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Determination of Solar Radiation Value by Month Using Artificial Neural Network Model; Ankara, Sivas, Erzurum example

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Anahtar Kelimeler

Yapay sinir ağı
Enlem
Meteorolojik veriler
Güneş radyasyonu

Graphical/Tabular Abstract (Grafik Özet)

This study examines the estimation of solar radiation using artificial neural network (ANN) models in Turkish cities with similar latitude values such as Ankara, Sivas and Erzurum. The aim of the study is to investigate whether cities at similar latitudes exhibit similar trends in solar radiation values, despite their geographical differences. In the study, solar radiation was estimated with a multilayer neural network. / Bu çalışma, Ankara, Sivas ve Erzurum gibi benzer enlem değerlerine sahip Türkiye şehirlerinde yapay sinir ağı (YSA) modellerini kullanarak güneş ışınımının tahmin edilmesini incelemektedir. Çalışmanın amacı, coğrafi farklılıklarına rağmen, benzer enlemdeki şehirlerin güneş ışınımı değerlerinde benzer eğilimler sergileyip sergilemediğini araştırmaktır. Çalışmada çok katmanlı sinir ağı ile güneş ışınımı tahmini yapılmıştır.

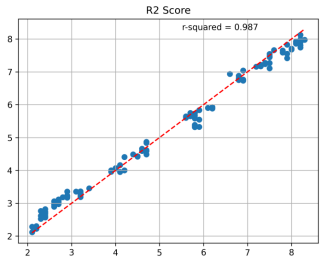

***Figure A**: R2 score value /**Şekil A:** R2 skor değeri*

Highlights (Önemli noktalar)

- *70% of the data set is allocated to training and 30% to testing data set. / Veri setinin %70'i eğitim, %30'u ise test veri setine ayrılmıştır.*
- *Similar solar radiation trends were obtained in the same latitude regions. / Aynı enlem bölgelerinde benzer güneş ışınımı eğilimleri elde edilmiştir.*
- *R2 value was determined as 0.984. / R2 değeri 0,984 olarak belirlenmiştir.*

***Aim (Amaç):** The aim of this study is to investigate whether cities at similar latitudes exhibit similar trends in solar radiation values, despite their geographical differences./ Bu çalışmanın amacı, coğrafi farklılıklarına rağmen, benzer enlemdeki şehirlerin güneş ışınımı değerlerinde benzer eğilimler sergileyip sergilemediğini araştırmaktadır.*

***Originality (Özgünlük):** This study was carried out for Ankara, Sivas and Erzurum, which have similar latitude values./ Benzer enlem değerlerine sahip Ankara, Sivas ve Erzurum için bu çalışma gerçekleştirilmiştir.*

***Results (Bulgular):** As a result, similar solar radiation trends were obtained in the same latitude regions, the results were confirmed by meteorological data. While the solar radiation value taken from meteorological data for Ankara in July was 8.2 kWh/m^{2}d, this value was obtained as approximately 7.9 kWh/m^{2}d with the artificial neural network model./ Sonuç olarak, aynı enlem bölgelerinde benzer güneş ışınımı eğilimleri elde edilmiş, sonuçlar meteorolojik veriler ile doğrulanmıştır. Temmuz ayında Ankara için meteorolojik verilerden alınan solar radyasyon değeri 8.2 kWh/m^{2}d iken yapay sinir ağı modeli ile bu değer yaklaşık 7.9 kWh/m^{2}d olarak elde edilmiştir.*

***Conclusion (Sonuç):** The analyzes revealed the ability of the ANN model to successfully predict solar radiation values. Agreement between predicted values and measured values was observed, indicating that the model has wide applicability in different climatic conditions. The results obtained from this study show that the ANN method can be used effectively in estimating solar radiation values./ Analizler, YSA modelinin güneş ışınım değerlerini başarılı bir şekilde tahmin etme yeteneğini ortaya çıkardı. Tahmin edilen değerler ile ölçülen değerler arasında uyumun gözlenmesi, modelin farklı iklim koşullarında geniş uygulanabilirliğe sahip olduğunu göstermektedir. Bu çalışmadan elde edilen sonuçlar, güneş ışınımı değerlerinin tahmin edilmesinde YSA yönteminin etkin bir şekilde kullanılabileceğini göstermektedir.*

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Abstract

This research examines the estimation of solar radiation using artificial neural network (ANN) models in Turkish cities with similar latitude values such as Ankara, Sivas and Erzurum. The aim of this study is to investigate whether cities at similar latitudes exhibit similar trends in solar radiation values, despite their geographical differences. In this study, solar radiation prediction was made for 3 cities with a multi layer perceptron neural network. Monthly solar radiation intensity was estimated for the 10-year period between 2012 and 2022 with a total of 4764 samples taken from the General Directorate of State Meteorology. An artificial neural network model was developed with 8 neurons in the first hidden layer and 4 neurons in the second hidden layer. The optimizer used in compiling the model was determined as Adam, the loss function as 'mean_squared_error' and the metric as 'mse'. ReLU activation function was used in the input layer and hidden layers. A 10-year solar radiation intensity value was used in the output layer. 70% of the data set is reserved for training and 30% for testing data set. As a result, similar solar radiation trends were obtained in the same latitude regions, the results were confirmed by meteorological data. While the solar radiation value taken from meteorological data for Ankara in July was 8.2 kWh/m^{2}d, this value was obtained as approximately 7.9 kWh/m^{2}d with the artificial neural network model. Additionally, as a result of the study, the R2 value was determined as 0.984.

Yapay Sinir Ağı Modeli Kullanılarak Aylara Göre Güneş Radyasyon Değerinin Belirlenmesi; Ankara, Sivas, Erzurum örneği

Makale Bilgisi

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Öz

Bu araştırma, Ankara, Sivas ve Erzurum gibi benzer enlem değerlerine sahip Türkiye şehirlerinde yapay sinir ağı (YSA) modellerini kullanarak güneş ışınımının tahmin edilmesini incelemektedir. Bu çalışmanın amacı, coğrafi farklılıklarına rağmen, benzer enlemdeki şehirlerin güneş ışınımı değerlerinde benzer eğilimler sergileyip sergilemediğini araştırmaktır. Bu çalışmada çok katmanlı sinir ağı ile 3 şehir için güneş ışınımı tahmini yapılmıştır. Devlet Meteoroloji Genel Müdürlüğü'nden alınan toplam 4764 numune ile 2012-2022 yılları arasındaki 10 yıllık süre için aylık güneş radyasyon yoğunluğu tahmin edilmiştir. İlk gizli katmanda 8 nöron, ikinci gizli katmanda 4 nöron bulunan bir yapay sinir ağı modeli geliştirilmiş ve Modelin derlenmesinde kullanılan optimizasyon fonksiyonu Adam, kayıp fonksiyonu 'mean_squared_error' ve metrik ise 'mse' olarak belirlenmiştir. Giriş katmanında ve gizli katmanlarda ReLU aktivasyon fonksiyonu kullanılmıştır. Çıkış katmanında 10 yıllık güneş ışınım şiddeti değeri kullanılmıştır. Veri setinin %70'i eğitim, %30'u ise test veri setine ayrılmıştır. Sonuç olarak, aynı enlem bölgelerinde benzer güneş ışınımı eğilimleri elde edilmiş, sonuçlar meteorolojik veriler ile doğrulanmıştır. Temmuz ayında Ankara için meteorolojik verilerden alınan solar radyasyon değeri 8.2 kWh/m^{2}d iken yapay sinir ağı modeli ile bu değer yaklaşık 7.9 kWh/m^{2}d olarak elde edilmiştir. Ayrıca çalışmanın sonucunda, R2 değeri 0,984 olarak belirlenmiştir.

1. INTRODUCTION (GİRİŞ)

Solar energy is an important resource to meet the increasing energy needs in the world [1]. It has many advantages (unlike fossil fuels) such as being an unlimited and renewable resource, being environmentally friendly, having low maintenance costs, being able to produce and use electricity in a wider geographical area so that there is no need to lay energy transmission lines over long distances and being produced locally increases energy independence [2-4].

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With the developing technology in recent years, the use of artificial intelligence and related artificial neural network models has also increased. Artificial neural networks have begun to be used in many applications, from neurological rehabilitation studies [5] to air pollution prediction [6], from economic studies [7-9] to student achievement evaluation [10]. Another important area where artificial neural network models are used is climate and weather studies. For example, in the study conducted for Muğla province, an artificial neural network model based on meteorological data was used to predict the dew point temperature in 2019. The analyzes show that the model makes predictions with acceptable accuracy and can be especially useful for agriculture. This study highlights that artificial neural networks are an effective tool for making dew point prediction for a specific region and meteorological parameters and can be used for similar predictions in the future [11].

In another study, by using Artificial Neural Network (ANN) to predict daily solar radiation in the Samsun region, the highest performance was achieved with 9 different meteorological variables such as average temperature, humidity and wind speed. When evaluated with the test data, the ANN model demonstrated successful prediction power with an R value of 0.9603 and an MSE value of 0.3516 and it was seen that the sunshine duration alone was effective in the prediction. This study reveals that ANN is a powerful tool in solar radiation prediction and can improve the prediction performance of different meteorological variables [12].

In the study, which aims to develop Artificial Neural Network (ANN) models to predict the soil temperature of the next year with monthly meteorological data between 1970 and 2011 collected from 88 stations in Turkey, five separate ANN models were used for five different soil depths. And the resulting predictions are more accurate and closer to actual measured soil temperatures than regression models [13].

Researchers examined the artificial neural network model developed for Slovenia for different climates and predicted half-hour diffuse solar radiation. This study provides one of the first examples of a regionally transferable diffuse solar radiation model [14].

There are also studies using artificial neural network models for power estimation in photovoltaic panels [15] and comparison of thermal efficiencies of solar collectors [16].

Radiation prediction studies using artificial neural network modeling have also gained momentum. A study on the subject developed [17] a model that estimates solar radiation values using data obtained from a small-scale solar power plant in Konya and information from meteorology. The model predicted solar radiation with 86% accuracy using the data recorded at the power plant and the voltage and power values obtained from the PV panel. Again, in a study conducted to estimate solar radiation, an artificial neural network (ANN) was used with meteorological data collected from a weather station in Porto. The analysis reveals that ANN can predict solar radiation in different weather conditions with an accuracy of up to 99% in sunny and clear weather and in rainy and cloudy weather conditions with up to 96% accuracy [18]. The common result obtained from many studies [19-22] conducted for solar radiation prediction is that artificial neural network modeling gives results very close to meteorological data.

In climate and weather studies such as weather forecasting, ANNs are often trained to predict future weather conditions using a variety of meteorological data such as current weather conditions, temperature, humidity, wind speed and direction. By analyzing historical data, such models learn certain patterns and can make predictions for future weather. Since artificial neural network models were very effective in determining solar radiation in previous studies, within the scope of this study, radiation estimation for some cities in Turkey was made with the artificial neural network model. The cities discussed are Ankara, Sivas and Erzurum. These three cities considered have similar latitude values. The aim of this study is; to investigate whether solar radiation values of cities at the same latitude show similar trends.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

Turkey is a country that is generally exposed to high amounts of sunlight throughout the year. In most parts of the country, the number of sunny days is quite high and the average annual sunshine duration is quite high. This shows that Turkey is a rich source of solar radiation and has a high solar energy potential. While this potential creates a favorable environment for the installation and use of solar energy systems in the country, it is considered an important resource in terms of energy production and sustainability. A map representation of the distribution of Turkey's monthly average daily solar radiation is given in Figure 1 [23].

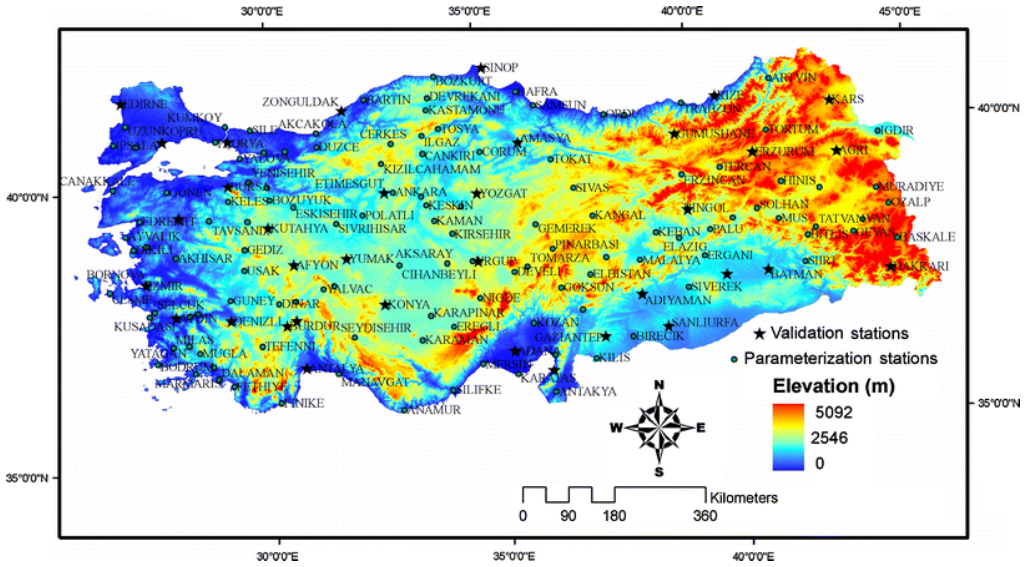

Figure 1. Distribution of monthly average daily solar radiation (Aylık ortalama günlük güneş ışınımının dağılımı)

In this study, the climate data and radiation intensity of the cities of Ankara, Sivas and Erzurum, located at similar latitude values, were determined. Ankara, Erzurum and Sivas have similar latitude values and their latitude values are shown in Table 1. Location of Ankara, Sivas and Erzurum on the map of Türkiye is shown in Figure 2.

Table 1. Latitude information of cities (Şehirlerin enlem bilgileri)

City	Latitude
Ankara	39°54′ N
Sivas	39°45′ N
Erzurum	39°55′ N

Figure 2. Location of Ankara, Sivas and Erzurum on the map of Türkiye (Ankara, Sivas ve Erzurum'un Türkiye Haritasındaki Konumu)

Apart from latitude, other data considered are longitude and altitude values. The largest part of the data set consists of climate data. This climate data; average temperature, average highest and lowest temperature, number of rainy days, average monthly total rainfall, sunshine duration, cloudiness index and wind speed values. The averages of the climate data discussed in the study are shown in

Table 2. Within the scope of this study, all climate data of the last 10 years, that is, between 2012 and 2022, were considered. However, since this amounts to a lot of data, Table 2 gives the average values of the climate data considered for the three cities. The three lines next to each value represent the values for Ankara, Sivas and Erzurum, respectively.

Table 2. Climate data for Ankara, Sivas and Erzurum (Ankara, Sivas ve Erzurum için iklim verileri)

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	City
Average temperature (°C)	-1 -1 -10	1 -0 -8	5 5 -3	10 11 4	15 15 9	19 19 14	23 22 18	23 22 18	18 18 13	12 13 7	5 6 -1	1 1 -7	Ankara Sivas Erzurum
Ave. highest temperature (°C)	4 2 -4	6 4 -3	11 10 2	16 16 10	21 21 16	26 25 21	30 29 25	29 30 26	25 26 21	19 19 14	11 11 5	5 5 -2	Ankara Sivas Erzurum
Ave. lowest temperature (°C)	-5 -5 -15	-4 -4 -14	-1 0 -8	4 5 -2	8 9 2	12 12 6	15 15 9	15 14 9	10 11 4	5 7 -1	0 1 -6	-3 -3 -12	Ankara Sivas Erzurum
Precipitation (day)	5.4 5.0 3.7	4.9 5.0 4.0	5.7 6.4 5.1	6.3 7.5 8.1	6.5 8.2 8.6	4.8 4.6 5.0	2.4 1.5 2.5	1.8 1.1 1.8	2.5 2.4 3.3	4.2 4.9 5.9	4.7 5.4 4.8	5.9 5.5 4.0	Ankara Sivas Erzurum
Average monthly total rainfall (mm)	0.9 20.6 1.6	0.8 19.7 2.5	0.9 27 13.3	1.3 39.5 35.5	1.3 40.8 45.8	1.0 22.5 26.9	0.5 7.7 13.1	0.4 4.1 9.1	0.5 11.7 18.8	0.9 29.5 33.2	1.0 32.9 20.8	1.1 25.9 5.3	Ankara Sivas Erzurum
Sunshine duration (hour)	9.7 9.7 9.7	10.7 10.7 10.7	12.0 12.0 12	13.3 13.3 13.3	14.4 14.4 14.4	15.0 14.9 15	14.7 14.6 14.7	13.7 13.7 13.7	12.4 12.4 12.4	11.1 11.1 11.1	10.0 10.0 10	9.4 9.4 9.4	Ankara Sivas Erzurum
Cloudiness index (%)	50 52 47	50 54 48	47 50 48	43 47 49	33 37 38	15 16 14	4 3 3	3 3 2	15 16 13	35 40 36	46 48 44	52 53 46	Ankara Sivas Erzurum
Wind speed (m/s)	3.1 4.3 3.3	3.5 4.5 3.5	3.5 4.3 3.7	3.2 3.9 3.7	2.9 3.3 3.1	3 3.6 3	3.3 4.2 3.3	3.3 4 3	3 3.4 2.9	2.9 3.3 2.9	2.9 3.7 3	3.1 4.2 3.1	Ankara Sivas Erzurum

The method of this study is based on the use of artificial neural network. Artificial neural networks (ANNs) are one of the artificial intelligence models that mimic the functioning of the human brain. In data analytics and prediction, artificial neural networks are very important in determining future trends.

In this study, solar radiation prediction was made for 3 cities with a multi layer perceptron neural network. Monthly solar radiation intensity was estimated for the 10 years between 2012 and 2022 with a total of 4764 samples taken from Turkish State Meteorological Service [24]. The proposed ANN model is shown in Figure 3. The model in this study is designed for a regression problem with 11 features in the input. These features; year, month, city, temperature, highest temperature, lowest temperature, number of rainy days, total rainfall average, sunshine duration, cloudiness index and wind speed values. There are 8 neurons in the first hidden layer and 4 neurons in the second hidden layer. The Dropout layer is added before the output layer to prevent network overfitting. The optimizer used in compiling the model was determined as Adam, the loss function as 'mean_squared_error' and the metric as 'mse'. ReLU activation function was used in the input layer and hidden layers. In the output layer, the solar radiation intensity value for 10 years was used. 70% of the data set is divided into training and 30% is divided into testing data set. Data are normalized between [-1, 1] with min max normalization. The model was trained for 50 epochs. The trained network was tested with the test dataset.

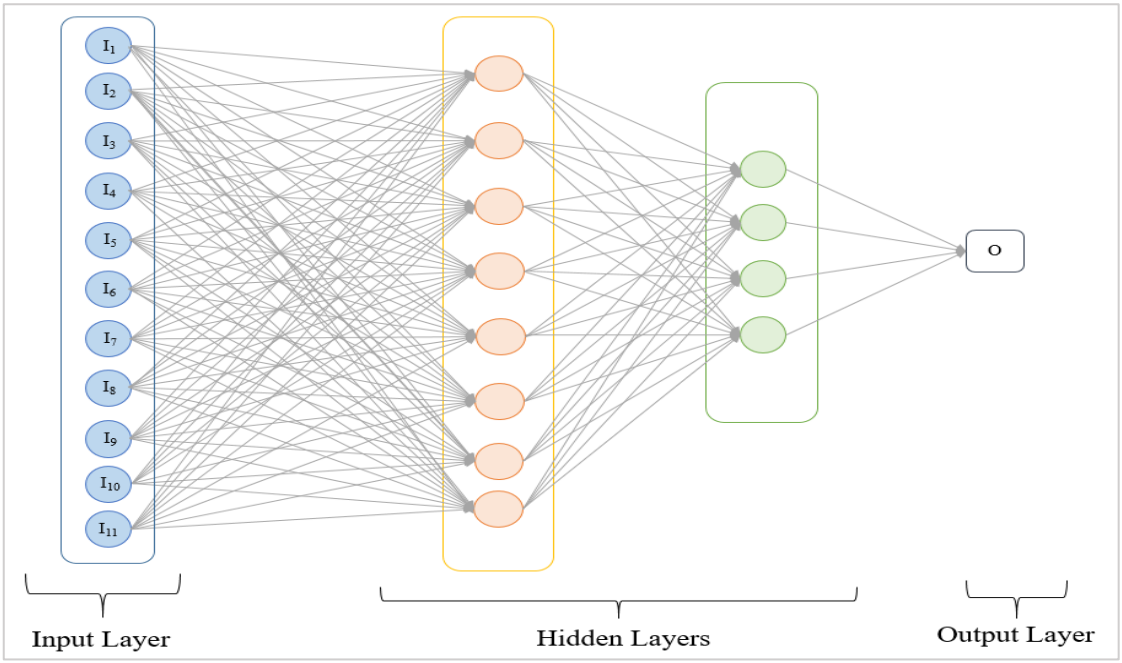

Figure 3. Proposed Artificial neural network model (Önerilen Yapay sinir ağı modeli)

To evaluate the performance of the model, Mean Absolute Error (MAE) (Eq.1), Mean Squared Error (MSE) (Eq.2). and Correlation Coefficient (R2) (Eq.3) [25] metrics were used. While the correlation coefficient R shows the relationship between variables, MSE measures the predictive performance of the model. Both are used in analysis to help evaluate model accuracy and relationships.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_{true,i} - y_{pred,i}\right| \quad (1)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_{true,i} - y_{pred,i}\right)^2 \quad (2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_{true,i} - y_{pred,i}\right)^2}{\sum_{i=1}^{n}\left(y_{true,i} - \bar{y}_{true}\right)^2} \quad (3)$$

3. RESULTS (BULGULAR)

Within the scope of the study, radiation exposure was estimated for three different cities with similar latitude values. Comparative graphics were obtained with Turkish Meteorological Service (TMS) data. Figure 4 shows how the model's loss changes for each epoch during training. The loss of the model decreased and became almost constant after 25 epochs. Figure 5 shows the comparison of the solar radiation value obtained by the ANN model with the TMS for Ankara. Accordingly, just like in TMS, the month with the highest solar radiation was determined as July. And the solar radiation value here is approximately 8.2 kWh/m^{2}d. Similarly, the month with the lowest solar radiation is December and the solar radiation value here is approximately 2.4 kWh/m^{2}d.

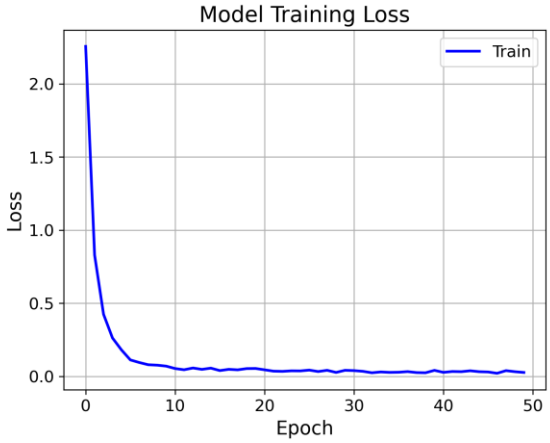

Figure 4. Model train loss graph (Model eğitim kayıp grafiği)

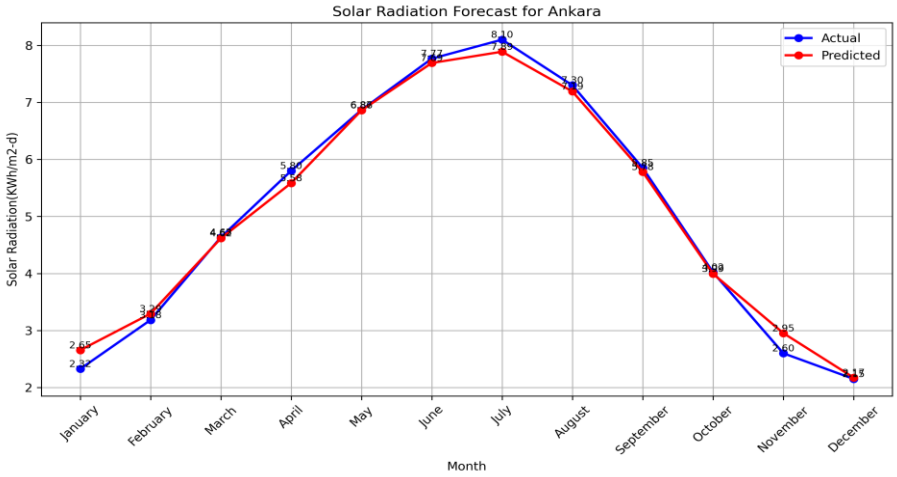

Figure 5. Monthly solar radiation values for Ankara (Ankara için aylık güneş radyasyon değerleri)

Figures 6 and 7 show monthly solar radiation values for Sivas and Erzurum provinces. Just like in Ankara, the ANN model was compatible with TMS data in these cities. In previous similar studies, the artificial neural network model was compatible with the reference [26].

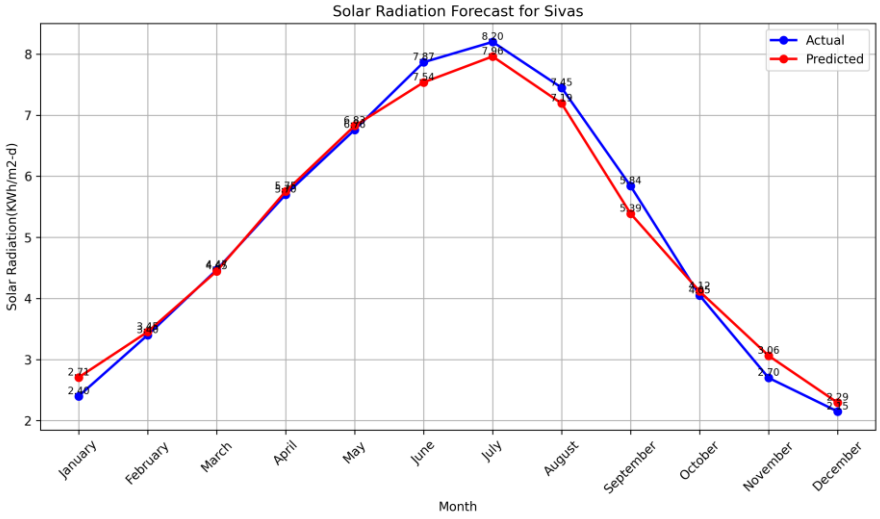

Figure 6. Monthly solar radiation values for Sivas (Sivas için aylık güneş radyasyon değerleri)

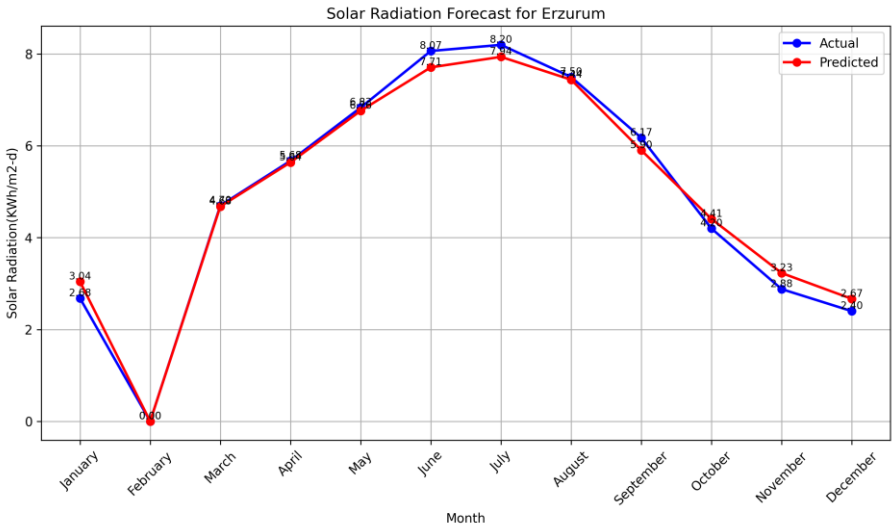

Figure 7. Monthly solar radiation values for Erzurum (Erzurum için aylık güneş radyasyon değerleri)

Artificial neural network (ANN) modeling is often used for regression problems. Regression is the process of using input variables to predict an output variable. The R2 score is a commonly used metric to evaluate the performance of regression models and is important for understanding how well the model makes predictions. The higher the R2 value, the better the model fits the real data. An R2 value approaching 1 means that the model explains the dependent variable perfectly. The R2 value of 0.984 shown in Figure 8 is a very high value and shows that the model explains a large part of the variance in the data set.

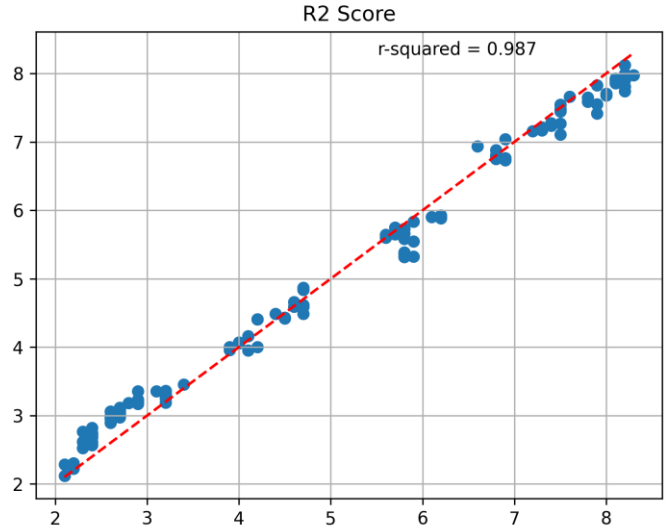

Figure 8. R2 score value of the artificial neural network model used in this study (Bu çalışmada kullanılan yapay sinir ağı modelinin R2 skor değeri)

4. CONCLUSIONS (SONUÇLAR)

This study focuses on estimating solar radiation values through artificial neural network (ANN) modelling, using meteorological and geographical data in Ankara, Sivas and Erzurum provinces. In order to understand the effects of climate on forecasting, basic meteorological variables such as highest temperature, lowest temperatureand number of rainy days were selected as inputs of this model. The diversity resulting from different climate zones and similar latitude values in the specified provinces was selected to evaluate the overall performance of the ANN model.

Similar solar radiation values are expected in the same latitude regions. However, different factors can cause differences in solar radiation values between cities. These factors include cloud cover, climatic conditions, geographical features, local topography and air pollution. Therefore, solar radiation values of cities located at the same latitude may show similar trends, but may not be exactly the same.

The analyzes revealed the ability of the ANN model to successfully predict solar radiation values. Agreement between predicted values and measured values was observed, indicating that the model has wide applicability in different climatic conditions. The results obtained from this study show that the ANN method can be used effectively in estimating solar radiation values. In addition, the fact that it provides high-precision predictions that will guide future studies increases the scientific importance of the research.

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The authors would like to thank the Turkish State Meteorological Service for sharing Turkey's climate data for this study.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Sinem UZUN*:** She contributed to the analysis, analyzed the results and performed the writing process.

***Hatice ARSLANTAŞ*:** She performed the analyzes and contributed to interpreting the results.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

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