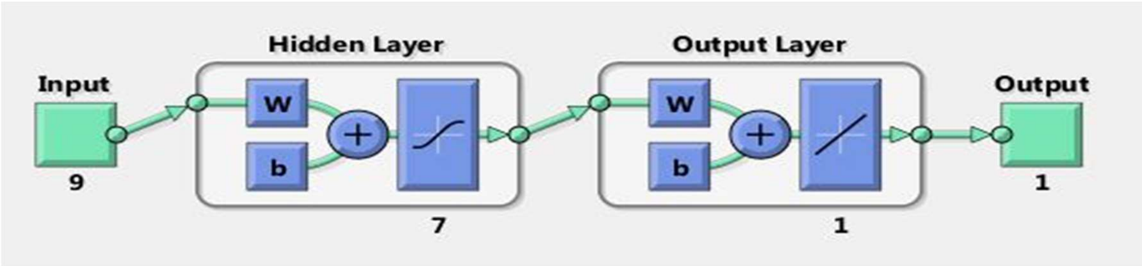

Fig 5.29 Neural network structure of model 1-scenario 1

Figure 5.30 demonstrates the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 1-scenario 1.

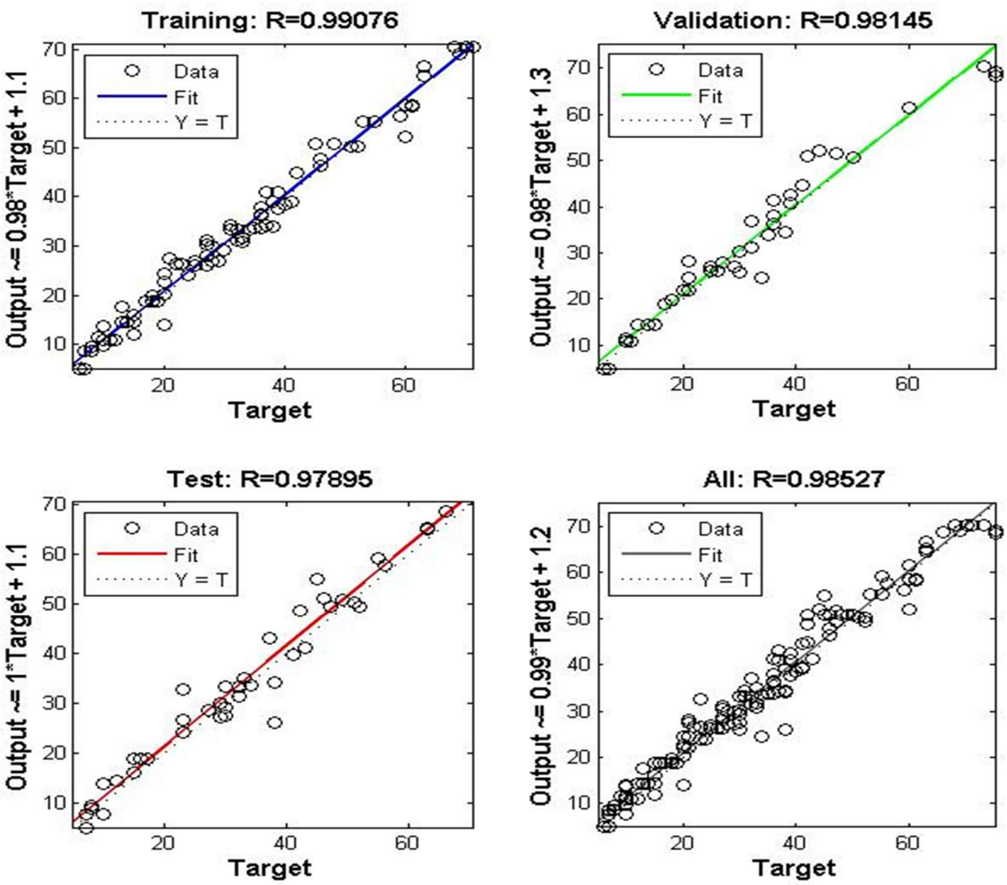

Fig 5.30 Neural network Target-Output graphs of training, testing and validation phases of model 1-scenario 1

Figure 5.31 shows the architecture of model 2. This model has nine inputs, 6 hidden layers and one output (WCP).

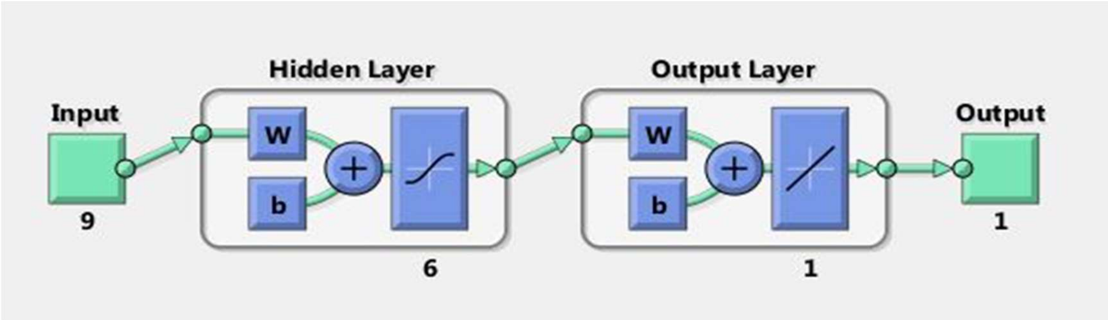

Fig 5.31 Neural network structure of model 2-scenario 1

Figure 5.32 represents the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 2-scenario 1.

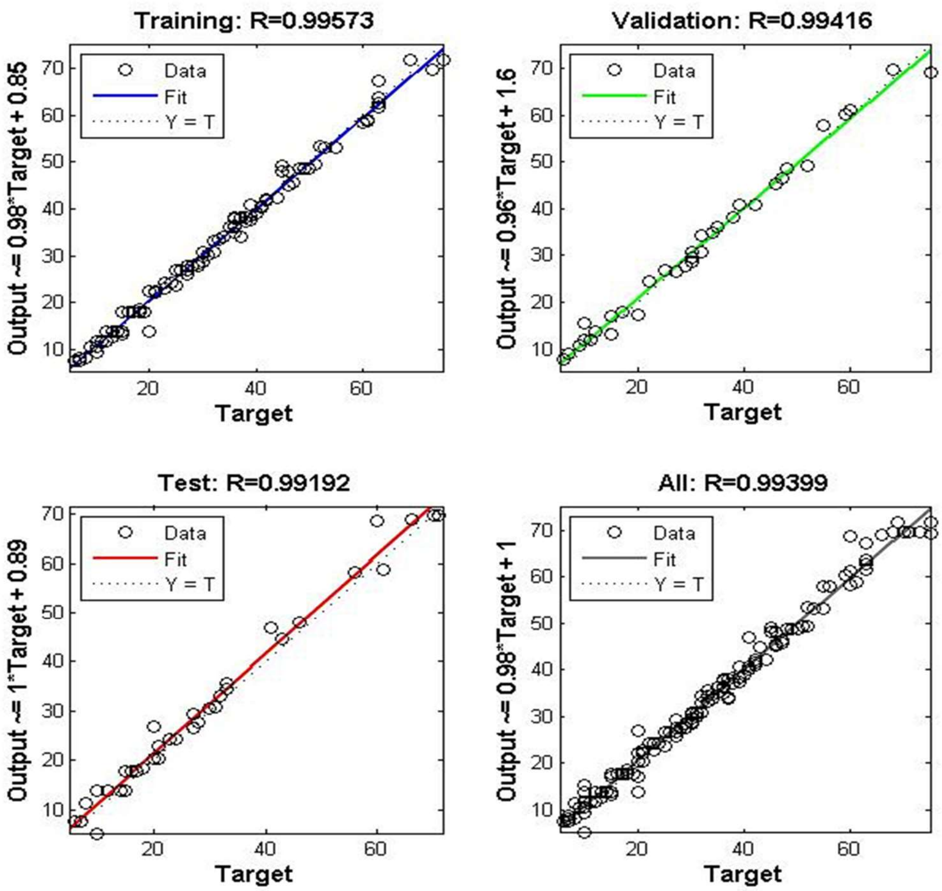

Fig 5.32 Neural network Target-Output graphs of training, testing and validation phases of model 2-scenario 1

Figure 5.33 shows the architecture of model 3. Model 3 has nine inputs, 6 hidden layers and one output (WCP).

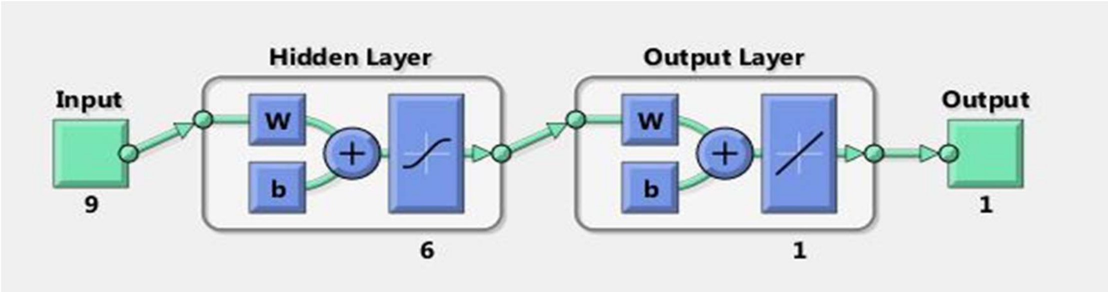

Fig 5.33 Neural network structure of model 3-scenario 1

Figure 5.34 shows the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 3-scenario 1.

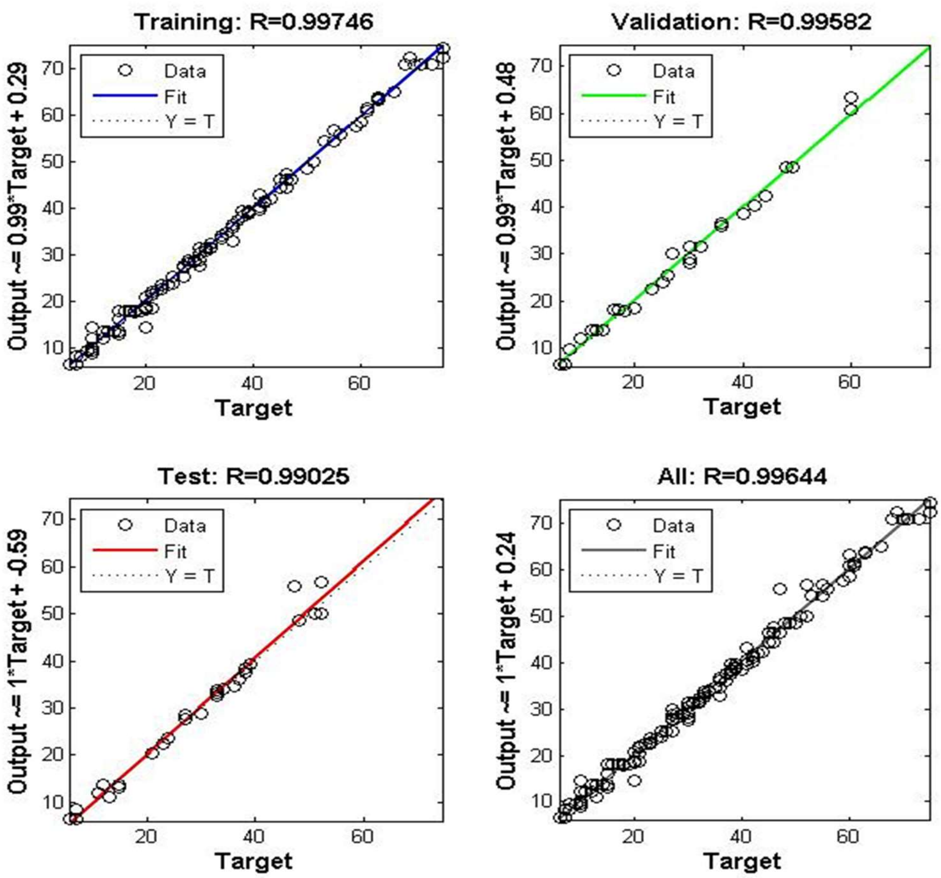

Fig 5.34 Neural network Target-Output graphs of training, testing and validation phases of model 3-scenario 1

Figure 5.35 represents the architecture of model 4. The last model in scenario 1 has nine inputs, 5 hidden layers and one output (WCP).

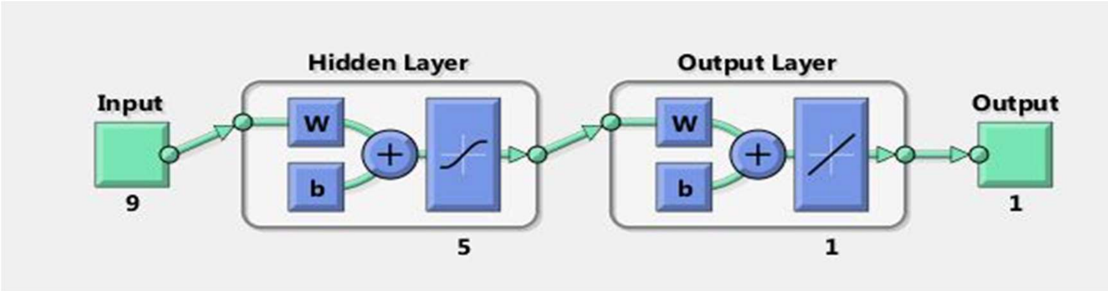

Fig 5.35 Neural network structure of model 4-scenario 1

Figure 5.36 illustrates the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 4-scenario 1.

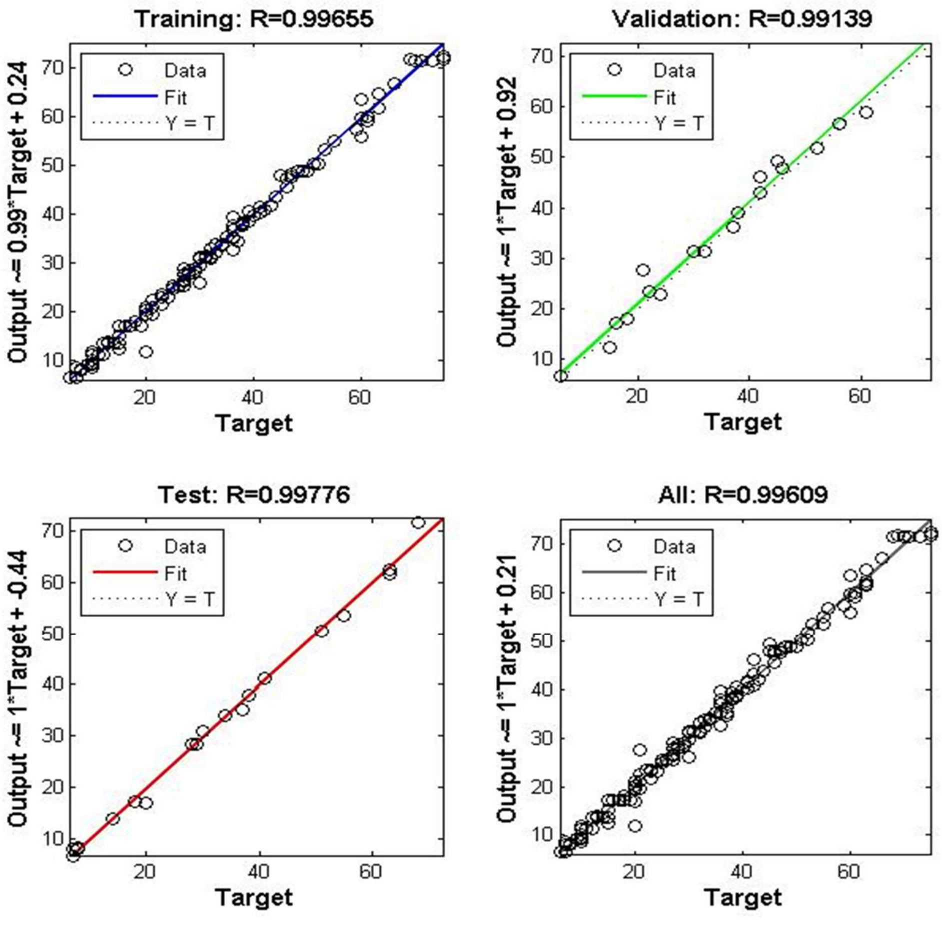

Fig 5.36 Neural network Target-Output graphs of training, testing and validation phases of model 4-scenario 1

5.12.2.2. Scenario2: Models architectures and their performances

Table 5.24 demonstrates the five selected models for the second scenario, besides to the training, testing and validation **"MSE"**, besides to the training, testing and validation **"R"**.

Table 5.24: Summary of the architectures and the performance of the scenario2 models

Models	**M5**	**M6**	**M7**	**M8**	**M9**
Input layer	S2	S2	S2	S2	S2
Training size	50 %	60 %	70 %	80 %	60 %
Testing size	25 %	20 %	15 %	10 %	30 %
Validation size	25 %	20 %	15 %	10 %	10 %
Structure	(3 4 1)	(3 2 1)	(3 2 1)	(3 2 1)	(3 4 1)
Hidden layer	4	2	2	2	4
Training MSE	1.526	1.755	1.541	1.389	1.155
Validation MSE	0.741	0.529	0.449	0.432	0.572
Testing MSE	0.562	0.249	0.576	0.443	0.164
All MSE	**0.912**	**1.211**	**1.234**	**1.200**	**0.882**
Training R	0.97	0.97	0.97	0.98	0.98
Validation R	0.98	0.99	0.99	0.99	0.99
Testing R	0.98	0.99	0.99	0.99	0.99
All R	**0.98**	**0.98**	**0.98**	**0.98**	**0.98**

Table 5.24 indicates that the five models (M5, M6, M7, M8 and M9) have a good correlation coefficient (> 0.97) between WCP and the selected physical characteristics of building units variables.

Figure 5.37 represents the architecture of model 5. The first model in scenario 2 has three inputs, 4 hidden layers and one output (WCP).

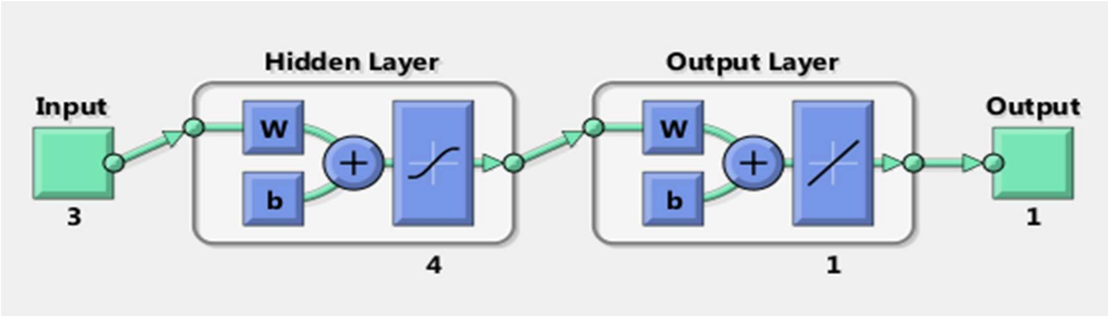

Fig 5.37 Neural network structure of model 5-scenario 2

Figure 5.38 illustrates the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 5-scenario 2.

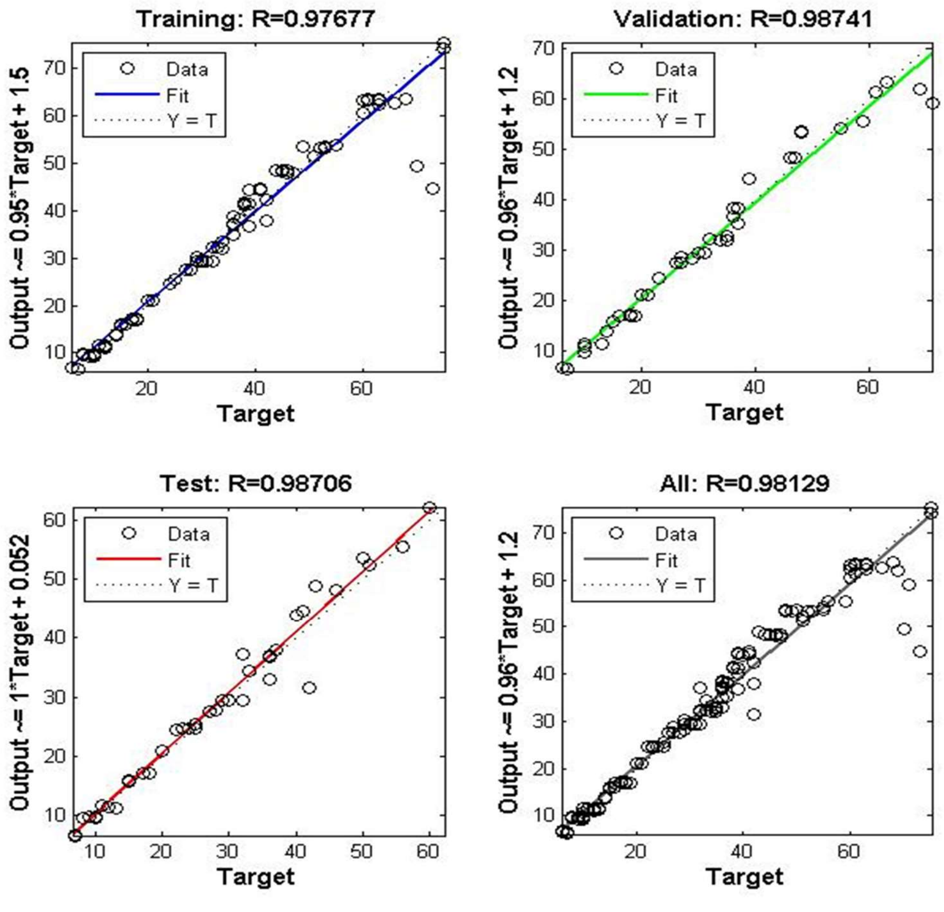

Fig 5.38 Neural network Target-Output graphs of training, testing and validation phases of model 5-scenario 2

Figure 5.39 illustrates the architecture of model 6 from scenario 2. It has three inputs, 2 hidden layers and one output (WCP).

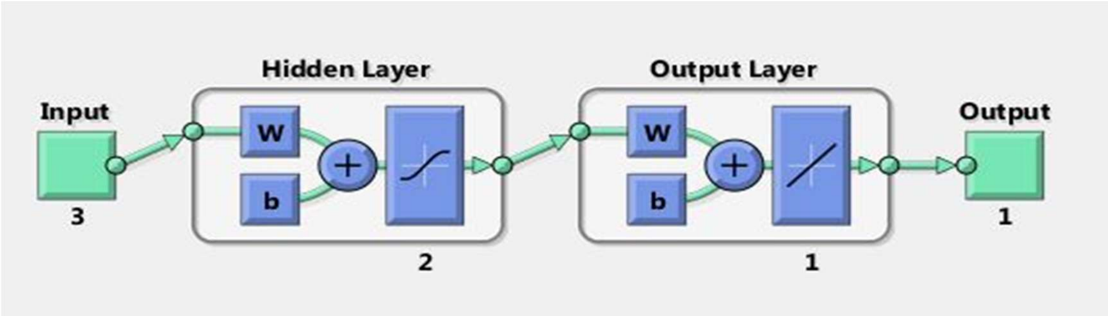

Fig 5.39 Neural network structure of model 6-scenario 2

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 6-scenario 2 are illustrated in figure 5.40 below.

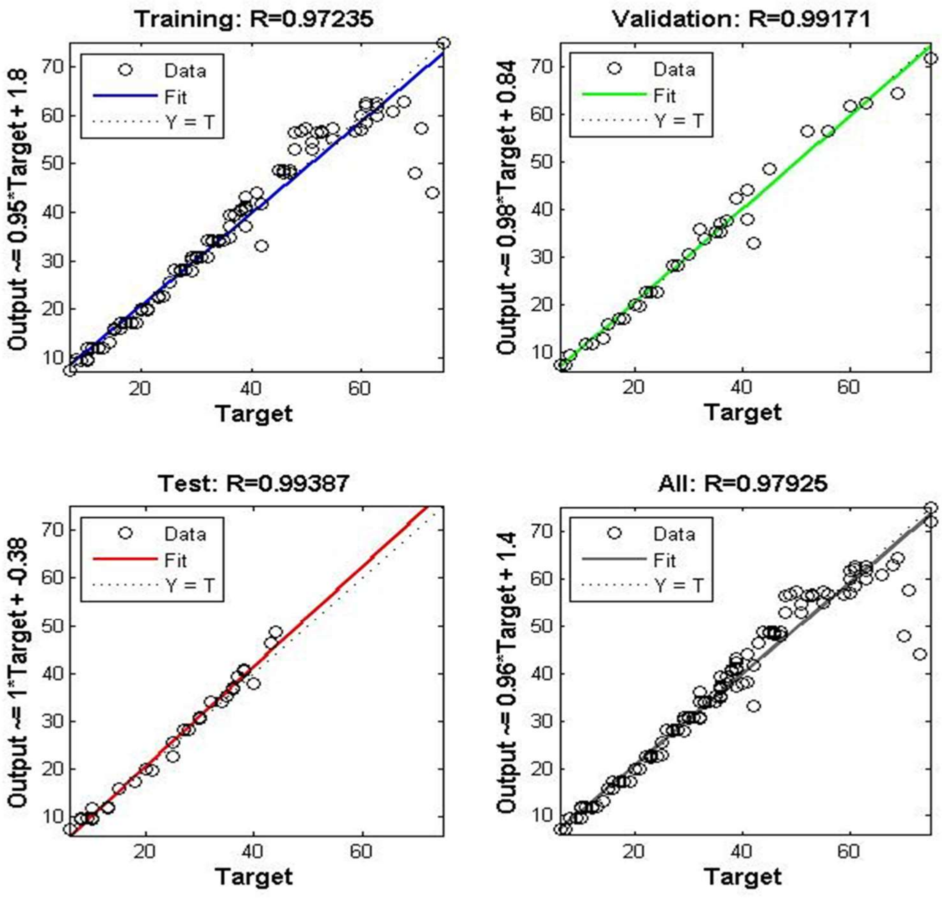

Fig 5.40 Neural network Target-Output graphs of training, testing and validation phases of model 6-scenario 2

Figure 5.41 demonstrates the architecture of model 7 from scenario 2, where this model has three inputs, 2 hidden layers and one output (WCP).

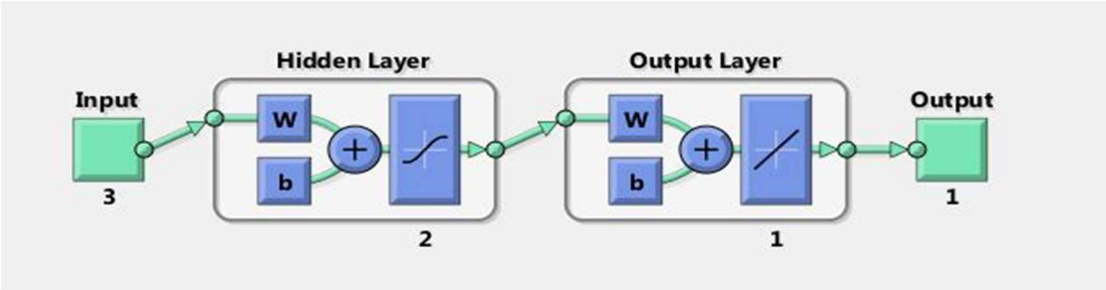

Fig 5.41 Neural network structure of model 7-scenario 2

Figure 5.42 shows the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 7-scenario 2.

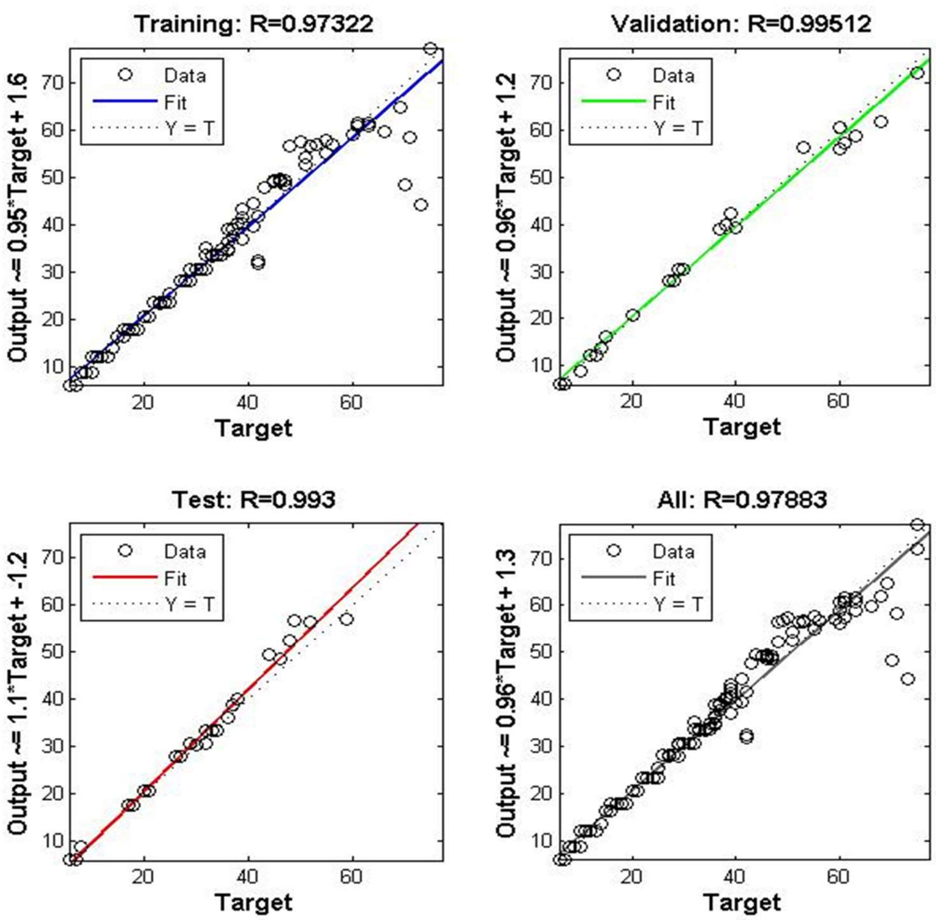

Fig 5.42 Neural network Target-Output graphs of training, testing and validation phases of model 7-scenario 2

The architecture of model 8-scenario 2 is given in figure 5.43 below. Model 8 has three inputs, 2 hidden layers and one output (WCP).

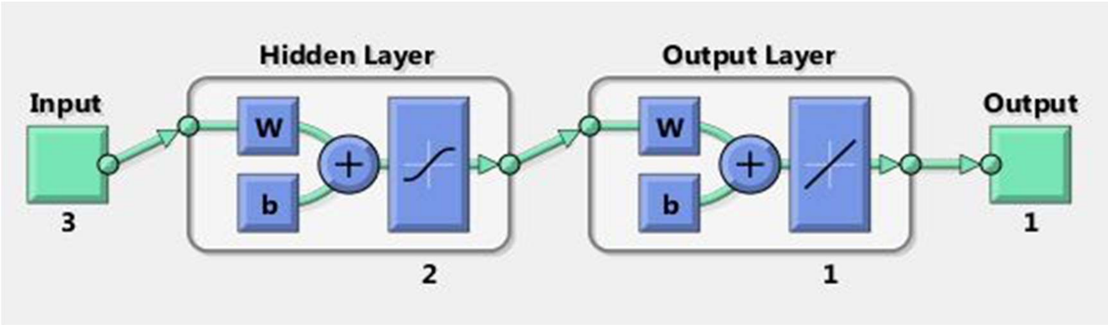

Fig 5.43 Neural network structure of model 8-scenario 2

Figure 5.44 illustrates the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 8-scenario 2.

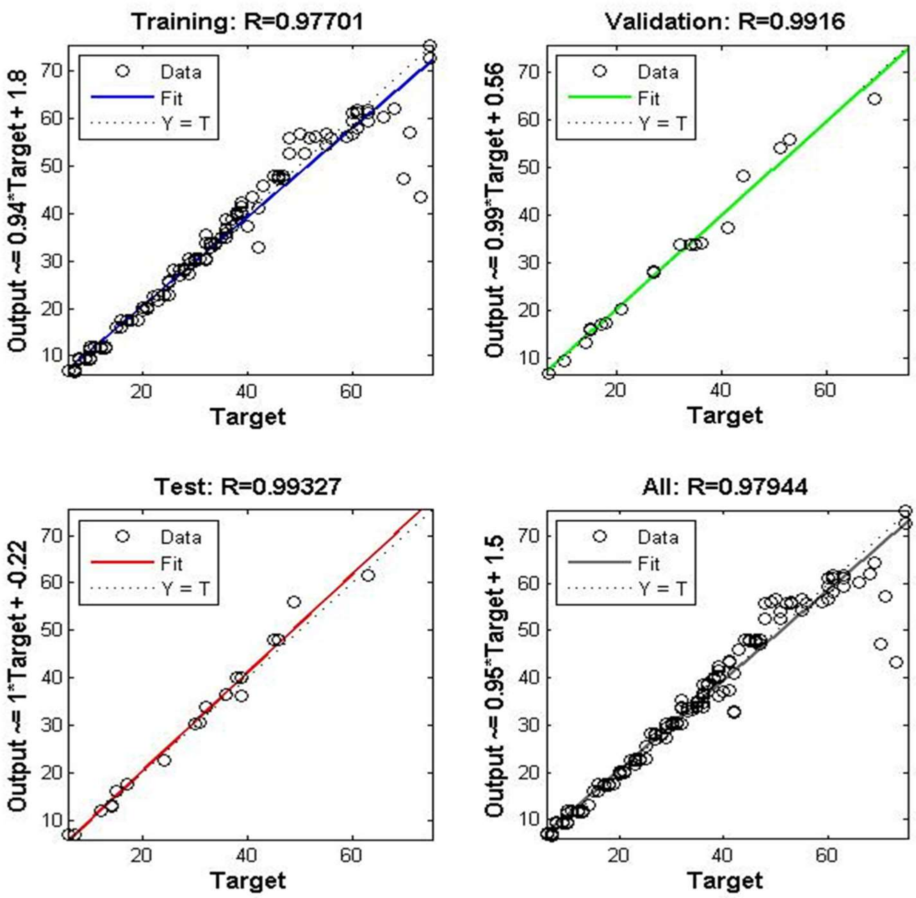

Fig 5.44 Neural network Target-Output graphs of training, testing and validation phases of model 8-scenario 2

Figure 5.45 shows the architecture of model 9 from scenario 2, where this last has three inputs, 4 hidden layers and one output (WCP).

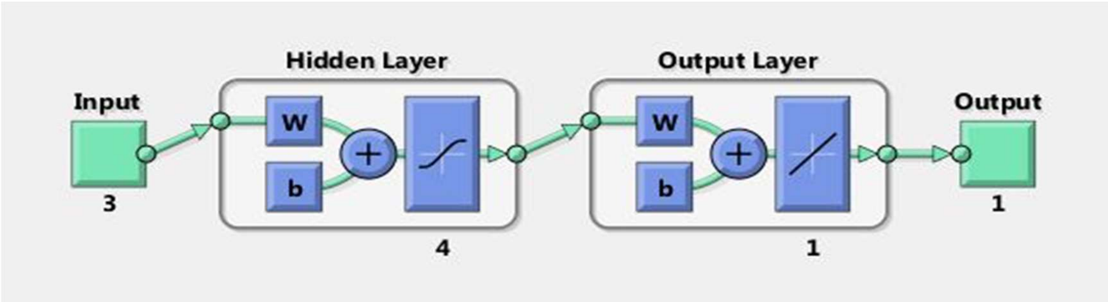

Fig 5.45 Neural network structure of model 4-scenario 1

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 9-scenario 2 are illustrated in figure 5.46.

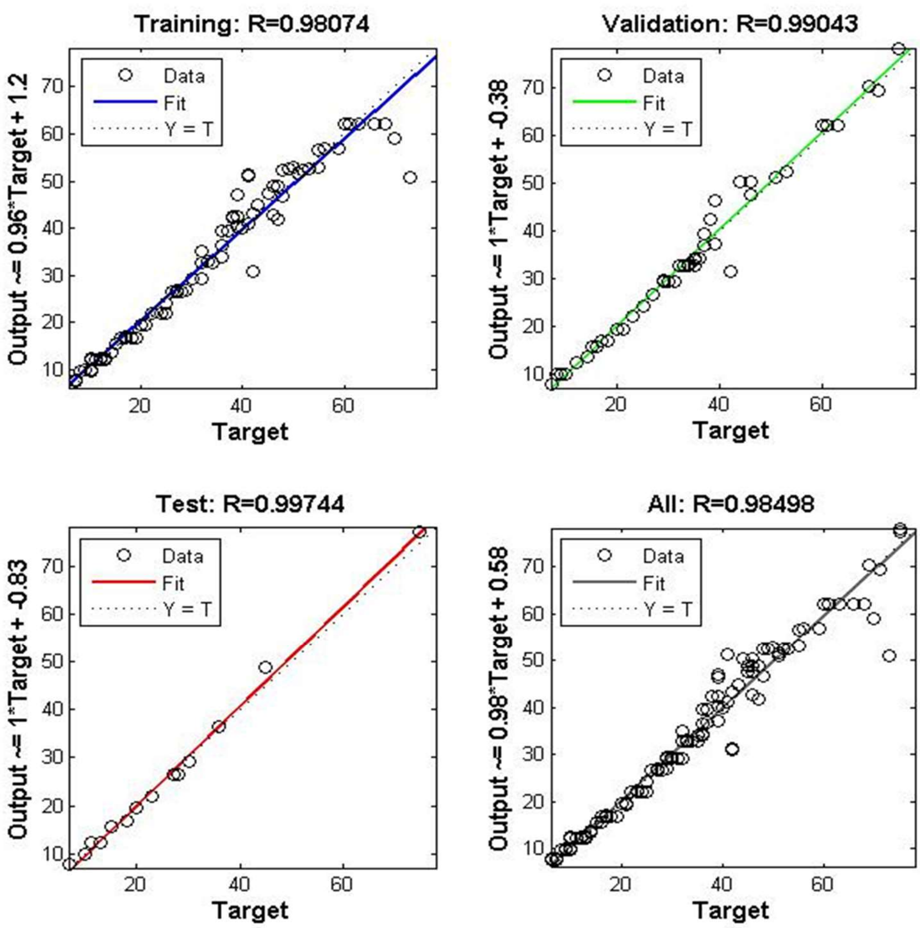

Fig 5.46 Neural network Target-Output graphs of training, testing and validation phases of model 9-scenario 2

5.12.2.3. Scenario3: Models architectures and their performances

The six selected models for the third scenario, the training, testing and validation **"MSE"** and the training, testing and validation **"R"** are demonstrated in table 5.25 below.

Table 5.25: Summary of the architectures and the performance of the scenario3 models

Models	M10	M11	M12	M13	M14	M15
Input layer	S1+S2	S1+S2	S1+S2	S1+S2	S1+S2	S1+S2
Training size	50 %	60 %	70 %	80 %	80 %	60 %
Testing size	25 %	20 %	15 %	10 %	10 %	25 %
Validation size	25 %	20 %	15 %	10 %	10 %	15 %
Structure	(12 10 1)	(12 9 1)	(12 6 1)	(12 6 1)	(12 4 1)	(12 7 1)
Hidden layer	10	9	6	6	4	7
Training MSE	0.235	0.713	0.117	0.322	0.137	0.027
Validation MSE	0.365	0.376	0.303	0.417	0.184	0.301
Testing MSE	0.752	0.191	0.189	0.621	0.134	0.189
All MSE	**0.396**	**0.156**	**0.156**	**0.091**	**0.141**	**0.119**
Training R	0.99	0.99	0.99	0.99	0.99	0.99
Validation R	0.99	0.99	0.99	0.99	0.99	0.99
Testing R	0.99	0.99	0.99	0.99	0.99	0.99
All R	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**	**0.99**

Table 5.25 indicates that the six models (M10, M11, M12, M13, M14 and M15), where the inputs are the combination between the socio-economic parameters and the physical characteristics of housing units have a good correlation coefficient (equal to 0.9) between them and WCP.

Figure 5.47 shows the architecture of model 10 from scenario 3, where this last has twelve inputs, 10 hidden layers and one output (WCP).

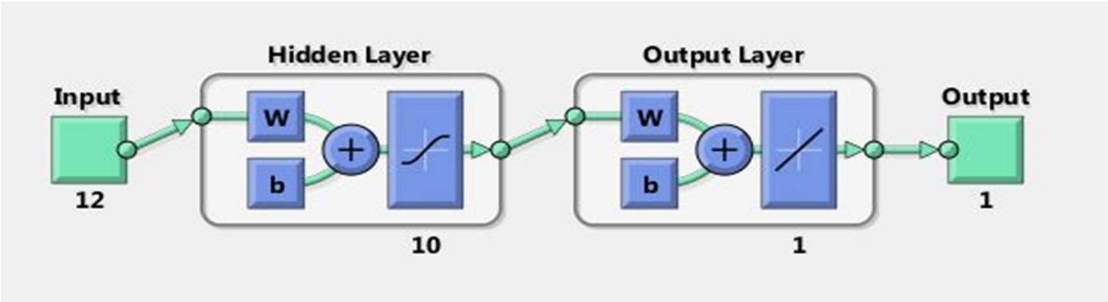

Fig 5.47 Neural network structure of model 10-scenario 3

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 10-scenario3 are illustrated in figure 5.48.

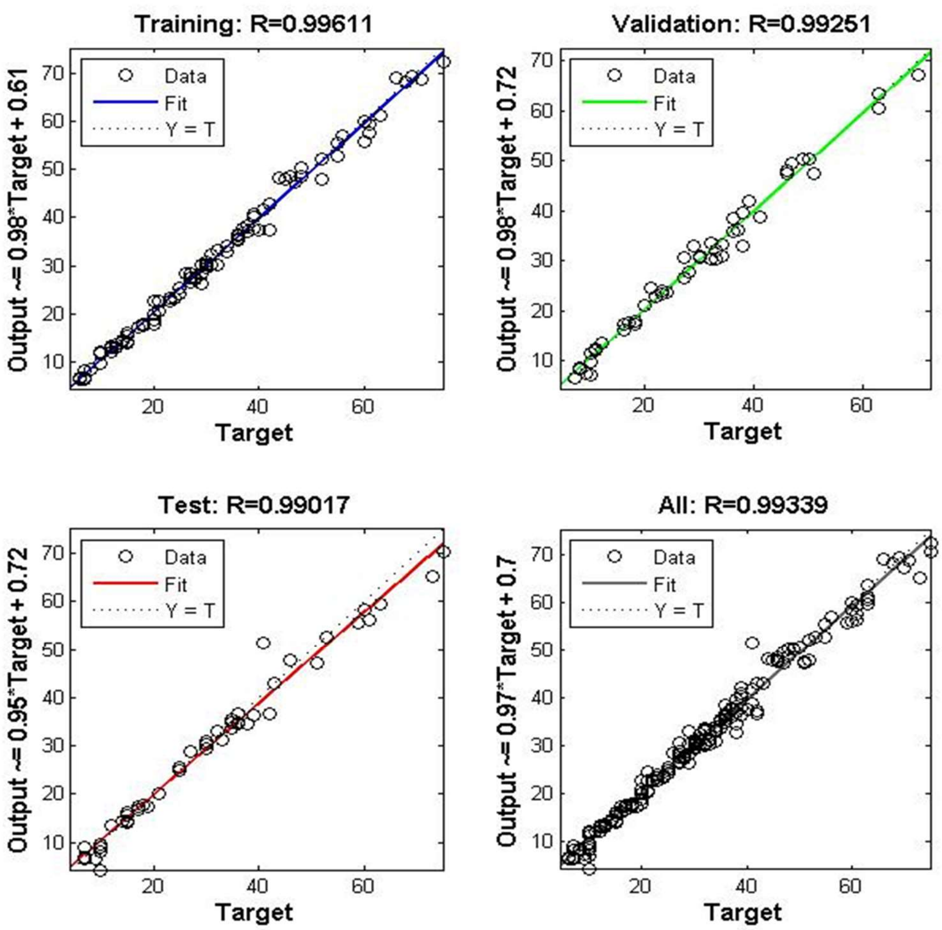

Fig 5.48 Neural network Target-Output graphs of training, testing and validation phases of model 10-scenario 3

Figure 5.49 demonstrates the architecture of model 11 from scenario 3. Model 11has twelve inputs, 9 hidden layers and one output (WCP).

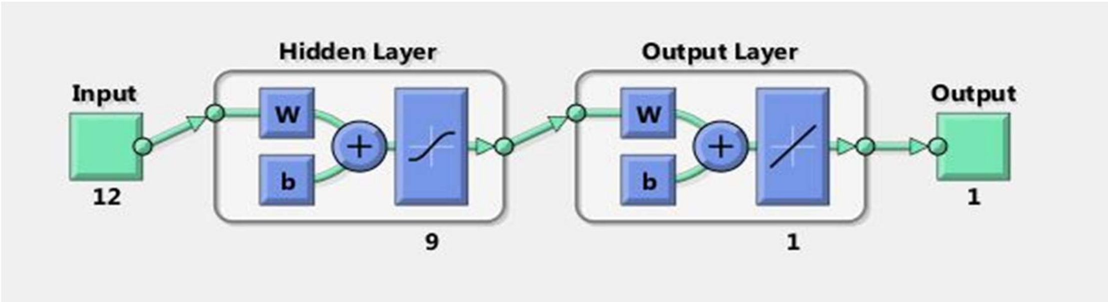

Fig 5.49 Neural network structure of model 4-scenario 3

Figure 5.50 shows the Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 11-scenario3.

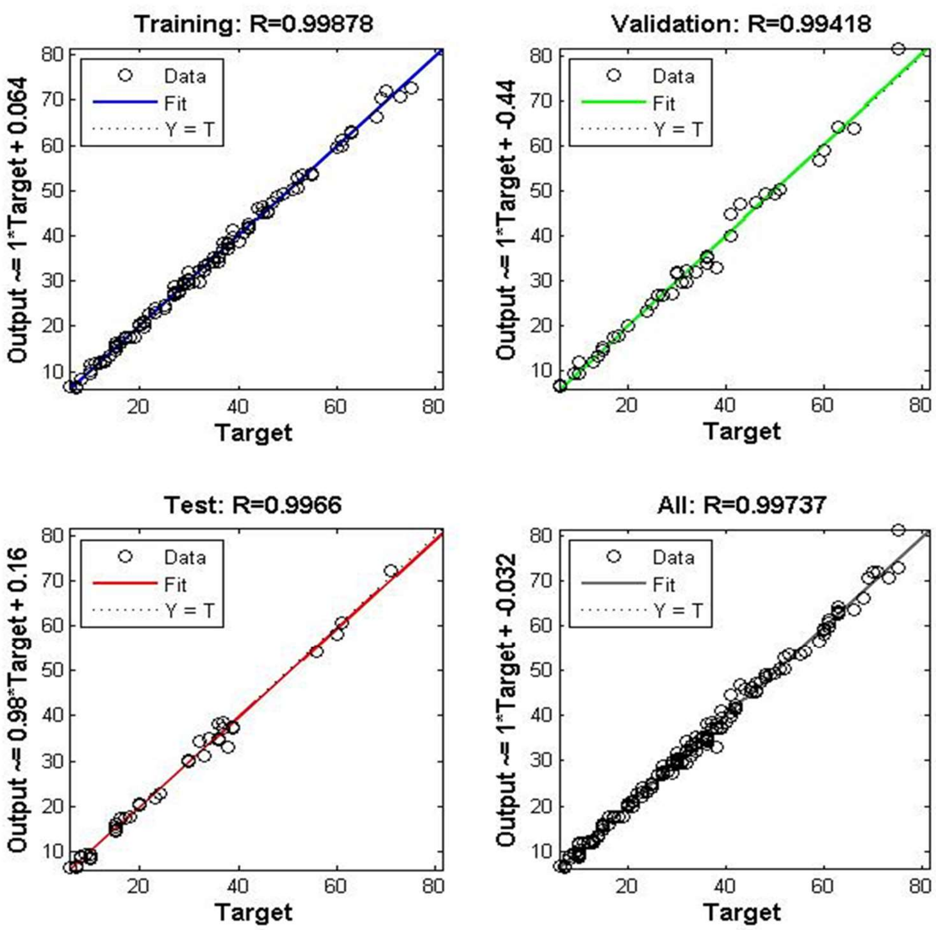

Fig 5.50 Neural network Target-Output graphs of training, testing and validation phases of model 11-scenario 3

The architecture of model 12 from scenario 3 is illustrated in figure 5.51 below, where it has twelve inputs, 6 hidden layers and one output (WCP).

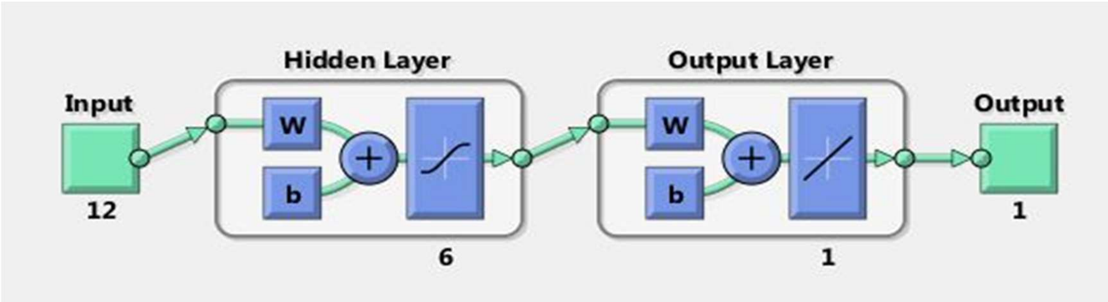

Fig 5.51 Neural network structure of model 12-scenario 3

The following graphs in figure 5.52 represents Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 12-scenario3.

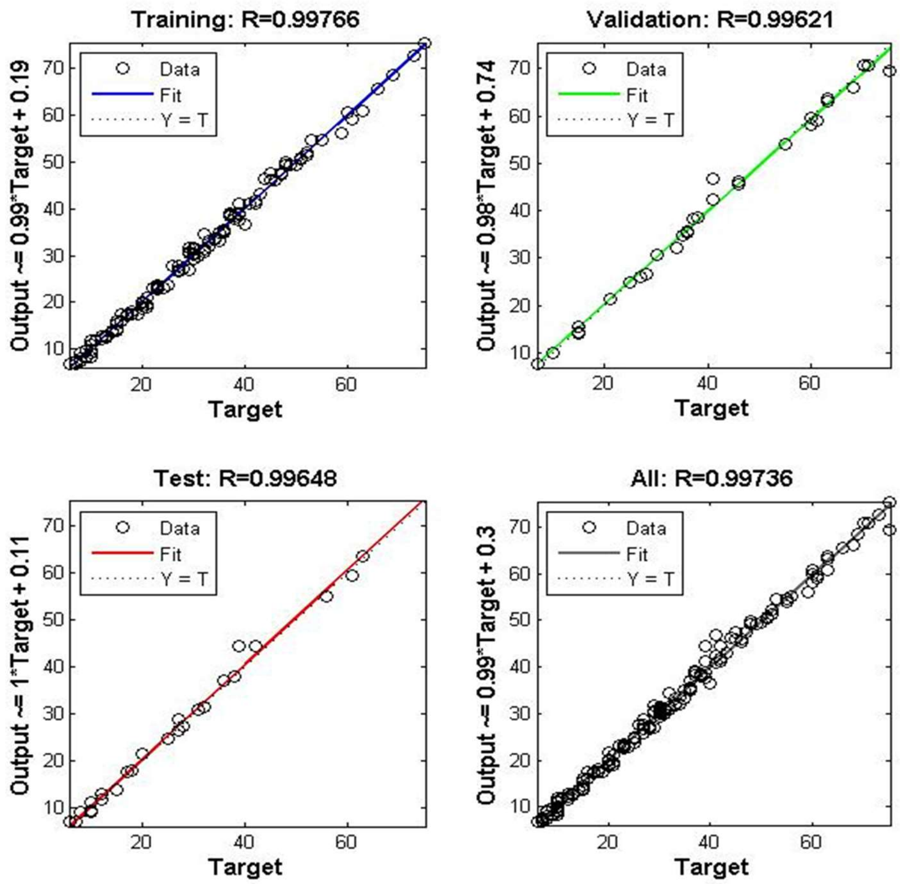

Fig 5.52 Neural network Target-Output graphs of training, testing and validation phases of model 12-scenario 3

Figure 5.53 illustrates the architecture of model 13 from scenario 3, where this last has twelve inputs, 6 hidden layers and one output (WCP).

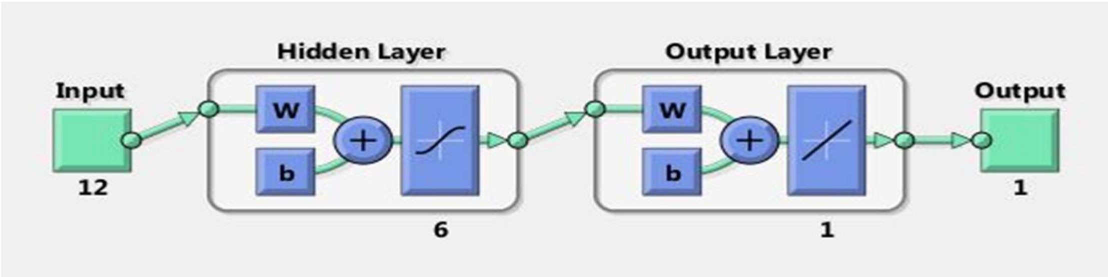

Fig 5.53 Neural network structure of model 4-scenario 3

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 13-scenario3 are illustrated in figure 5.54.

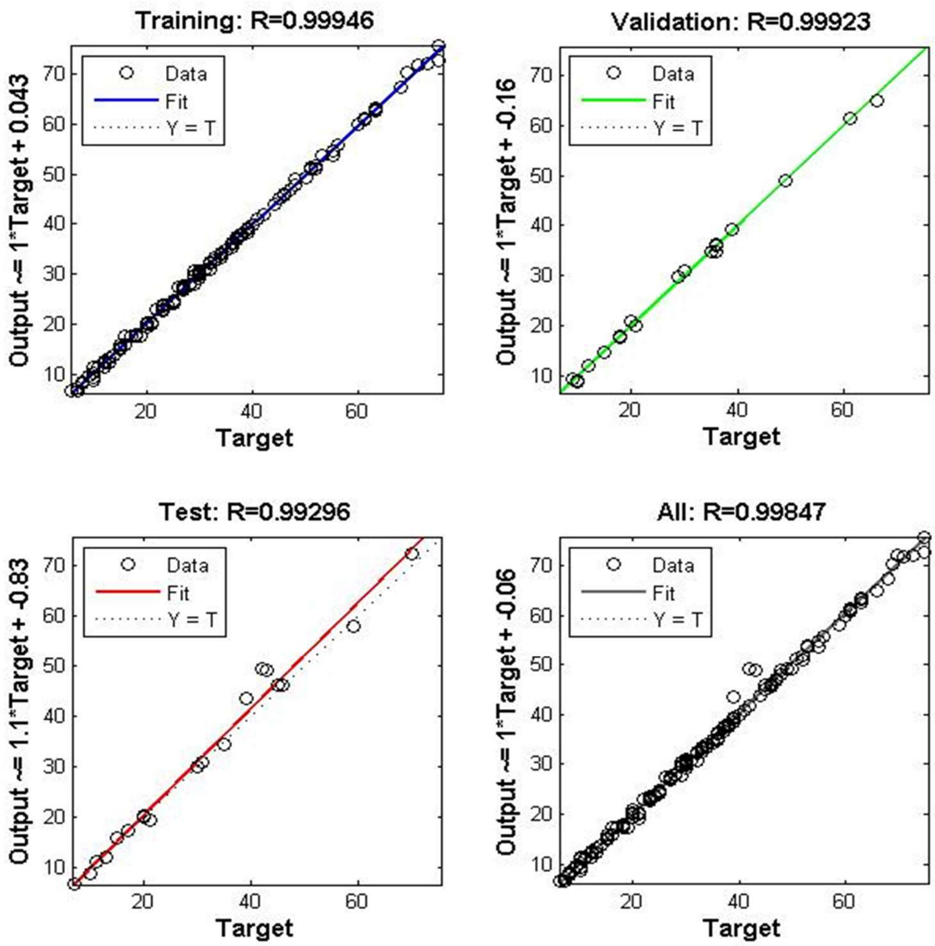

Fig 5.54 Neural network Target-Output graphs of training, testing and validation phases of model 13-scenario 3

Figure 5.55 shows the architecture of model 14 from scenario 3. It has twelve inputs, 4 hidden layers and one output (WCP).

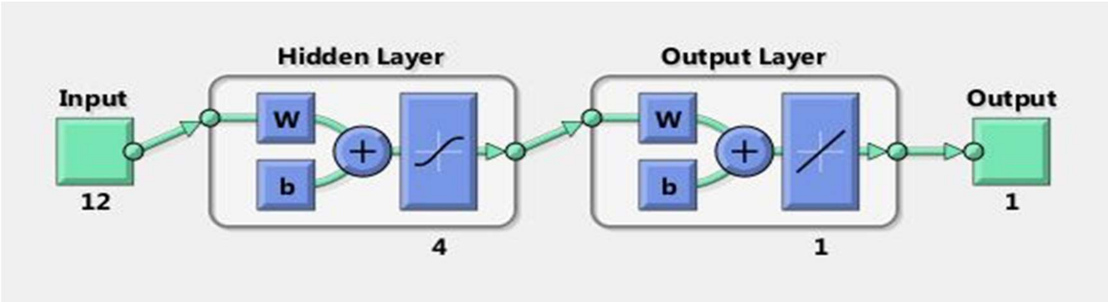

Fig 5.55 Neural network structure of model 14-scenario 3

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 14-scenario3 are illustrated in figure 5.56.

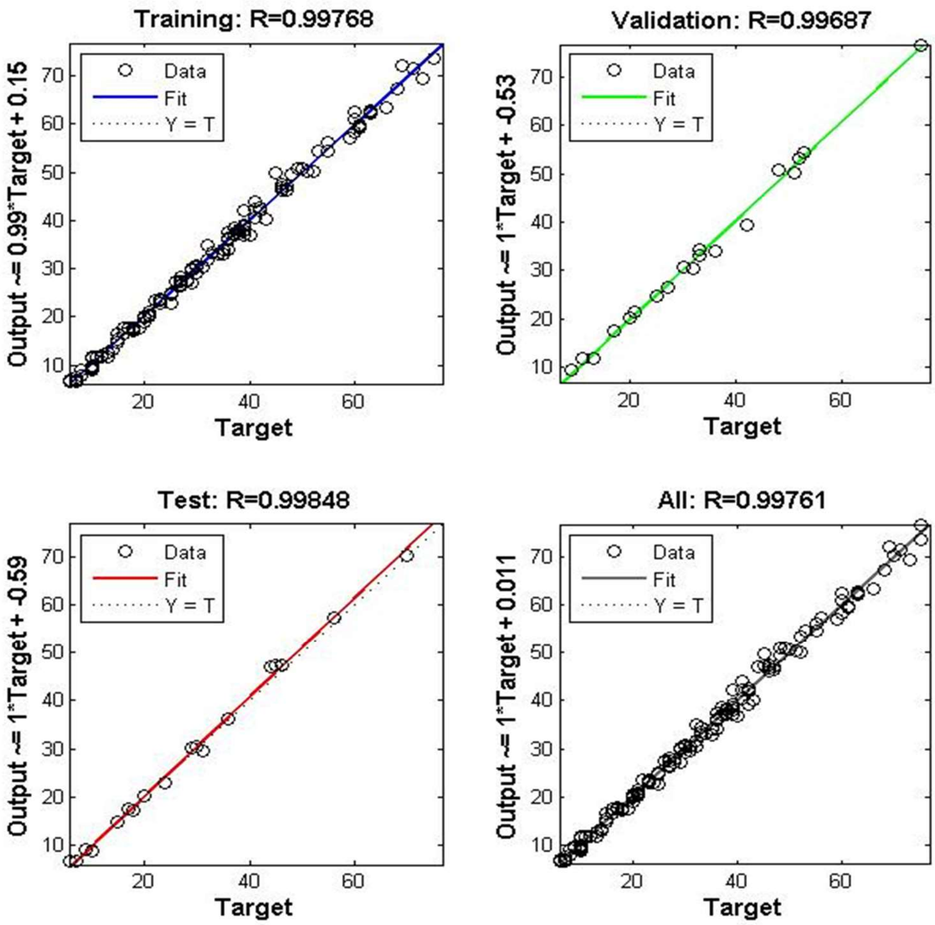

Fig 5.56 Neural network Target-Output graphs of training, testing and validation phases of model 14-scenario 3

Figure 5.57 shows the architecture of model 15 from scenario 3, where this last has twelve inputs, 7 hidden layers and one output (WCP).

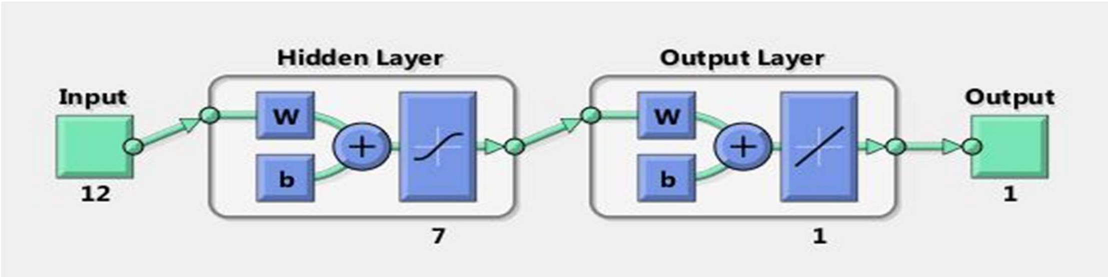

Fig 5.57 Neural network structure of model 15-scenario 3

The Target-Output graphs of training, testing and validation phases with their correlation coefficients of the model 15-scenario3 are illustrated in figure 5.58.

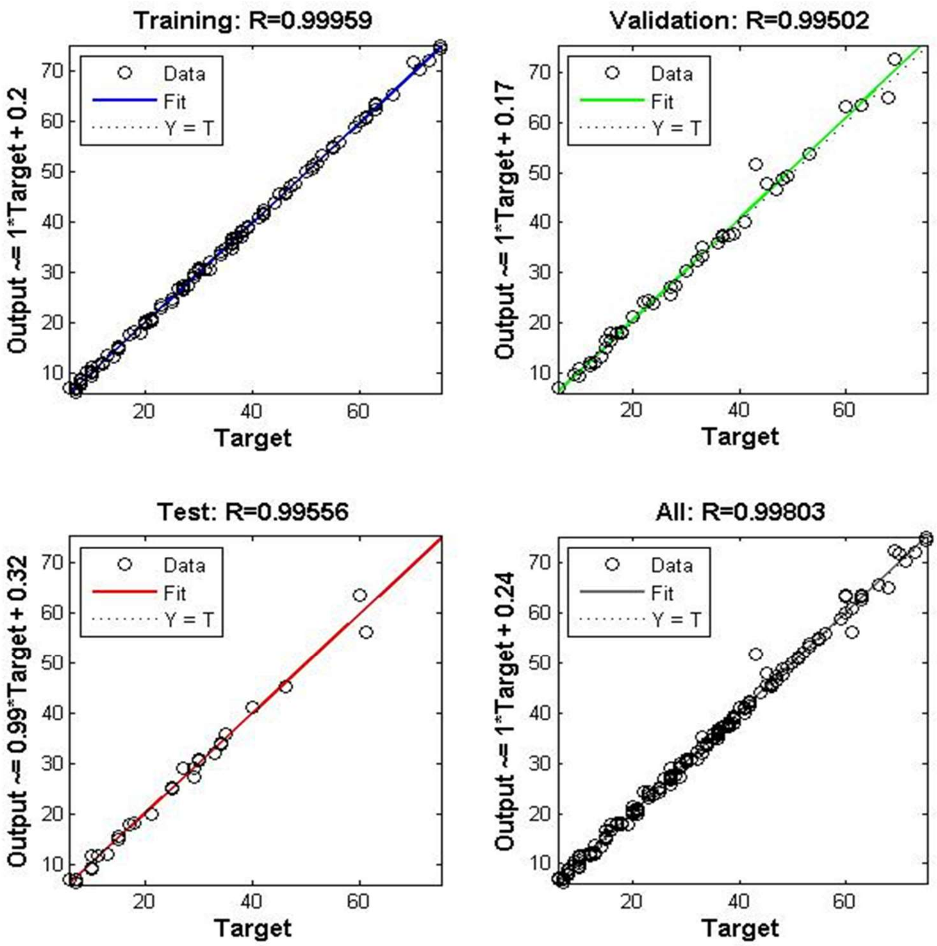

Fig 5.58 Neural network Target-Output graphs of training, testing and validation phases of model 15-scenario 3

5.12.3. ANNs predicted models and their performances

In order to test the accuracy and predictive ability of the 15 ANNs models for each household, actual data set (observed) and its predicted values are plotted and displayed in figures 5.59, 5.60 and 5.61 below. It can be seen that the predicted values are well fitted with the original data.

Moreover, and by combining the two groups of variables (socio-economic parameters and physical characteristics of building units), the neural models would gain more information than it would be separately. A possible explanation is that the inter correlation between variables.
In addition, the correlation coefficients are equal to 0.99 in the training, testing and validation phases for the 6 last models.

In general, the combination of variables improves significantly the model performance, that is why the choice of input variables is utmost important. Other studies aiming to model water consumption but with different variables agrees with the obtained results Bougadis et al., 2005, Al-Zahrani and Abo-monasar,, 2015 and El Masri et al., 2016).

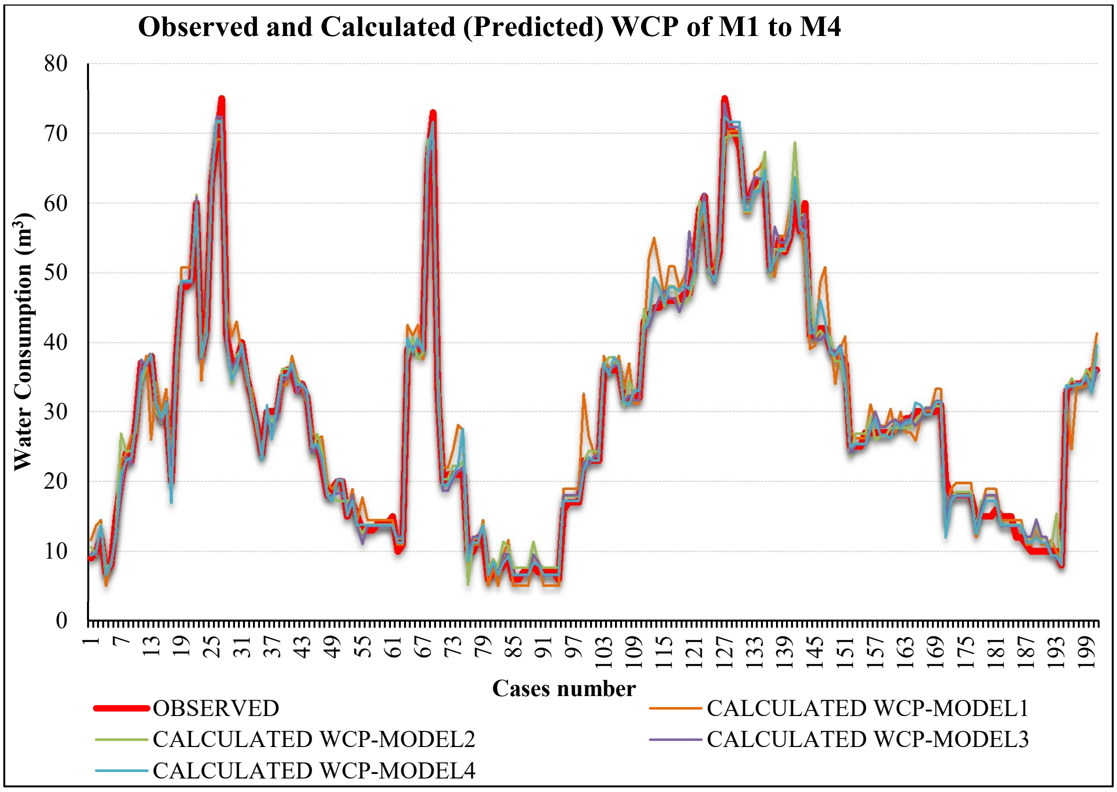

Fig 5.59 Comparison between Observed and Calculated (Predicted) WCP of the models M1, M2, M3 and M4

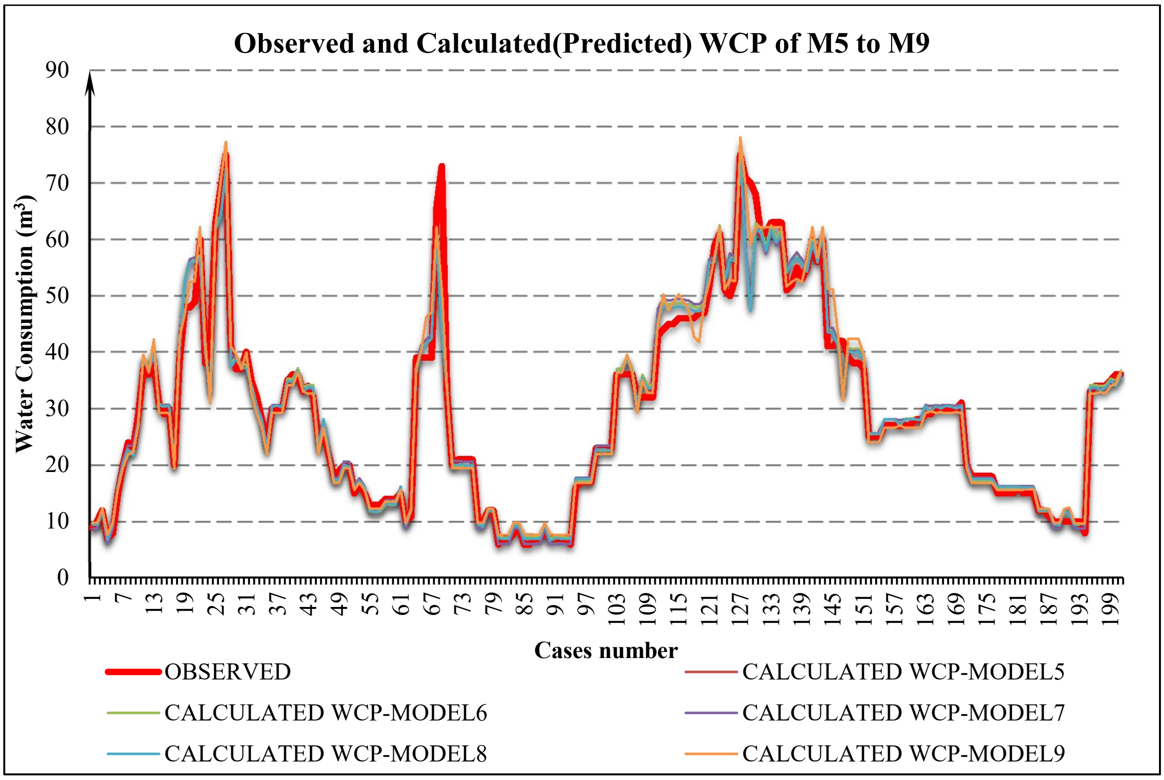

Fig 5.60 Comparison between Observed and Calculated (Predicted) WCP of the models M5, M6, M7, M8 and M9

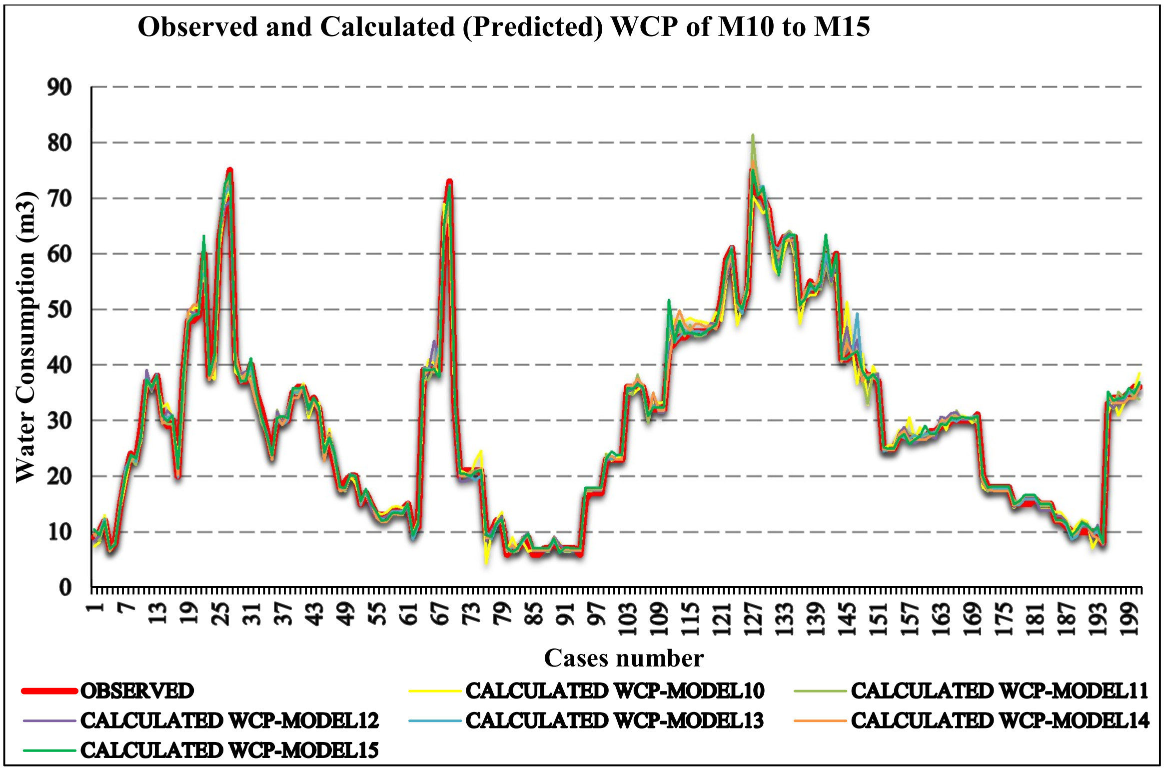

Fig 5.61 Comparison between Observed and Calculated (Predicted) WCP of the models M10, M11, M12, M13, M14 and M15

Basing on the correlation coefficient, 15 models on total are selected with values greater than 0.95 for all the phases and more efficient in forecasting water consumption of Sedrata city.

The Mean Square Error (MSE) is an excellent indicator of models performance and lower values are preferable especially during the training phase.
Values of MSE for the three scenarios are illustrated in (figures 5.62, 5.63 and 5.64). In training phase, the MSE coefficient of the last models (M10, M11, M12, M13, M14 and M15) are the smallest with 0.235, 0.713, 0.117, 0.322, 0.137 and 0.027 respectively. Furthermore, the MSE values for the models M1, M2, M3 and M4 are low too (0.576, 0.240, 0.165 and 0.199, respectively) compared with the MSE values of M5, M6, M7, M8 and M9 (1.526, 1.755, 1.541, 1.389 and 1.155, respectively). Taking these results into account, the last models (M10 to M15) appear to be the most efficient for forecasting domestic water consumption in study zone. In testing phase, the correlation coefficient values of the best models (M10 to M15) are similar and equal to 0.99. The MSE values obtained during the test phase also allow the rest models to be compared (Tables 5.23, 5.24 and 5.25).

Summing up the results, the models M10-M15 represent the best performing models. The main reason behind is the inputs and neural structure, where the best models have higher number of inputs.

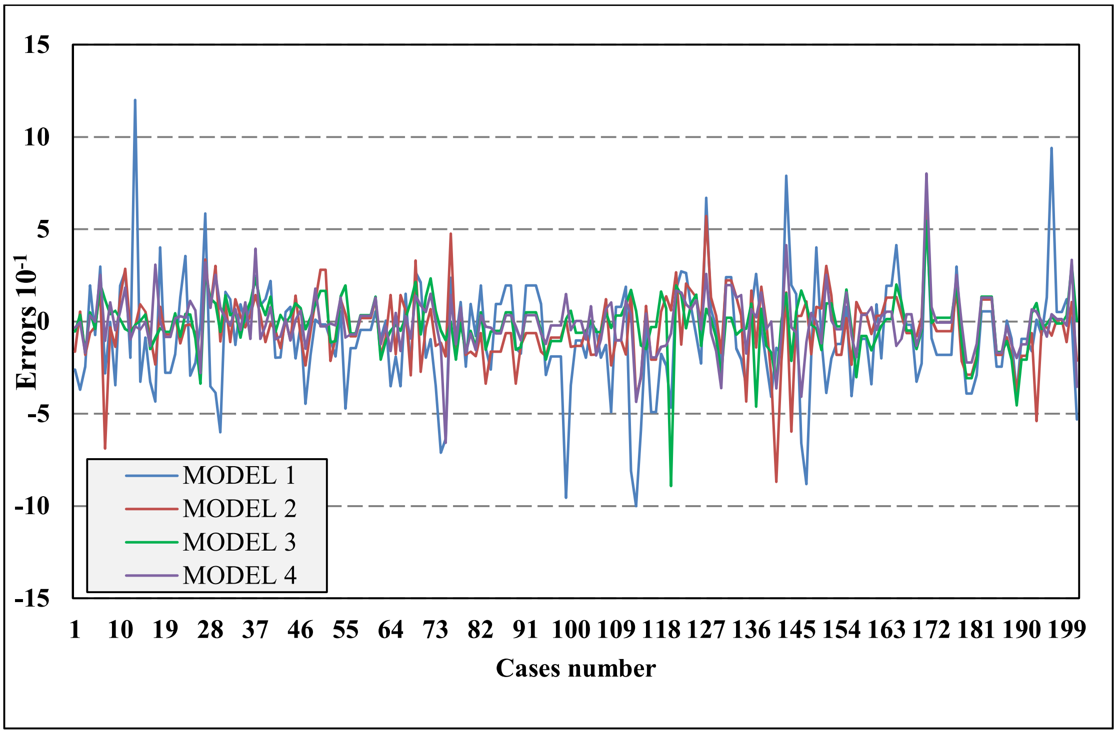

Fig 5.62 errors values of the models M1, M2, M3 and M4

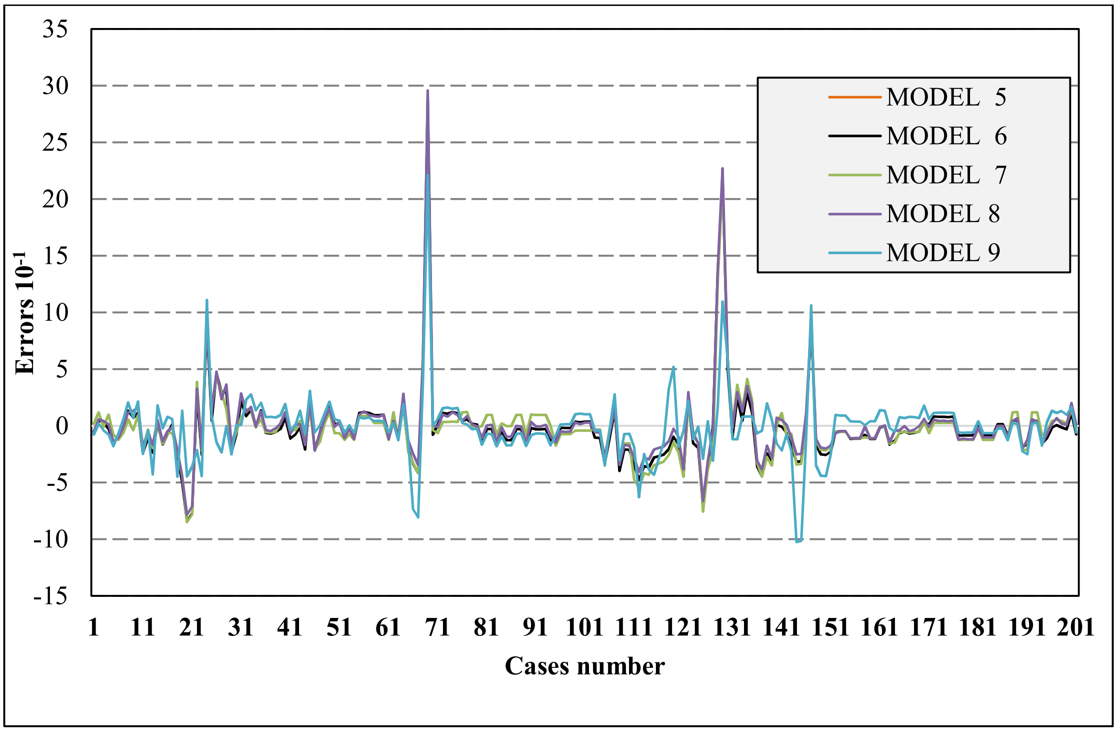

Fig 5.63 Errors values of the models M5, M6, M7, M8 and M9

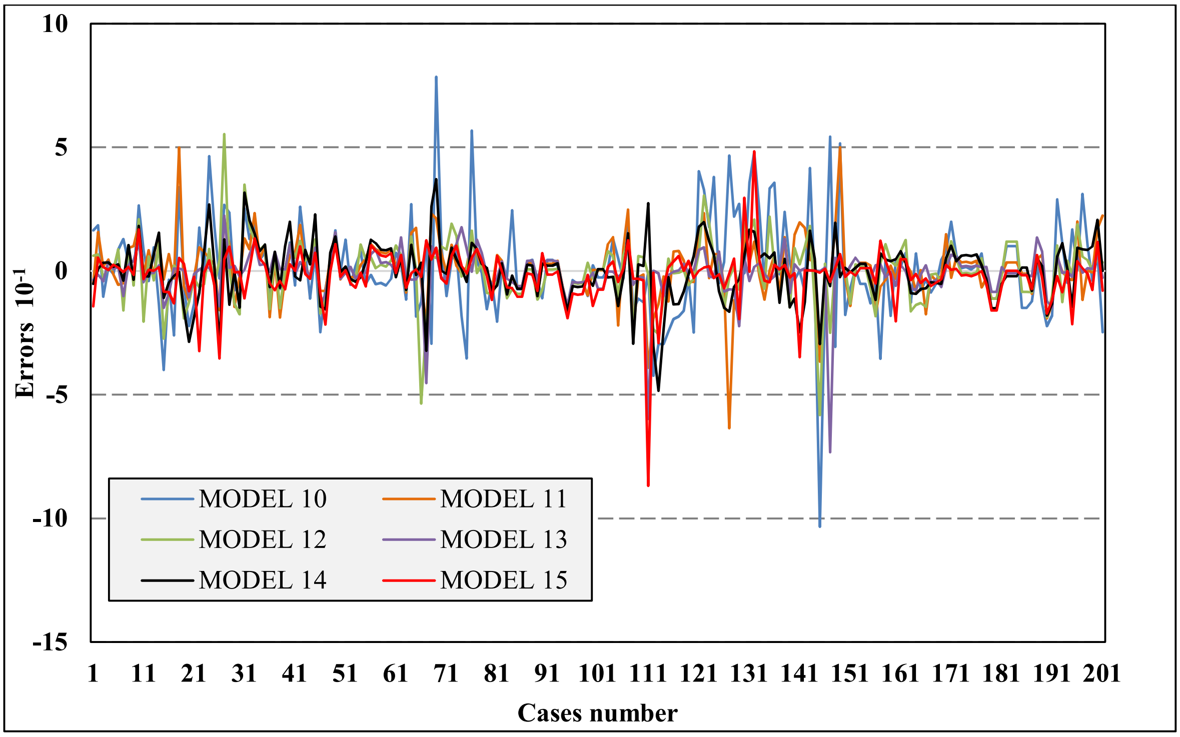

Fig 5.64 errors values the errors of the models M10, M11, M12, M13, M14 and M15