Meteorol Atmos Phys (2012) 115:81–87
DOI 10.1007/s00703-011-0168-2

ORIGINAL PAPER

Estimation of relative humidity based on artificial neural network approach in the Aegean Region of Turkey

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Received: 9 April 2011 / Accepted: 7 October 2011 / Published online: 20 October 2011

Abstract The aim of this study is to estimate the monthly mean relative humidity (MRH) values in the Aegean Region of Turkey with the help of the topographical and meteorological parameters based on artificial neural network (ANN) approach. The monthly MRH values were calculated from the measurement in the meteorological observing stations established in Izmir, Mugla, Aydin, Denizli, Usak, Manisa, Kutahya and Afyonkarahisar provinces between 2000 and 2006. Latitude, longitude, altitude, precipitation and months of the year were used in the input layer of the ANN network, while the MRH was used in output layer of the network. The ANN model was developed using MATLAB software, and then actual values were compared with those obtained by ANN and multi-linear regression methods. It seemed that the obtained values were in the acceptable error limits. It is concluded that the determination of relative humidity values is possible at any target point of the region where the measurement cannot be performed.

Responsible Editor: L. Gimeno.

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1 Introduction

Turkey is located in the Northern Hemisphere at the junction of Europe and Asia, and it has a land surface area of 785,347 km^2 officially (TUIK 2010). It is situated in Anatolia and southeastern Europe, and has seven geographical regions. Aegean Region is one of these regions. The Aegean Region located in the west of Turkey includes the provinces of Izmir, Aydin, Denizli, Mugla, Manisa, Afyon, Kutahya and Usak. The area of the region is 9.039.000 ha and constituted 11.54% of the whole area of Turkey. The altitude of the region goes up to 2,528 m from the sea level (Aegean Region Agriculture Master Plan 2006).

The Aegean Region is surrounded by the Marmara Region in north, the Interior Anatolia Region in east and the Mediterranean Region in south and southeast. The Region has a washboard coastline along with the Aegean Sea in west and a shape that gets gradually narrower toward the east. The Aegean Region is divided into two groups of Coast Aegean and Interior West Anatolia in terms of natural, mortal and economics features. The continental climate is observed at higher altitudes of the region, and there is the typical Mediterranean climate in the coast of the region. The annual mean temperature is 17°C in the part of region with the typical Mediterranean climate and 12.8°C in the part of region with the continental climate. The annual mean temperature is 15.6°C and the annual MRH is 62.44% (Aegean Region Agriculture Master Plan 2006).

Climatic differences were studied by many authors. Parishwad et al. (1998) predicted monthly mean hourly values of relative humidity, ambient temperature and wind velocity for an Indian location based on the least square regression analysis of the available measured data.

Akinbode et al. (2008) presented a preliminary assessment of the variations in the temperature and humidity in a capital city in Southwest Nigeria. Yilmaz et al. (2007) investigated the climatic differences between rural, urban and urban forest areas of the city of Erzurum/Turkey over a 10-month period. It was concluded that canopy and evapotranspiration effects of the urban forest area influenced the mean, maximum and minimum temperature differences.

The lack or excess of the humidity is the most effective factor on the human comfort initially, then lifespan, the sort of crops, the building structure, the forest fires, the structure and dimensions of air condition systems, the manufacturing systems and the determination of residential areas. In selection of climate system, the humidity where the foundation is established directly affects the capacity of the device, the foundation activities and costs of the air condition system. At the same time, the humidity is also related to the kinds and thickness of insulation. Therefore, it also affects the construction sector. Information on monthly mean hourly values of humidity, ambient temperature and wind velocity are useful in the thermal analysis of building, heating and cooling load calculations to decide the correct sizing of an air conditioning system for thermal comfort (Parishwad et al. 1998). Hitle and Pendersen (1981) also analyzed actual weather data for the calculation of heat conduction through multi-layer building walls.

Little is known about the effect of the relative humidity in the cities of Aegean Region, and has not been well documented, while much information is available on the effect of climatic variations in European and American countries (Akinbode et al. 2008; Yilmaz et al. 2007; Kalkstein and Greene 1997; Hajat et al. 2002; Sozen and Arcaklioglu 2005). As mentioned above, the estimation of relative humidity is an important factor in many engineering applications. The accurate knowledge of the relative humidity availability is required by meteorologists. Furthermore, the evaluation of relative humidity is also necessary for places where there is no monitoring station with the help of the suitable prediction models.

In this study, an artificial neural network (ANN) model was developed to obtain the MRH values at any target point not being measured in the Aegean Region. The used data were taken from Izmir, Mugla, Aydin, Denizli, Usak, Manisa, Kutahya and Afyonkarahisar meteorological stations. The MRH values of the target area were predicted with the help of latitude, longitude, altitude, precipitation and months of the year.

2 Analysis of data

The MRH and monthly total precipitation (MTP) values used in this study were measured by Turkish State Meteorological Service (TSMS) in the Aegean Region of Turkey. The precipitation data is measured with rain gauge by recording the total precipitation amount falling from the atmosphere to the Earth's surface. The measurement of the monthly total precipitation amount is a basic and easy process within the other meteorological data. So, the determination of the relative humidity is possible with a great accuracy without taking measurement by means of precipitation when the ANN is applied in practice. Because, the analysis depends only on the available data in the ANN method.

The regional distribution of the annual MRH in the Aegean Region and the meteorological observing stations are given in Fig. 1. The coordinates and the altitudes from the sea level of the stations are presented in Table 1. The altitudes of the stations range from 28.55 to 969.28 m above the sea level. Kutahya has the maximum altitude above the sea level, whereas Izmir has the minimum altitude.

2.1 MRH in the Aegean Region

The monthly MRH values and the MTP between 2000 and 2006 are shown in Figs. 2 and 3. The variations of monthly MRH and precipitation have the same tendency. The maximum values are observed in December and January in all stations, while monthly both values are the lowest in

Fig. 1 The regional distribution of the annual MRH in the Aegean Region

Table 1 The coordinates of meteorological stations

Stations	Latitude	Longitude	Altitude (m)
Mugla	37°13′N	28°22′E	646.07
Denizli	37°47′N	29°05′E	425.29
Aydin	37°51′N	27°51′E	56.30
Izmir	38°23′N	27°04′E	28.55
Afyonkarahisar	38°44′N	30°34′E	1,034.00
Usak	38°41′N	29°24′E	919.22
Manisa	38°37′N	27°26′E	71.00
Kutahya	39°25′N	29°58′E	969.28

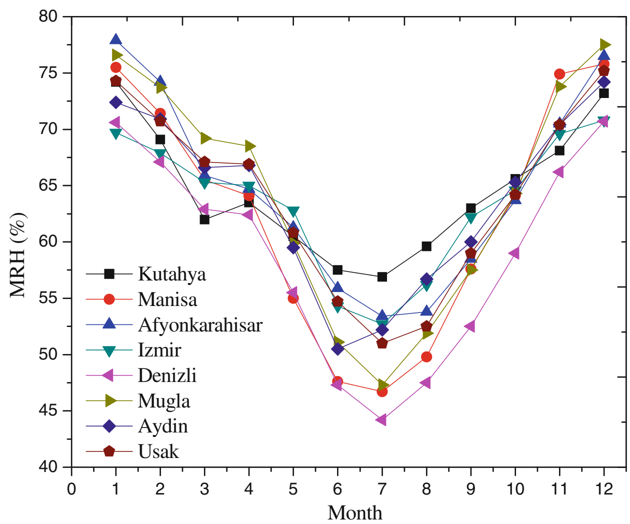

Fig. 2 The monthly MRH values calculated between 2000 and 2006

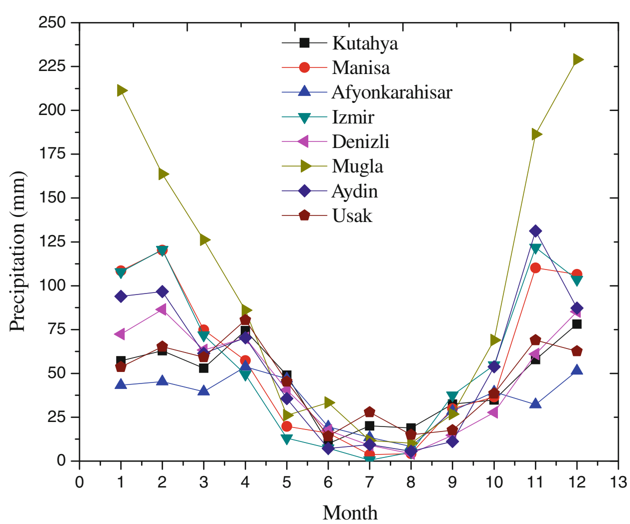

Fig. 3 The MTP values calculated between 2000 and 2006

June, July and August. Furthermore, the highest MTP values are obtained from Mugla station in January and December. The minimum variations of MRH and precipitation during the year are 44.2% at the Denizli station in August and 0.49 mm at the Izmir station in July. However, the maximum value is 74.2% at the Kutahya station in January and 229.03 mm at the Mugla station in December. Examining the MRH values in August, the highest value is 56.9% at the Kutahya station and the lowest value is 47.5% at the Denizli station. Considering the mean values of relative humidity in December and January with the minimum values of all the data, the maximum value is 77.9% at the Afyonkarahisar station and the minimum value is 69.7% at the Izmir station. The highest values of MRH in all months are obtained at the Afyonkarahisar station, and are decreasingly followed by Mugla, Manisa, Usak, Kutahya, Aydin, Denizli and Izmir stations, respectively.

3 Artificial neural network

Artificial neural networks are physical cell systems that involve receiving, processing, storing and using information. It is generally used to solve the problems that are not defined or hardly defined with mathematical models. The idea of binding the neurons (data processing elements) as a network is performed by inspiring from the binding of the cells in human brain. Artificial Neural Networks are original approaches to form a new system by imitating the processing of human brain. The source of inspiration of ANN structures is unexceptionally the processing method of biological neuron networks (Sagiroglu et al. 2003). There are many studies about the ANN model used in the analysis of many different problems. This method is successfully applied to the areas of mathematics, engineering, medicine, economy, meteorology, psychology, neurology, electricity etc. (Sagiroglu et al. 2003; Kalogirou et al. 1999; Bilgili et al. 2007; Bilgili and Sahin 2010; Bilgili 2010).

An artificial neuron basically consists of five parts such as inputs signals, synaptic weights, summing function, activation function and output as seen in Fig. 4 (Sagiroglu et al. 2003; Haykin 1994). The activation function is given by multiplying the vectors of inputs and weights and it is given as follows:

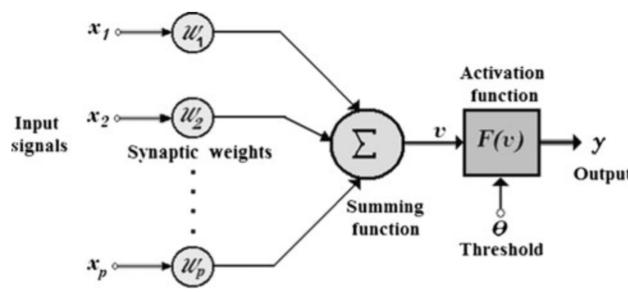

Fig. 4 The basic building block of a neuron of p-entry

$$v = \sum_{i=1}^{p} w_i x_i = \left[w_1 w_2 \ldots w_p\right]\left[x_1 x_2 \ldots x_p\right]^T \quad (1)$$

Later, the activation potential is passed through an activation function $F(v)$ delivering the output signals and the output value is obtained using the function given as follows:

$$y = F(v) \quad (2)$$

The activation function is a function that normalizes the activation potential for the standard values of output signals. Tangent sigmoid (tansig), logistic sigmoid (logsig) and linear (purelin) transfer functions are some of the functions used in MATLAB software. The logsig transfer function is given as follows:

$$F(v) = \frac{1}{1 + e^{-v}} \quad (3)$$

There are many learning algorithms in the literature (Haykin 1994). Most of these learning algorithms are based on mathematical principles and used to update the weights. Resilient Propagation (RP), Levenberg–Marquardt (LM) and Scaled Conjugate Gradient (SCG) are some of the algorithms recently used for various applications.

4 Application

The structure of ANN model used in this study is given in Fig. 5. An estimation model is developed using MATLAB software. As mentioned before, the parameters showing significant variability of relative humidity are latitude, longitude, altitude, precipitation and month of the year. Therefore, the monthly MRH value is used in the output layer of the ANN model, while these variables are used in the input layer of the ANN model. After selecting the input and output variables, the number of processing elements (artificial neurons) used in the hidden layer is determined.

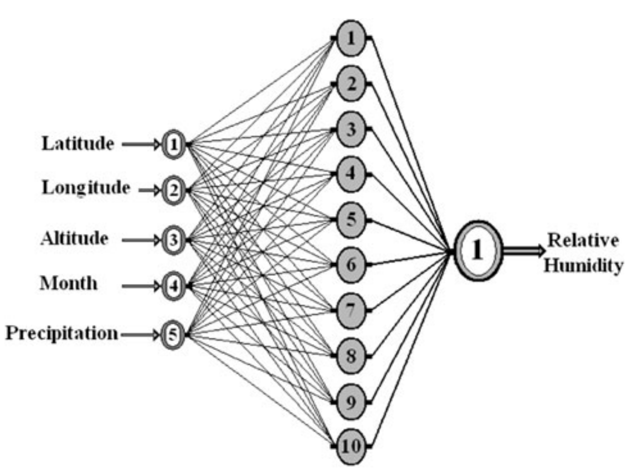

Fig. 5 The structure of artificial neural network model

As seen in Fig. 5, there are input, hidden and output layers in the ANN model. In this model, the hidden layer has 10 neurons. The different learning algorithms such as Resilient Propagation (RP), Levenberg–Marquardt (LM) and Scaled Conjugate Gradient (SCG) were applied to model prediction, and the best result was obtained from RP learning algorithm. The logistic sigmoid (logsig) and the linear (purelin) transfer functions are used as activation functions in the hidden and output layers. There is no activation function in input layer of the network.

The monthly MRH values used in this study are obtained at the province stations in Aegean Regions of Turkey between 2000 and 2006. The total number of measuring stations in the region is 8. Therefore, the total number of data used in the model of ANN is 96 (12 months and 8 stations) and divided into two groups. Seventy-two of these data belonging to the stations of Izmir, Mugla, Denizli, Manisa, Kutahya and Afyonkarahisar are used for learning process, the rest of the data belonging to Aydin and Usak stations are used to test the ANN model. The learning process is performed to design the ANN model. The testing process is also applied to investigate the performance of the ANN model.

5 Results and discussion

In order to suit the consistency of the model, the values applied in the input and output layers were normalized by the following formula in the range of 0.1–0.9 and then returned to original values after the simulation.

$$X_N = 0.8\left(\frac{X_R - X_{min}}{X_{max} - X_{min}}\right) + 0.1 \quad (4)$$

where X_N is normalized value, X_R is real value, X_{min} is minimum value and X_{max} is maximum value. Normalization of the training inputs generally improves the quality of the training. For this reason, all input and output variables were normalized by Eq. 4. The minimum and maximum values of them are given in Table 2.

As a result of the learning and testing processes, Eq. 5 was obtained to forecast the monthly MRH values

Table 2 Minimum and maximum values of input and output variables

Input and output variables	X_{min}	X_{max}
Mean relative humidity, MRH (%)	44.20	77.90
Latitude, LA (°)	37.13	39.25
Longitude, LN (°)	27.04	30.34
Altitude, A (m)	28.55	1,034.00
Monthly total precipitation, MTP (mm)	0.49	229.03
Month, M	1	12

Table 3 The weights obtained by RP algorithm

i	w_{1i}	w_{2i}	w_{3i}	w_{4i}	w_{5i}	w_{6i}
1	0.3269	−1.9967	−0.9318	0.6630	−8.5259	3.1431
2	−6.4663	7.0404	−8.6634	0.2076	−5.7914	8.7833
3	−5.5355	3.7232	−8.3713	3.6132	−1.6016	4.7770
4	−1.6048	−4.1357	0.2547	−11.4130	0.3765	6.2158
5	6.4629	−0.7282	2.6270	9.0951	1.5677	−12.3660
6	4.8049	−1.3738	−4.1033	−11.3385	8.3450	5.5217
7	3.7589	−6.3033	4.3814	0.7445	2.0426	−3.2109
8	−2.1708	−1.6742	−0.6115	11.3613	1.9310	−6.4316
9	−0.6208	−5.0724	8.5856	4.6706	20.4205	−13.9828
10	−9.0663	−3.3033	5.5480	0.7193	5.3436	−5.6998

belonging to the target point. F_i (1, 2, 3, …, 10) values are calculated by Eq. 6.

$$\begin{aligned}\mathrm{MRH} = & -0.1997F_1 + 0.1370F_2 - 0.3869F_3 + 0.5495F_4 \\ & + 0.2645F_5 + 0.1789F_6 - 0.1768F_7 + 0.7310F_8 \\ & - 0.1826F_9 + 0.2995F_{10} + 0.3086 \end{aligned} \quad (5)$$

$$F_i = \frac{1}{1 + e^{-E_i}} \quad (6)$$

E_i (1, 2, 3, …, 10) values are calculated by means of the independent variables of latitude (LA), longitude (LN), altitude (A), MTP and months (M) of the year using Eq. 7. The weights in Eq. 7 (w_{1i}, w_{2i}, w_{3i}, w_{4i}, w_{5i}, w_{6i}) are given in Table 3.

$$\begin{aligned}E_i = & w_{1i} \times \mathrm{LA} + w_{2i} \times \mathrm{LN} + w_{3i} \times A + w_{4i} \times M + w_{5i} \\ & \times \mathrm{MTP} + w_{6i}\end{aligned} \quad (7)$$

The predicted values obtained as a result of the testing processes were compared to the actual values and MLR model to investigate the performance of the ANN model. The performances for Usak and Aydin stations are given in Figs. 6 and 7. As seen in Figs. 6 and 7, the ANN prediction is a good agreement with the actual values.

The mean absolute percentage error (MAPE) and correlation coefficient (R) are calculated to validate the prediction. The parameters of MAPE and R are given as follows in Eqs. 8 and 9 (Valverde Ramirez et al. 2005).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \frac{|y_i - x_i|}{y_i} \times 100 \quad (8)$$

$$R = \frac{\left(\sum_{i=1}^{n} x_i . y_i\right) - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{\sqrt{\left[\left(\sum_{i=1}^{n} x_i^2\right) - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[\left(\sum_{i=1}^{n} y_i^2\right) - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \quad (9)$$

where x is actual value, y is predicted value, n is total number of data (month). The performance values of MAPE

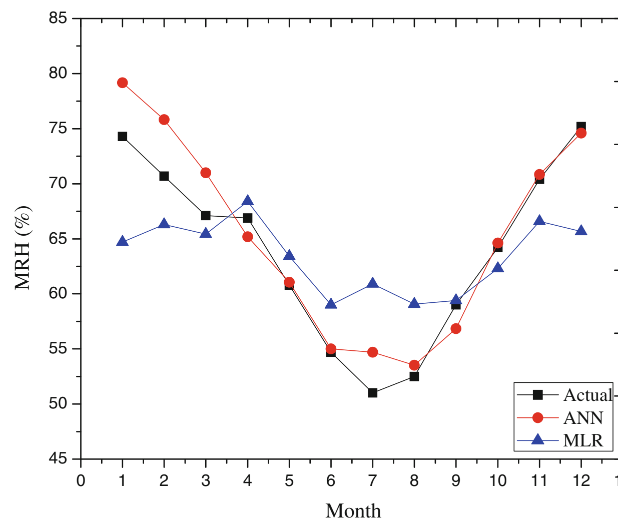

Fig. 6 Comparison of the predicted (ANN), MLR and actual MRH values for Usak station

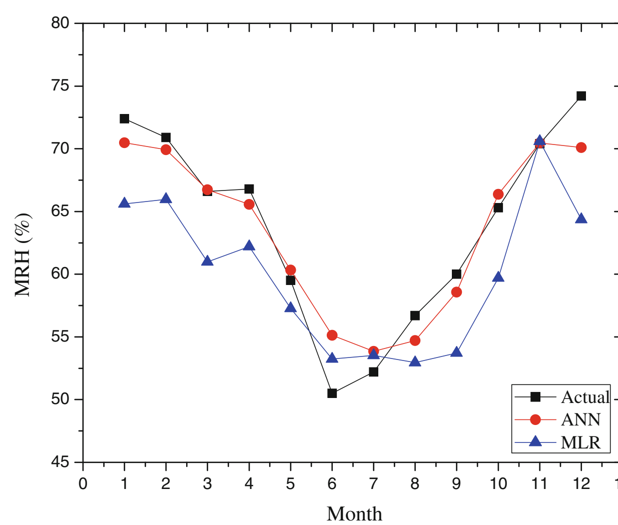

Fig. 7 Comparison of the predicted (ANN), MLR and actual MRH values for Aydin station

and *R* for the monthly MRH values for ANN and MLR models at all stations are given in Table 4. As a result of the training and testing process for ANN model, the MAPE values for the monthly MRH varied between 0.83 and 3.32%. The maximum MAPE value is obtained at the Manisa station. On the other hand, the best result is obtained at the Afyonkarahisar station due to the MAPE and *R* values. The maximum *R* value between the actual and predicted values is calculated as 0.9965 at the Afyonkarahisar station. Besides, the minimum *R* value is obtained as 0.9624 at the Usak station. However, the MAPE values for the monthly MRH for MLR model varied between 3.88 and 8.56%. According to the obtained results, the ANN model is more appropriate than the MLR model. Artificial neural network seems a very useful method to predict the monthly MRH values for a target station.

Table 4 The MAPE and *R* values of the monthly predicted MRH values obtained by the ANN model

Meteorological stations	MLR		ANN	
	MAPE (%)	*R*	MAPE (%)	*R*
Kutahya	5.16	0.7379	1.74	0.9689
Manisa	7.15	0.9489	3.32	0.9932
Afyonkarahisar	8.56	0.7482	0.83	0.9965
Izmir	3.88	0.9059	3.16	0.9657
Denizli	8.12	0.9329	1.85	0.9910
Mugla	7.06	0.9350	1.56	0.9929
Usak[a]	7.47	0.8169	3.18	0.9624
Aydin[a]	6.88	0.8992	2.74	0.9696

[a] Testing process

Data of some stations not used during the training and testing processes were tested to validate the applicability of the model. For this purpose, the monthly total precipitation, MRH and topographic data were provided by Nazilli meteorological station in Aegean Region and other neighboring meteorological stations in Burdur, Isparta and Balikesir, respectively. With the help of these data, the monthly MRH values of these stations were predicted using Eqs. 5–7 and compared with actual data. According to the results shown in Fig. 8, the MAPE values obtained from

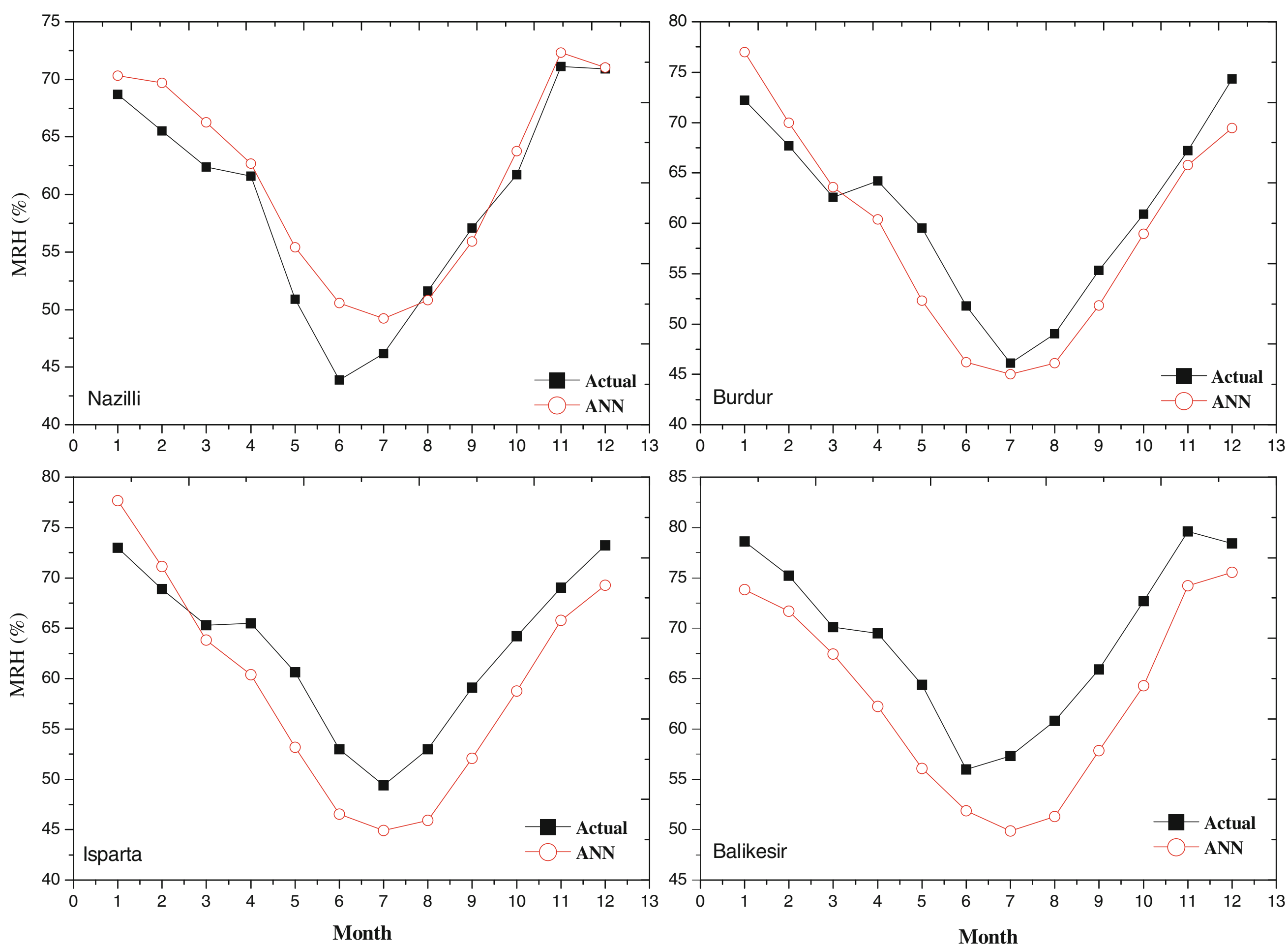

Fig. 8 The performance of ANN model on another dataset for a period different from the training and testing process

Nazilli station in the Aegean Region and Burdur station located out of Aegean Region were found to be 5.0 and 5.6%, respectively. However, it was determined that MAPE values obtained from Isparta and Balikesir meteorological stations located in other geographical regions were 8.0 and 9.0%, respectively. In conclusion, the developed model gives more accurate results in estimating the monthly MRH for the Aegean Region of Turkey. But, different models should be developed for each region of Turkey due to distinct topographic and meteorological properties.

6 Conclusions

The relative humidity in the region directly affects the conjectural construction components, the structure and thickness of heat transfer materials, and the serpentine capacity of air condition systems. At the same time, estimation of relative humidity has an important role for preventing and extinguishing the forest fires in the region. According to the results derived from ANN and MLR model, the ANN model is more suitable for estimating the MRH than the MLR model. In this study, it is suggested that this method can be used to achieve suitable results as the use of ANN is more convenient, cheaper and faster than methods used by meteorological services in the estimation of MRH. Besides, with the help of the developed method, it is possible to predict the missing data of the stations with a greater accuracy for the Aegean Region. It is seen that the developed method can give more accurate results for the Aegean Region and its neighbouring provinces. But, different models should be developed for each region of Turkey due to distinct topographic and meteorological properties. This method can also be used by researchers dealing with the climatic properties of Aegean Region.

Acknowledgments The authors would like to express their appreciation to the Turkish State Meteorological Services (TSMS) for providing the data.

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