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Estimating daily pan evaporation data using adaptive neuro fuzzy inference system: case study within Van local station-Turkey

Günlük tava buharlaşma verilerinin uyarlamalı sinirsel bulanık çıkarım sistemi kullanılarak tahmini: Van bölge istasyonu-Türkiye örneği

Yazar(lar) (Author(s)): *Nadire ÜÇLER*[1], *Fatih KUTLU*[2]

ORCID1: 0000-0001-6407-121X
ORCID2: 0000-0002-1731-9558

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Estimating Daily Pan Evaporation Data Using Adaptive Neuro Fuzzy Inference System: Case Study Within Van Local Station-Turkey

Highlights

- 4 different models were set with meteorological variables.
- Temperature, relative humidity, actual pressure, and wind velocity were most suitable as inputs.
- In all models, similar results were observed in Konya Airport and Van Local stations.
- The result of the Kocaeli station was relatively poor.

Graphical Abstract

The prediction model of the total daily pan evaporation parameter was created using different meteorological parameters as inputs with data of 2013-2018. 3 stations were used for the evaluation of the model.

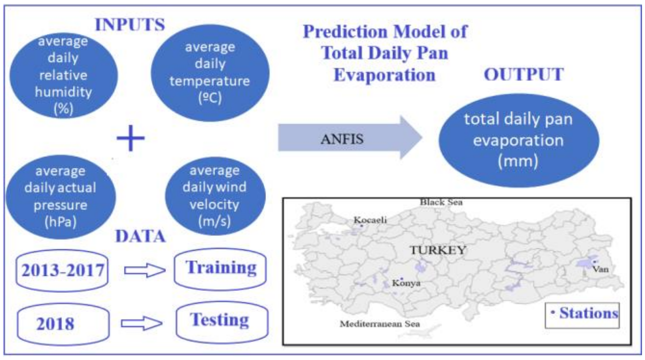

Figure. *Prediction model of total daily pan evaporation using ANFIS*

Aim

The aim of this study is to model the evaporation data, which is one of the important parameters of the hydrological cycle, by using the Adaptive Neuro-Fuzzy Inference System (ANFIS).

Design & Methodology

4 different models were installed starting from one input up to 4 inputs by using average daily temperature (ºC), relative humidity (%), current pressure (hPa), wind speed (m/s) as inputs parameters. Total daily pan evaporation (mm) was selected as output parameter.

Originality

The difference of this study is the revelation of whether a model prepared for another station can be used in the stations where evaporation measurement is not possible for technical or economic reasons.

Findings

In all models, while similar results were observed in Konya Airport and Van Local stations, the result of Kocaeli station was relatively poor. Fourth model, which was established using four input parameters, achieved the lowest error values at all stations and the Kocaeli station got the best R^2 *value at this model.*

Conclusion

It is shown that a model formed by using data of another station with similar meteorological characteristics can be used to estimate the evaporation if needed due to lack of data or irregularity during the management of water resources.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Estimating Daily Pan Evaporation Data using Adaptive Neuro Fuzzy Inference System: Case Study within Van Local Station-Turkey

Research Article /Araştırma Makalesi

Nadire ÜÇLER[1]*, Fatih KUTLU[2]

[1] Van Vocational School of Higher Education, Department of Construction Technology, Van Yuzuncu Yil University, Turkey
[2] Faculty of Science, Department of Mathematic, Van Yuzuncu Yil University, Turkey

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ABSTRACT

The aim of this study is to model the evaporation data, which is one of the important parameters of the hydrological cycle, by using the Adaptive Neuro Fuzzy Inference System (ANFIS). Four different models were designed starting from one input up to four inputs used average daily temperature (ºC), average daily relative humidity (%), average daily current pressure (hPa) and average daily wind speed (m/s) as inputs parameters. Total daily pan evaporation (mm) was selected as output parameter. The normalized daily data of the Van Local Station between 2013 - 2017 was used for training of the model. Data for 2018 were used for testing purposes. Also, two stations in different cities were selected for comparison in order to determine whether the models prepared using data from Van Local Station can be used in other stations. For this purpose, a station from Konya province with climatic characteristics similar to Van province and a station from Kocaeli province with different climatic characteristics were selected. In all models, similar results between Van Local Station and the station selected from Konya were observed, while the results between Van Local Station and the station selected from Kocaeli were observed as relatively low compared to the previous comparison. The fourth model, which was designed using four input parameters, achieved the lowest error values at all stations and Kocaeli station got the best R^2 value at this model.

Keywords: Evaporation, temperature, humidity, wind, ANFIS.

Günlük Tava Buharlaşma Verilerinin Uyarlamalı Sinirsel Bulanık Çıkarım Sistemi Kullanılarak Tahmini: Van Bölge İstasyonu-Türkiye Örneği

ÖZ

Bu çalışmanın amacı, hidrolojik döngünün önemli parametrelerinden olan buharlaşma verisinin Uyarlamalı Sinirsel Bulanık Çıkarım Sistemi (USBÇS) kullanılarak modellenmesidir. Giriş parametresi olarak ortalama günlük sıcaklık (ºC), ortalama günlük bağıl nem (%), ortalama günlük aktüel basınç (hPa), ortalama günlük rüzgâr hızının (m/s) kullanıldığı, girdi sayısının birden başlayıp dörde çıktığı dört farklı model kurulmuştur. Van Bölge İstasyonu'na ait 2013-2017 yılları arasındaki normalize edilmiş günlük veriler modelin eğitilmesi için kullanılmıştır. 2018 verileri ise test amaçlı kullanılmıştır. Van Bölge İstasyonu'nun verileri kullanılarak hazırlanan modelin başka istasyonlarda kullanılıp kullanılamayacağını ortaya koymak için farklı şehirlerde bulunan iki istasyon karşılaştırma için seçilmiştir. Bu amaçla, iklim özellikleri Van iline benzeyen Konya ilinden bir istasyon ve farklı iklim özelliklerine sahip Kocaeli ilinden bir istasyon seçilmiştir. Tüm modellerde, Konya ilinden seçilen istasyon ile Van Bölge İstasyonu arasında benzer sonuçlar gözlemlenirken, Kocaeli ilinden seçilen istasyon ile Van Bölge İstasyonu arasında sonuçlar bir önceki karşılaştırmaya nispeten daha düşük çıkmıştır. Dört girdi parametresi ile kurulan dördüncü model, tüm istasyonlarda en düşük hata değerlerine ulaşmış ve Kocaeli istasyonunda bu modelde en iyi R^2 değeri hesaplanmıştır.

Anahtar kelimeler: Buharlaşma, sıcaklık, nem, rüzgâr, USBÇS.

1. INTRODUCTION

Evaporation, which is an important and the less understood parameter of the hydrological cycle [1], is the process of turning water from the liquid state into gas or steam. The term implicates evaporation of water and soil surfaces and also water held by vegetative surfaces [2]. The rate of evaporation from surface is depend on the surrounding airs temperature, vapor pressure, vapor velocity and the net available heat, and the wetness of the evaporating surface [3].

It is important for decision makers to estimate the evaporation loss during the management of water resources. It is also important for determining the irrigation method at regions with water shortage.

The pan evaporation refers to the measurement and modeling of evaporation using a pan with certain diameter and depth made of galvanized iron. US Weather Bureau Class A pan is the most used pan with 122 cm in diameter and 25 cm in depth and is placed on a wood grill

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**Sorumlu Yazar (Corresponding Author)*
e-posta : nadireucler@yyu.edu.tr

about 15 cm above the soil surface. Pan evaporation values are used to estimate lake and reservoir evaporation [4].

It may not be practical and economical to place the evaporation pan in each region where we want to determine the evaporation loss, or it may not be possible to place the pan and make regular measurements for reasons such as the physical conditions of the area. So, prediction of pan evaporation value where no pans are placed using model set with existing meteorological parameters is important to decision makers. Because of this reason, this topic has attracted the attention of many researchers. For example: Lim et al. aimed to develop a new model called the ''PenPan-V2" model for application under steady state conditions and two versions are tested using pan evaporation data available across the Australian continent [5]. Shiri at al. evaluated a Gene Expression Programming (GEP) model for estimating evaporation using daily climatic data from six automated weather stations in the US [6]. Fakhreddine estimated daily evaporation from poorly monitored lakes using limited meteorological data at Qaraoun dam [7]. Althoff et al. wanted to improve methods for estimating small reservoir evaporation in the Brazilian savanna region [8]. Other approaches can be examined from referenced studies [9-17].

The use of intelligent methods in the modeling and estimation of natural phenomena such as evaporation is an up-to-date issue. Among these methods, the fuzzy logic method, which was born as a theoretical approach but has been applied in many fields such as engineering sciences, social sciences, computer sciences, management sciences, medicine and meteorology, is also used to create forecasting models by using the existing datasets. As it is known, when designing fuzzy systems, the general structure of the system is replaced by a technique closer to the nature of human thinking rather than complex and difficult mathematical expressions. Furthermore, the cause and effect relationship are more effectively demonstrated by ANFIS, which is formed by hybridizing artificial neural networks (ANN) and fuzzy inference system designed. Thus, with the help of ANFIS and expert opinion, it is provided to model the correct relationship between the factors affecting the events examined. Some studies in the literature using ANFIS are listed below: Kisi and Tombul [18] examined the utility of fuzzy genetic approach in prediction of monthly pan evaporation and determined that monthly pan evaporation could be successfully estimated using this approach. Ozturk et al. [19] selected Sugeno type Fuzzy Inference System for modeling the daily evaporation at Northern Cyprus by using temperature, relative humidity and atmospheric pressure. Kisi [20] used Neuro Fuzzy Computing Technique to boost the precision of daily evaporation prediction and figured out that this technique could be utilized successfully in estimating evaporation. Kermani et al. [21] investigated the ability of artificial intelligence–based models and metaheuristic algorithms in modeling monthly evaporation at two different stations in Turkey and indicated that the ANFIS model have better results in one of the stations. Maroufpoor et al. [22] compared the success of ANN, ANFIS and Gene Expression Programming (GEP) with previous studies to predict the wind drift and evaporation losses and the results indicated that the ANFIS, ANN and GEP got better results than the others.

In this study, ANFIS was used to estimation of the total daily pan evaporation (mm) and four different model were set using meteorological parameters as inputs. In order to set the first model, average daily temperature (ºC) was selected as input, for the second, third and fourth models average daily relative humidity (%), average daily actual pressure (hPa) and average daily wind velocity (m/s) were added as inputs, respectively. For the purpose of evaluating the performance of the model, the Van Local Station's daily data in 2018 and the data of the Konya Airport Station which has similar meteorological features with Van province and the data of the Kocaeli Station which has different meteorological features were used. Thus, it is aimed to determine the success of a model created using the data of a region to estimate the evaporation data of other regions with similar or different meteorological characteristics.

2. MATERIAL and METHOD

2.1. Adaptive Neuro-Fuzzy Inference System

ANFIS is a hybrid intelligent method which is obtained by combining the learning ability of ANN and the estimation capabilities of Takagi-Sugeno (TS) fuzzy inference systems. ANFIS, originally developed by Jang in 1993 [23], has been implemented in many areas and achieved successful results. The general structure of ANFIS is given as follows (Figure 1):

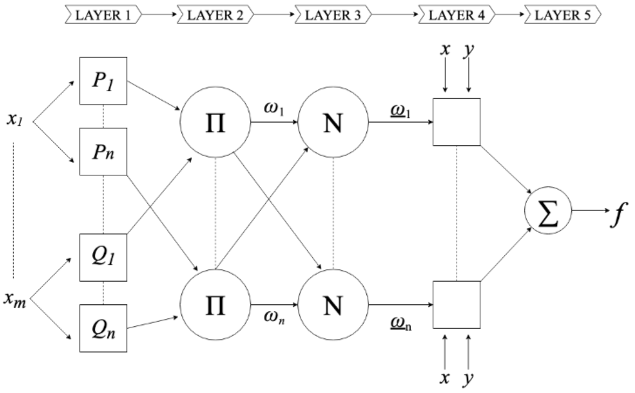


Figure 1. The general structure of ANFIS

In the figure, P_i and Q_i show the linguistic variables used in the system and modeled with the help of fuzzy sets. In the first layer, the input values are transferred to layer 2 by taking the membership degrees by means of the membership P_i and Q_i. In the second layer, the inputs are multiplied and exited from the node. In the third layer, the firing strength values are normalized by proportioning them to the total firing strength values. In the fourth layer, the nodes compute a parameter function on the layer. So, Parameters which is called consequent parameters are obtained in this layer. After the fourth layer, Takagi-Sugeno inference system is used. The general structure of the TS extraction system is given below (Figure 2):

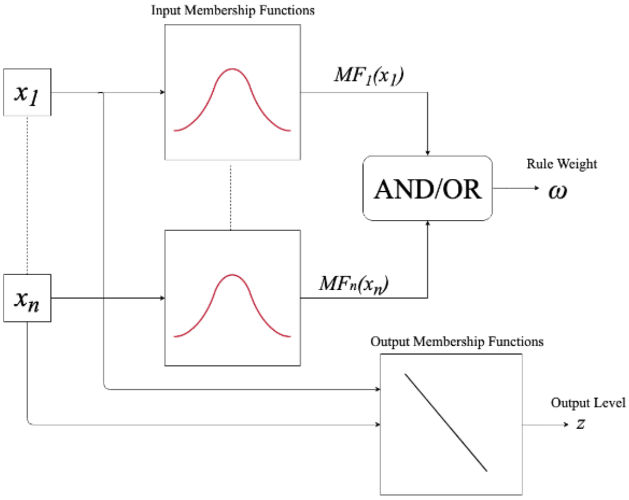


Figure 2. The general structure of Takagi-Sugeno inference system

In this diagram, x_i represents the input values. In our study, Gaussian fuzzy numbers have been used as membership functions. As it is known, many events in nature exhibit Gaussian distribution epistemologically. The definition of Gaussian fuzzy numbers is as follows:

$$P_i(x) = e^{\frac{-(x-b)^2}{2a}} \tag{1}$$

Here, the number b is the center and the number a indicates the width. In this study, product and probabilistic product are used for "AND" and "OR" conjunctions which are used in the rule base. In Takagi-Sugeno (TS) Inference Method, the output variable is defined as a fixed number or polynomial function connected to the variable. In this study, different four rule bases were used for TS inference system according to number of inputs. The output values in each rule are the polynomials given below. Mathematical expression of the system was given as below:

Calculating membership degrees:

$$P_i(x_i) = MF_i(x_i) \tag{2}$$

Calculating weights:

$$\omega_i = \prod_{i=1}^{n} MF_i(x_i) \tag{3}$$

Calculating firing strengths:

$$\bar{\omega}_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \tag{4}$$

Calculating the overall output:

$$z_i = \bar{\omega}_i f_i(x_n) \tag{5}$$

Calculating the implication and the rule consequences:

$$f(x_1, x_2, \dots, x_n) = \sum_{i=1}^{n} \bar{\omega}_i f_i(x_n) = \frac{\sum_{i=1}^{n} \omega_i f_i(x_n)}{\sum_{i=1}^{n} \omega_i} \tag{6}$$

The calculations have been made with Fuzzy Logic Toolbox and ANFIS Toolboxes in MATLAB software.

2.2. Case Study

The daily meteorological data of three stations controlled by the Turkish State Meteorological Service in Turkey were used in the study. The locations of the Van Local (station no: 17172, elevation: 1675 m, latitude 38.4693 N, longitude 43.3460 E), Konya Airport (station no: 17244, elevation: 1031 m, latitude 37.9837 N, longitude 32.5740 E) and Kocaeli (station no: 17066, elevation: 74 m, latitude 40.7663 N, longitude 29.9173 E) stations are shown in Figure 3.

Figure 3. The locations of stations in Turkey

Van Local Station is in Eastern Anatolia Region in Turkey, while the Konya Airport Station in Central Anatolia Region and Kocaeli Station in the Marmara Region. In the Eastern Anatolia Region, the summers are hot and dry, and the winters are cold and snowy. The average annual rainfall is small. The annual and daily temperature difference is high. The climate characteristics of the Central Anatolia region are like those of the Eastern Anatolia region. Marmara Region has a transition climate. In the parts where Kocaeli station is located, summers are hot and less rainy, winters are rainy and occasionally snowy and cold.

The data sample is consisting of 5205 daily records from the year 2013 to 2018 of air temperature (T), wind velocity (W), actual pressure (P), humidity (H) and pan evaporation (PE). For Van Local station, the first 4 years data (82% of the whole data) were used to train the models, the remaining one-year data (18% of the whole data) were used for testing. The model was also tested with 2018 daily data of Konya Airport and Kocaeli stations. Some statistical parameters of the data are shown in Table 1. In the table can be seen the mean, minimum and maximum values of parameters, standard deviation, skewness and correlation with pan evaporation. While Van Local and Konya Airport stations show similarities in meteorological data, wind velocity and pan evaporation values of Kocaeli station are lower, the actual pressure, temperature and especially relative humidity values are higher than the other two stations. For each station, temperature data have the highest correlation between PE. Relative humidity data appear to be the second efficient parameters on pan evaporation with compared to correlation rates at the Van Local and Konya Airport stations. Wind velocity data show low skewed distribution and is more effective than relative humidity data at Kocaeli station.

Table 1. The daily statistical parameters of the climatic data.

Station	Data	Unit	Xmean	Xmin	Xmax	Standard Deviation (S)	Skewness	Correlation with Pan Evaporation
Van (2013-2017)	wind velocity	m/s	1.70	0.70	4.80	0.49	1.95	0.15
	actual pressure	hPa	832.25	823.70	841.60	2.83	0.14	-0.35
	relative humidity	%	42.23	17.80	890.00	13.09	0.77	-0.64
	temperature	ºC	18.68	5.20	28.40	4.95	-0.42	0.76
	pan evaporation	mm	6.29	0.00	14.5	2.45	-0.41	1.00
Konya (2018)	wind velocity	m/s	3.90	1.20	8.30	1.47	0.55	0.44
	actual pressure	hPa	897.58	887.10	909	4.13	0.35	-0.39
	relative humidity	%	47.99	20.60	83.70	14.67	0.41	-0.62
	temperature	ºC	20.31	5.00	28.10	4.87	-0.72	0.86
	pan evaporation	mm	5.88	1.00	10.40	2.29	-0.29	1.00
Kocaeli (2018)	wind velocity	m/s	1.49	0.70	2.80	0.35	0.34	0.35
	actual pressure	hPa	1004.50	993.30	1019.30	5.09	0.36	-0.23
	relative humidity	%	75.77	49.30	98.20	8.94	-0.49	-0.32
	temperature	ºC	22.22	11.00	27.80	3.81	-0.58	0.60
	pan evaporation	mm	4.04	0.00	10.00	2.53	0.09	1.00
Van (2018)	wind velocity	m/s	1.62	1.10	3.90	0.41	2.40	0.13
	actual pressure	hPa	832.26	823.70	843.40	3.07	0.21	-0.48
	relative humidity	%	42.88	16.40	89.00	13.15	0.70	-0.72
	temperature	ºC	18.79	5.20	29.40	4.95	-0.43	0.80
	pan evaporation	mm	6.10	0.00	14.50	2.43	-0.32	1.00

3. APPLICATION AND RESULTS

Equation (7) suggested by Kişi [16] was used to normalize the data before the application of the method. Here, x_{norm}, x_{min} and x_{max} indicate the normalized, minimum and maximum values of the data set, respectively.

$$x_{norm} = 0.6\frac{x_i - x_{min}}{x_{max} - x_{min}} + 0.2 \qquad (7)$$

In this study different combinations of meteorological parameters were used as inputs of ANFIS model to investigate the degree of effect of each parameter on forecasting of evaporation. ANFIS model was built four times with one new variable joined into the inputs per time. Input combinations of four models are (T), (T and H), (T, H and P) and (T, H, P and W), respectively. As assessment criteria, root mean square errors (RMSE), mean absolute relative error (MARE) and determination coefficient (R^2) statistics were selected.

$$\mathrm{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(f_{i(observed)}-f_{i(predicted)}\right)^2} \qquad (8)$$

$$MARE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{fi_{observed} - fi_{predicted}}{fi_{observed}}\right| 100 \qquad (9)$$

$$R^2 = 1 - \frac{\left[\sum_{i=1}^{n}(fi_{observed}-\overline{fi}_{observed})\cdot(fi_{predicted}-\overline{fi}_{predicted})\right]^2}{\sum_{i=1}^{n}(fi_{observed}-\overline{fi}_{observed})^2 \cdot \sum_{i=1}^{n}\left(fi_{predicted}-\overline{fi}_{predicted}\right)^2} \qquad (10)$$

Where; n, $f_{iobserved}$, $\overline{fi}_{observed}$, $f_{ipredicted}$ and $\overline{fi}_{predicted}$ represent number of data, observed, average of observed, predicted and average of predicted values, respectively.

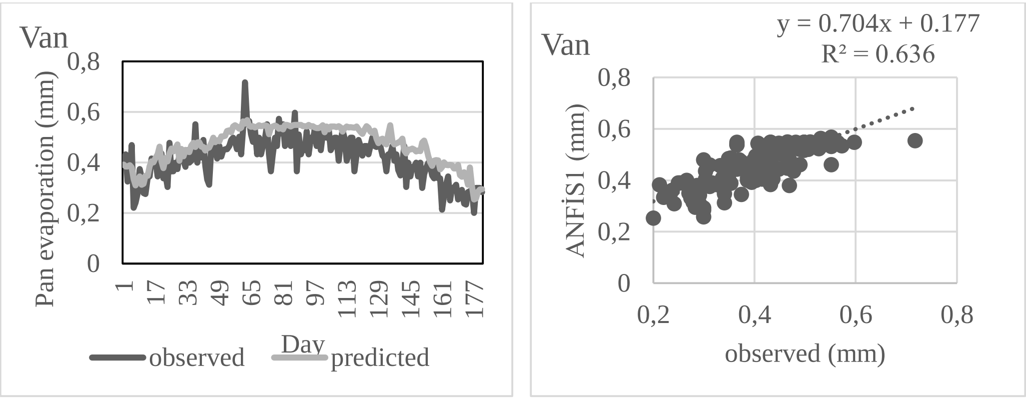
To get the minimum error and max R^2 values between observed and predicted values optimal model parameters were chosen. Sugeno type was used to set the ANFIS model. The input membership functions were chosen as 'gaussmf' and the output membership functions were chosen 'linear', defuzzification method was seleceted 'wtaver', generate fis type was chosen 'subtractive clustering' method and optimization method was chosen 'Hybrid Optimization Method'.

The RMSE, MARE and R^2 statistics of each model are given in Table 2. For 1 input model set with temperature (T) parameter (has highest correlation with pan evaporation) smallest RMSE (0.075 mm/day) and MARE (16.85%) are in Van Local station but highest R^2 (0.707) in Konya Airport station. Kocaeli station has highest RMSE, MARE and lowest R^2. For 2 inputs model set with temperature (T) and relative humidity (H) parameters, smallest RMSE (0.073 mm/day), MARE (15.88%) and highest R^2 (0.610) are in Van Local station. In the second model, when the values obtained at Kocaeli station are compared with the first model, a slight increase in RMSE and a slight decrease in MARE and a significant decrease in R^2 are observed. The decrease in R^2 value is related with humidity parameter. Because, the relative humidity parameter has the second largest correlation with evaporation at the Van and Konya stations, while it has the third largest correlation at Kocaeli station, and this parameter's correlation value at Kocaeli station is about half that of other stations. For 3 inputs model set with temperature (T), relative humidity (H) and actual pressure (P) parameters smallest RMSE (0.071 mm/day) and MARE (14.81%) are in Van Local station but highest R^2 (0.625) in Konya Airport station. Kocaeli station has highest RMSE, MARE and lowest R^2. For 4 inputs model set with temperature (T), relative humidity (H), actual pressure (P) and wind velocity (W) parameters smallest RMSE (0.067 mm/day) and MARE (14.464%) are in Van Local station but highest R^2 (0.668) in Konya Airport station. For Kocaeli station this model gives lowest RMSE, MARE and highest R^2. Because the relative humidity, actual pressure and wind velocity at Kocaeli station have similar correlation values with evaporation.

The evaporation estimates of the one input model are represented in Figure 4. As it is seen from the scatterplots at Van Local station, coefficients (a_0 and a_1) of $y = a_0x + a_1$ equation are closer to 1 and 0 respectively than the other stations.

Table 2. RMSE, MARE and R^2 statistics for each model and stations

Model	Station	RMSE (mm/day)	MARE (%)	R^2
1 input (T)	Training	0.065	11.50	0.594
	Van Local	0.075	16.85	0.636
	Konya Airport	0.104	17.43	0.707
	Kocaeli	0.133	32.43	0.324
2 inputs (T, H)	Training	0.086	15.61	0.618
	Van Local	0.073	15.88	0.610
	Konya Airport	0.108	18.46	0.567
	Kocaeli	0.143	31.06	0.114
3 inputs (T, H, P)	Training	0.059	10.35	0.663
	Van Local	0.071	14.81	0.589
	Konya Airport	0.103	16.23	0.625
	Kocaeli	0.200	39.07	0.162
4 inputs (T, H, P, W)	Training	0.059	10.42	0.661
	Van Local	0.067	14.46	0.668
	Konya Airport	0.088	14.55	0.670
	Kocaeli	0.130	28.92	0.330



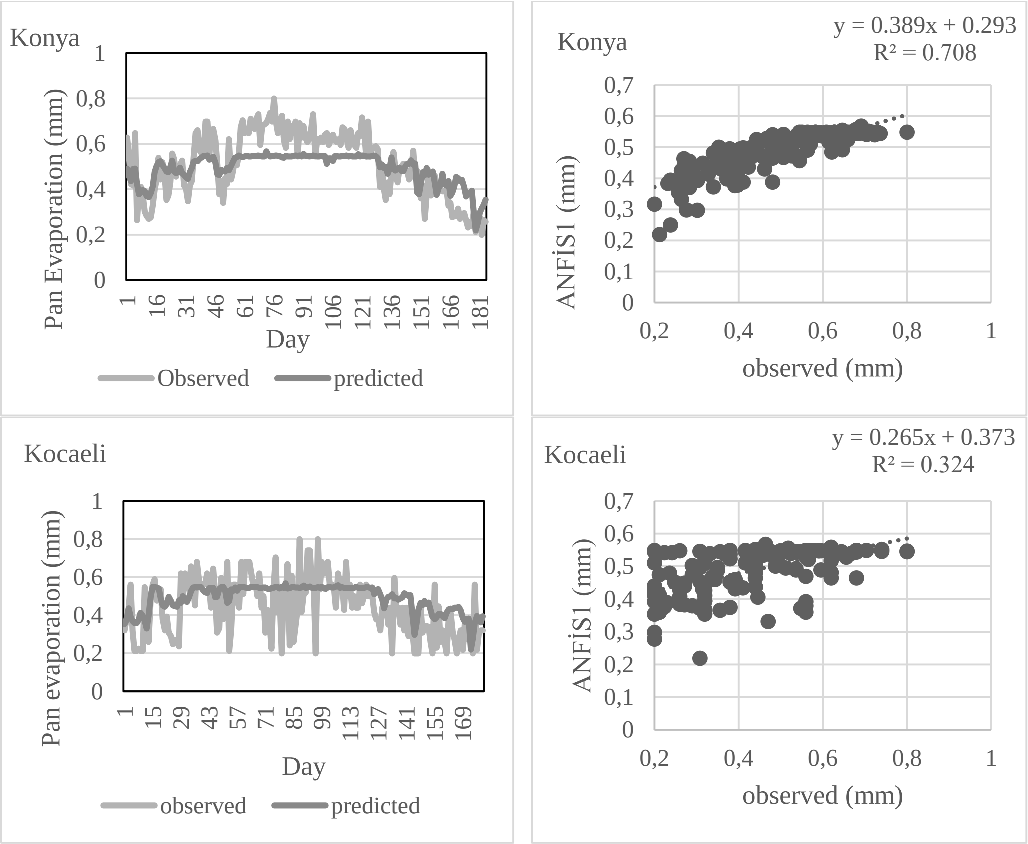
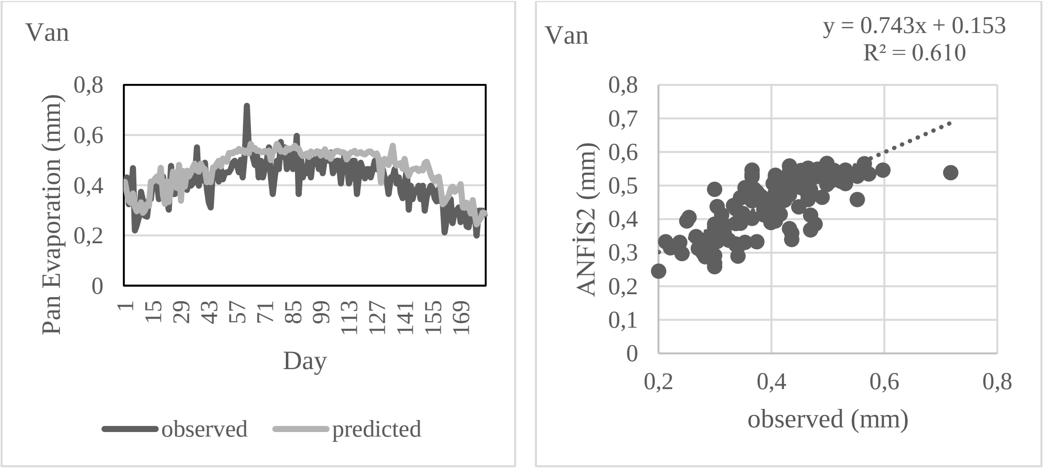


Figure 4. The observed and predicted values and the scatterplots of stations for 1 input

For two inputs model set with temperature (T) and relative humidity (H) parameters, all errors slightly have reduced but R^2 values, too. The best result in this model is at Van station (Figure 5).



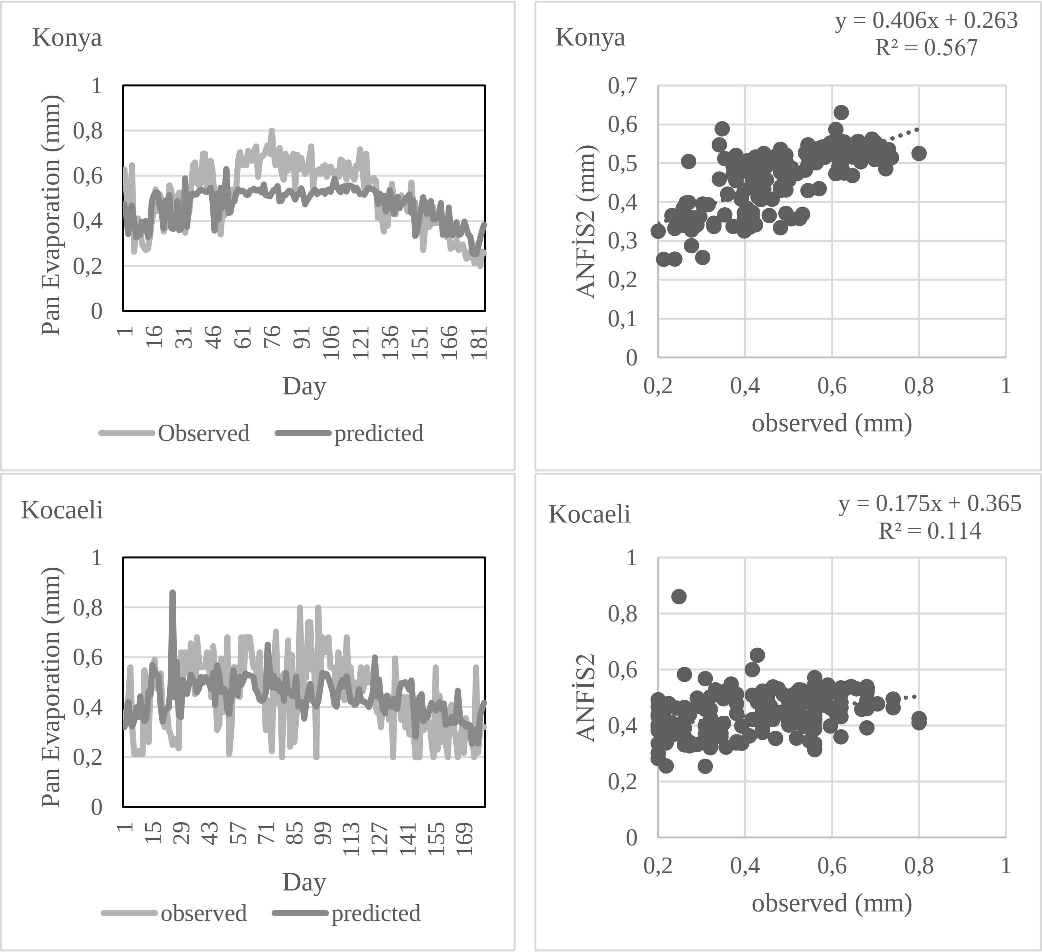
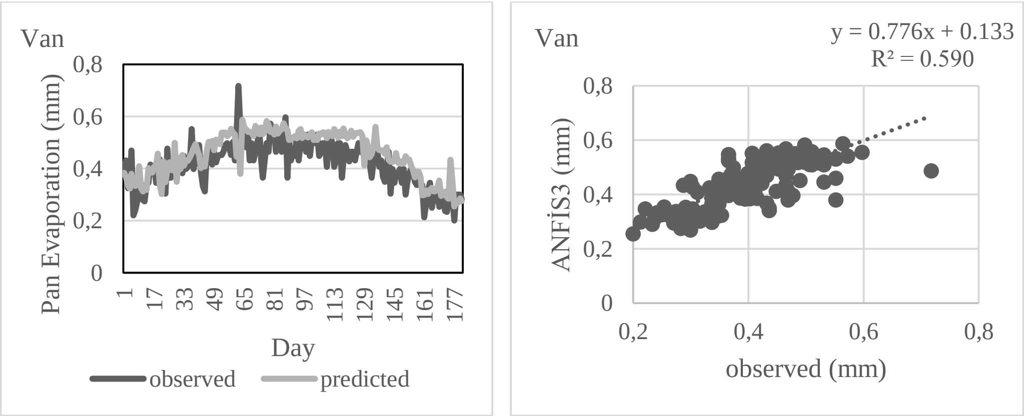


Figure 5. The observed and predicted values and the scatterplots of stations for 2 inputs

For three inputs model set with temperature (T), relative humidity (H) and actual pressure (P) parameters, RMSE, MARE values have reduced at Van and Konya stations but at Kocaeli stations those values have increased (Table 2). This can be explained by the fact that the actual pressure value has the lowest correlation with pan evaporation at Kocaeli station. Although the value of R^2 in Kocaeli station increased slightly compared to the previous model, it is considerably less than other stations (Figure 6).



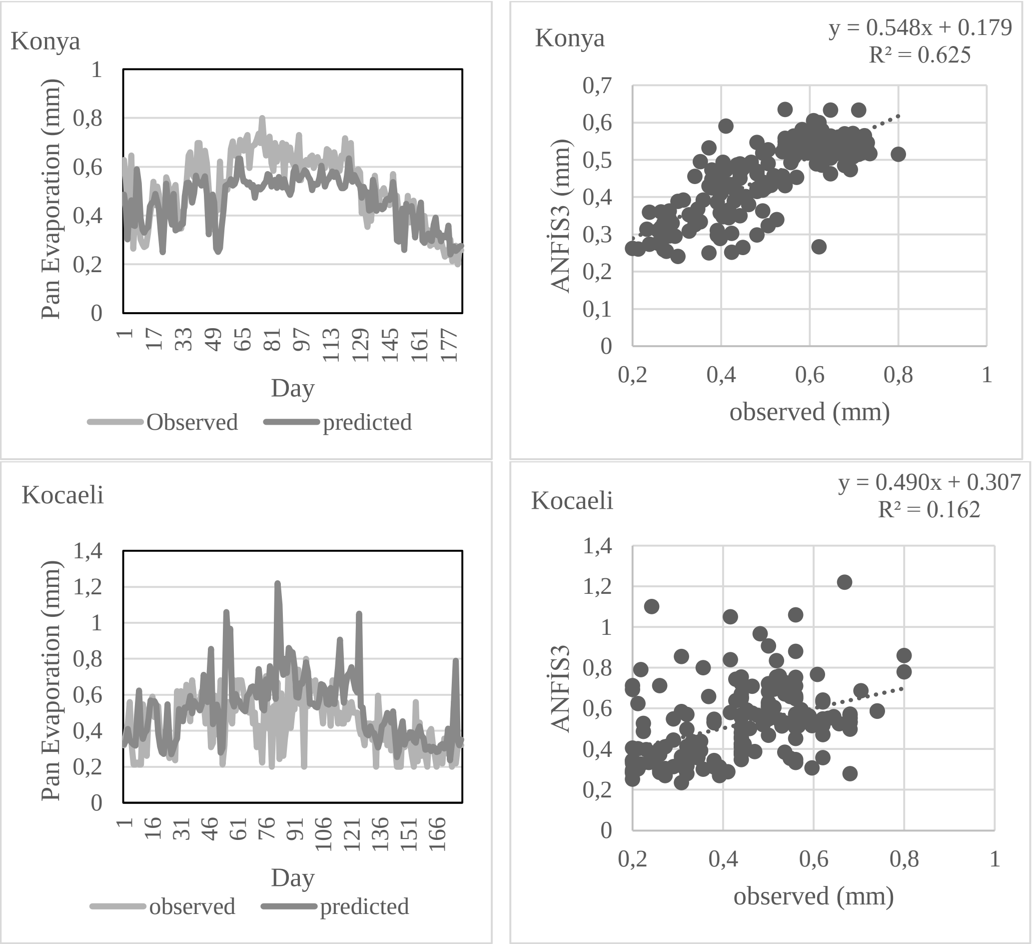
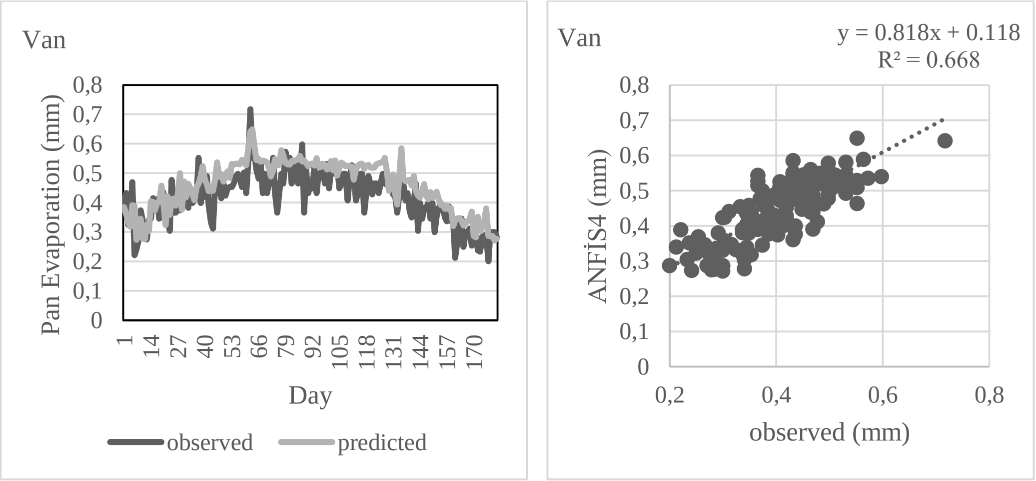


Figure 6. The observed and predicted values and the scatterplots of stations for 3 inputs

For four inputs model set with temperature (T), relative humidity (H), actual pressure (P) and wind velocity (W) parameters, lowest RMSE, MARE values have achieved at all stations and also Kocaeli station has best R^2 value at this model (Table 2). As it is seen from the scatterplots at Van station, coefficients of $y = a_0x + a_1$ equation are closer to 1 and 0 respectively than the other stations (Figure 7).



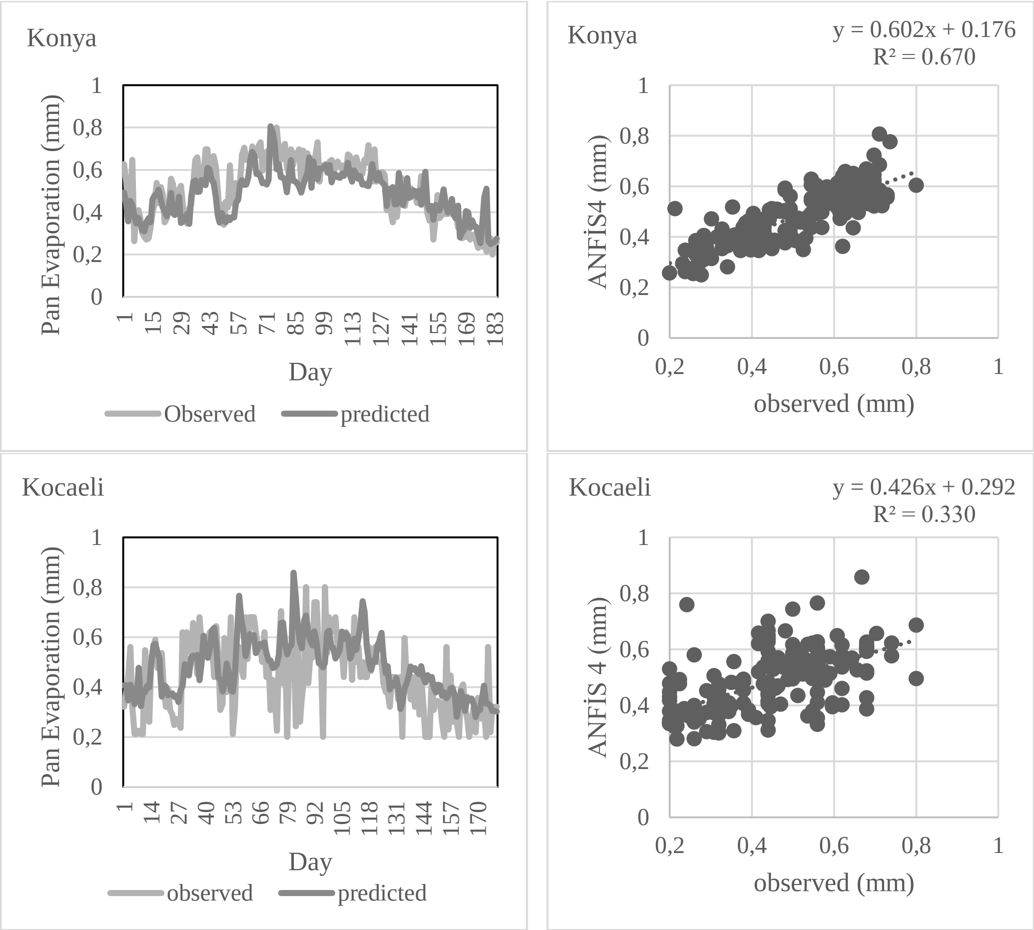


Figure 7. The observed and predicted values and the scatterplots of stations for 4 inputs

4. CONCLUSION

The utility of the ANFIS method in the prediction of meteorological data has been demonstrated by previous studies. The difference of this study is revelation of whether a model prepared for another station can be used in the stations where evaporation measurement is not possible for technical or economic reasons. In order to determine the effect of the meteorological characteristics of the stations on the model, the stations belonging to two cities which are similar and not similar to the climate characteristics of Van province were selected.

Four different models were set with meteorological variables. The best results were obtained in the fourth model, where temperature, relative humidity, actual pressure and wind velocity were selected as inputs. In all models, similar results were observed in Konya Airport and Van Local stations which have similar meteorological characteristics, while the result of Kocaeli station with different meteorological features was relatively poor. Due to the relative humidity which is the most significant meteorological difference between Van and Konya stations and Kocaeli stations, in the second model where relative humidity was added as the second input, the results of Kocaeli station gave worse results than the first model where only the temperature was selected as input.

In this study, it is shown that a model formed by using data of another station with similar meteorological characteristics can be used to estimate the evaporation if needed due to lack of data or irregularity during the management of water resources.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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