Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 31(2), ss. 179-185, Aralık 2016
Çukurova University Journal of the Faculty of Engineering and Architecture, 31(2), pp. 179-185, December 2016

Solar Radiation Modeling for Turkey Using Atmospheric Parameters with Artificial Neural Networks

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Geliş tarihi: 03.06.2016 *Kabul tarihi: 23.11.2016*

Abstract

Artificial neural network (ANN) method was applied for modeling and prediction of mean solar radiation in given atmospheric parameters **(**temperature, pressure, humidity, precipitable water and month) in Turkey (26–45ºE and 36–42ºN) during the period of 2004–2006. Levenberg-Marquardt (LM) learning algorithms and logistic sigmoid transfer function were used in the network. In order to train the network, meteorological measurements taken by the Turkish State Meteorological Service (TSMS) and Wyoming University for the period from 2004 to 2006 from five stations (Adana, Ankara, İstanbul, İzmir, Samsun) distributed in Turkey were used as training and testing data. Data from years 2004 and 2005 were used for training, while the year 2006 was used for testing and validating the model. Solar radiation is the output.

Keywords: Solar radiation, Atmospheric parameters, Artificial neural network, Meteorology, Turkey

Yapay Sinir Ağları ile Atmosferik Parametreler Kullanılarak Türkiye için Güneş Radyasyonu Modellemesi

Öz

Yapay sinir ağları (YSA) yöntemi, Türkiye'de (26-45ºE ve 36-42ºN) 2004-2006 dönemlerinde atmosferik parametreler olarak verilen (sıcaklık, basınç, nem, yoğuşmaya geçebilecek su miktarı ve ay) verileri kullanarak ortalama güneş radyasyonun tahmini ve modellenmesi için uygulanmıştır. Levenberg-Marquardt (LM) öğrenme algoritmaları ve logistic sigmoid transfer fonksiyonu ağ içinde kullanılmıştır. Ağı eğitmek amacıyla, Türk Devlet Meteoroloji İşleri Genel Müdürlüğü (DMİ) ve Wyoming Üniversitesi tarafından 2004'den 2006'ye kadar Türkiye'deki beş istasyon (Adana, Ankara, İstanbul, İzmir, Samsun) için alınan meteorolojik ölçümler değerleri eğitim ve test verileri olarak kullanılmıştır. 2004- 2005 yılı verileri eğitim için, 2006 yılı verileri ise test verilerini doğrulamak için kullanılmıştır. Güneş radyasyonu elde edilmiştir.

Anahtar Kelimeler: Güneş radyasyonu, Atmosferik parametreler, Yapay sinir ağı, Meteoroloji, Türkiye

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1. INTRODUCTION

Atmospheric parameters has been mainly measured by radiosondes (Radiosond is a complex device that has been especially designed to estimate several atmospheric parameters such as pressure, temperature, relative humidity, wind direction and speed) over and in the atmosphere. However on land, these instruments offer limited opportunities for spatial overage and continually measurements of atmospheric parameters [1]. The amount of solar radiation plays an important role in the design and analysis of energy efficient buildings in different climates. In cold and severe cold regions, passive solar designs and active solar heating systems will help lower the reliance on conventional fossil heating means using fossil fuels [2]. Energy is essential to the economic and social development and improved quality of life in a country. Due to limited energy resources Turkey has been importing energy and more than half of the energy requirement is supplied by imports [3]. Therefore, the solar energy is being seriously considered for satisfying a significant part of energy demand in Turkey, as is in the world [4]. Solar energy potential is quite high in Turkey. The yearly average solar radiation is about 3.6 kW h/m^2 days, and the total yearly radiation period is about 2610 h [5]. In recent years, many individual studies have been carried out for solar measurements at different locations in Turkey [4] and in other countries e.g., in Saudi Arabia [6,7], in Spain [8,9]. However, they were not been complete to cover large areas because of insufficient number of measuring stations [10]. Therefore, predictions about solar radiations at specific locations are still useful for many practical purposes. Several studies have been presented [11, 12] for the prediction of solar radiation in various cities and locations in Turkey. Solar radiation intercepted at the earth’s surface is of paramount importance for various applications, such as in the infrastructure and construction industry, estimation of crop productivity, environmental and agrometeorological research, atmospheric physics and the practical utilization of renewable energy resources [13].

It is clear from many studies that usage of ANN method is suitable and applicable for estimating global solar radiation especially for regions where very large distances exist between meteorological stations and also having abundant solar energy [14, 15]. Atmospheric parameter scan be used as input data for ANN method for predicting solar radiation. For some regions due to geography or cost problems atmospheric parameters are rarely available. For this case given atmospheric parameters may be useful and may be used for the solar radiation estimation models. In the present work we tried to use to given atmospheric parameters as an input for the ANN method to estimate the solar radiation at ground level and see the results of this approach. Also, some other models or techniques (semi-empirical, physical, statistical, wavelets, fractals, etc) have been used for estimating solar radiation [14] using air temperature, precipitation, relative humidity and cloudiness data [16,17].

We expect that results of this study give an idea about solar radiation potential in Turkey because five stations (Adana, Ankara, İstanbul, İzmir, Samsun) are selected in such a way that they represent different climatic conditions (see Figure 1). The geographical locations of these stations are given in Tab.1. Then, Artificial Neural Network (ANN), known as Levenberg-Marquardt (LM) is used to estimate solar radiation using atmospheric parameters.

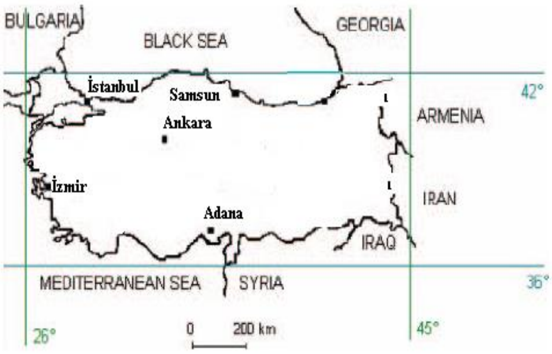

Figure 1. Solar radiation and atmospheric parameters measuring stations in Turkey

Table 1. Geographical parameters for the stations

Stations	Latitude (°N)	Longitude (°E)	Altitude (m)
Adana	36.59	35.21	27
Ankara	39.57	32.53	891
İstanbul	41.01	28.59	0
İzmir	38.26	27.10	29
Samsun	41.17	36.18	4

2. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANNs) are information processing systems that are non-algorithmic, non-digital and intensely parallel [18]. ANNs have broad applications in many fields such as mathematics, engineering, medicine, economics, meteorology, psychology, and neurology. This method learns from given examples by constructing an input–output mapping in order to achieve estimations [19]. This clearly implies that, input data and corresponding output values are required to train and test a neural network [20]. Therefore, the network usually consists of an input layer, some hidden layers, and an output layer [21]. The model used in this study is briefly explained below.

The fundamental element of a neural network is a neuron. Each neuron computes a weighted sum of its p input signals, y_i, for $i=0,1,2,...,n$, hidden layers, w_{ij} and then applies a nonlinear activation function to produce an output signals u_j. The model of a neuron is shown in Figure 2.

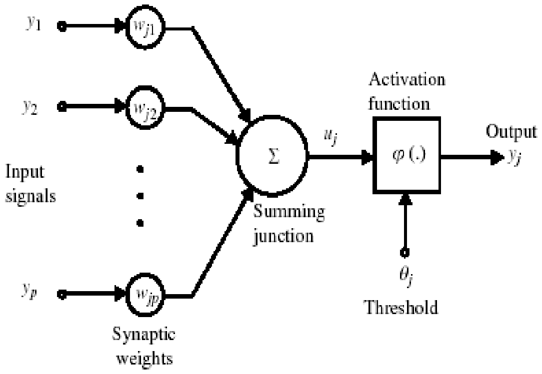

Figure 2. Nonlinear model of a neuron [22]

A neuron j can be described with the following pair of equations [22]:

$$u_j = \sum_{i=0}^{p} w_{ji} y_i \tag{1}$$

and

$$y_j = \varphi(u_j - \theta_j) \tag{2}$$

The use of threshold θ has the effect of applying an affine transformation to the output of the linear combiner in the model of Fig. 2 [22,23].

The sigmoid logistic nonlinear function can be defined by the following equation [24, 25]:

$$\varphi(x) = \frac{1}{1+e^{-x}} \tag{3}$$

ANN was used for modeling solar radiation in Turkey. This network consists of an input layer, single hidden layers and an output layer. Latitude, longitude, altitude, month and satellite-estimated sunshine duration were used as input layers in order to get output as the solar radiation. The algorithm used in the study is Levenberg-Marquardt (LM). Logistic sigmoid transfer function (logsig) and linear transfer function (purelin) were used in the hidden layers and output layer of the network as an activation function.

MATLAB software has been used to train and test the ANN on a personal computer. For the training, ten neurons are used in a single hidden layer. The selected ANN structure is given in Figure 3. For the period from 2004 to 2006 from five stations (Adana, Ankara, İstanbul, İzmir, Samsun), Data from 2004-2005 years are used for training and data from 2006 year are used for testing.

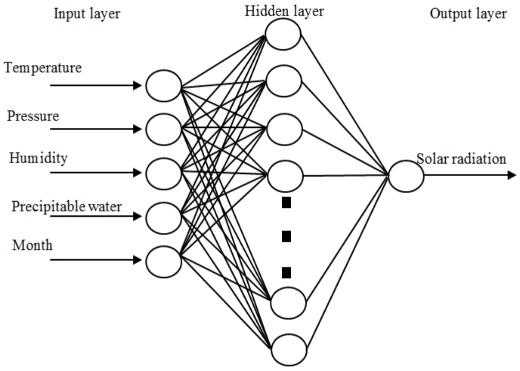

Figure 3. ANN architecture used for five neurons in a single hidden layer

3. RESULTS AND DISCUSSIONS

An ANN consisting of an input layer, several hidden layers and an output layer was used for computation of the solar radiation all over Turkey. MATLAB which is a commonly used software system was administered to train and test the ANN on a personal computer. The algorithm used in the study was Levenberg-Marquardt (LM) descripted by Logistic sigmoid transfer function (named 'logsig') and linear transfer function (named 'purelin') were used in the hidden layers and in the output layer of the network as an activation function. For the training, ten neurons were used in the hidden layer for solar radiation. Atmospheric parameters have influences on the intensity of incoming solar radiation on the Earth. Thus, meteorological data by the Turkish State Meteorological Service (TSMS) and Wyoming University database for Turkey for the period from 2004 to 2006 were used, first as training and later as testing data to train the neural network. Data set for two years in 2004-2005 were used for training the network, while another set for (one year, 2006) were used for testing and validating the LM model. Solar radiations over Turkey were determined using the ANN model shown in Figure 3. with the value of the monthly mean daily sum of atmospheric parameters. In the case of monthly mean daily sum correlation coefficient was found to be 98.50% (Figure 4), 95.99% (Figure 5) for solar radiation values (training and testing).

The performance values for all stations, such as MBE (Mean Bias Error) and RMSE Root Mean Square Error for training, testing values are given in Table 2. The performance values for all stations, such as MBE (Mean Bias Error) and RMSE for training and testing solar radiation values are given in Table 2. The maximum MBE was found to be 0.5111 values, while the minimum MBE was found as -0.8113 values. The RMSE values of solar radiation, ranging from 0.3633 to 2.4002% differ from the actual value for all stations. The maximum RMSE was found to be 2.4002% for Adana station in the testing values, while the best result was found to be 0.3633% for İzmir station in the training values. Moreover, another significant point in this table, the performance values of the training by method are generally better than the performance values of the testing Figure 6 shows a comparison between measured, ANN values for the five stations (training and testing stations) [25].

Table 2. Error values of the solar radiation method approach

Stations	Training		Testing	
	MBE	RMSE	MBE	RMSE
Adana	0.2588	1.2681	-0.6929	2.4002
İstanbul	0.5111	2.5032	0.4551	1.5765
İzmir	-0.0742	0.3633	-0.8183	2.3348
Samsun	-0.0859	0.4202	-0.2096	0.7260
Ankara	0.2290	1.1220	-0.3780	1.3095

The results of own study confirms the ability of ANN method to predict solar radiation values at every pixels of the study area, throughout Turkey. In addition, some meteorological atmospheric parameters observations are held on large TSMS climate stations, having minimal 250 km distance from each other. Small scale climate stations were unable to make some meteorological atmospheric parameters observation. Using ANN, solar radiation values can be calculated for each such station [25].

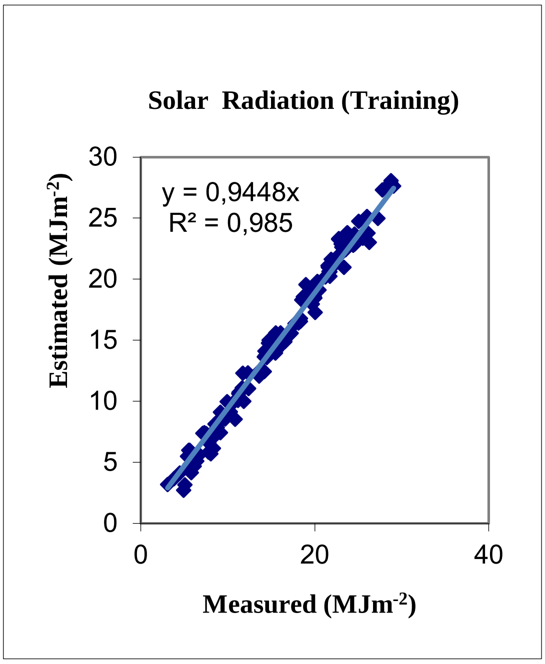

Figure 4. Comparison of monthly mean daily sum measured and estimated concerning training during the study period for solar radiation

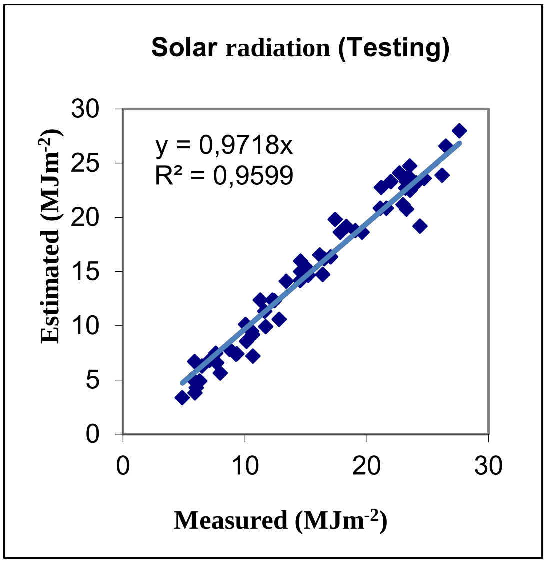

Figure 5. Comparison of monthly mean daily sum measured and estimated concerning testing during the study period for solar radiation

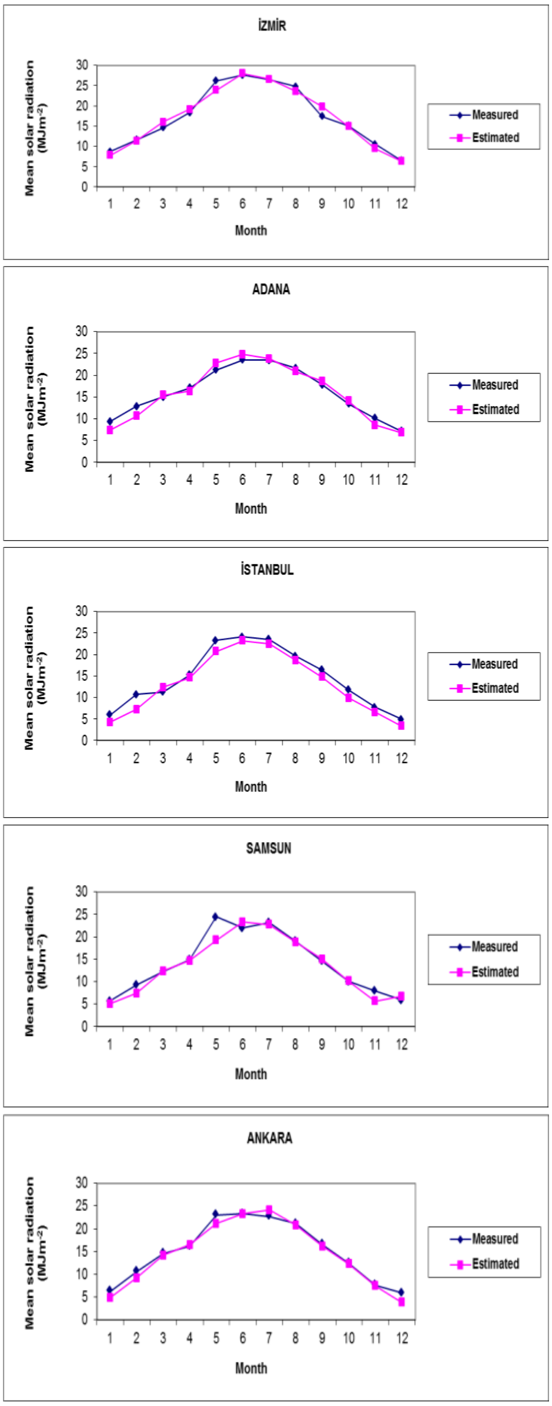

Figure 6. Comparison between measured and estimated monthly mean daily global solar radiation for 2006

4. CONCLUSION

Estimation of solar radiation on a surface at ground level and construction of solar radiation database is very useful for solar energy, engineering, environmental, agricultural and some other applications. Studies have shown that use of ANN for these purposes is really cheap and effective. In the present study ANN were used to predict to global solar radiation in Turkey by using atmospheric parameters. In order to train the neural network, 5 cities spread over Turkey were used as training (2004-2005) and testing (2006) data. Results of these 5 locations show a relatively good agreement between the measured and the predicted values for the all months. In fact, ANN needs Meteorological data to estimate the monthly mean daily sum at ground level. But it has been shown that using atmospheric parameters may help to increase the accuracy of the estimation. And model used here can be especially applied to areas, where reliable atmospheric parameters do not exist or the distances between the stations are very large. Therefore, method (the ANN technique) is very useful and presents a less costly way than using the classical direct observations carried out in some meteorology stations in a country. ANN method can be used by researchers in Turkey and other countries.

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