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Research Article

Global Solar Radiation Estimation with Sum of Sine Model

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Abstract

Renewable and clean energy sources are currently needed for the long-term growth of nations and to decrease the negative environmental effects of fossil fuels. One of the most significant sources of energy is solar energy. Understanding the radiation properties of the solar energy is crucial for making the most use of solar energy in a certain region. In addition, reliable solar energy measurements are necessary for research into climate change, one of the most pressing problems confronting humanity today. Nowadays, solar energy harvesting systems are widely used to satisfy the world's increasing energy needs. Satellite-based solar radiation forecasts currently provide the high spatial and temporal resolution, global, diffuse, and direct sunlight data needed for solar power system planning and efficient utilization. In this study, the solar radiation values of the determined area were estimated using sum of sine model for $n = 1,\ n = 2,\ n = 3$ in the Matlab program. Several statistical error analysis tests were used to evaluate the performance of the developed models. The estimated solar radiation values demonstrate how effectively the proposed prediction models performs.

Keywords: Solar energy, Solar radiation, Statistical error tests, Sum of sine model.

Sinüs Toplam Modeli ile Küresel Güneş Radyasyon Tahmini

Öz

Yenilenebilir ve temiz enerji kaynaklarına günümüzde ulusların uzun vadeli büyümesi ve fosil yakıtların olumsuz çevresel etkilerinin azaltılması için ihtiyaç duyulmaktadır. En önemli enerji kaynaklarından biri güneş enerjisidir. Güneş enerjisinin radyasyon özelliklerini anlamak, belirli bir bölgede güneş enerjisinden en iyi şekilde yararlanmak için çok önemlidir. Ayrıca, günümüzde insanlığın karşı karşıya olduğu en acil sorunlardan biri olan iklim değişikliği araştırmaları için güvenilir güneş enerjisi ölçümleri gereklidir. Günümüzde dünyanın artan enerji ihtiyacını karşılamak için güneş enerjisi üretim sistemleri yaygın olarak kullanılmaktadır. Uydu tabanlı güneş radyasyon tahminleri şu anda güneş enerjisi sistemi planlaması ve verimli kullanımı için gereken yüksek uzaysal ve zamansal çözünürlük, küresel, yaygın ve doğrudan güneş ışığı verilerini sağlar. Bu çalışmada, Matlab programında $n = 1,\ n = 2,\ n = 3$ için sinüs toplam modeli kullanılarak belirlenen bölgenin güneş radyasyon değerleri tahmin edilmiştir. Geliştirilen modellerin performansını değerlendirmek için çeşitli istatistiksel hata analiz testleri kullanılmıştır. Tahmin edilen güneş radyasyon değerleri, önerilen tahmin modellerinin ne kadar etkili performans sergilediğini göstermektedir.

Anahtar Kelimeler: Güneş enerjisi, Güneş radyasyonu, İstatistiksel hata testleri, Sinüs toplam modeli.

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1. Introduction

Because to rising populations, the depletion of fossil fuel reserves, and technological advancements, energy consumption has risen recently. The sun is without a doubt the primary source of energy for the entire planet. The energy of the sun travels through space on electromagnetic waves. The total solar radiation of the Sun that reaches the surface of the Earth varies depending on the curvature of the Earth, extra-atmospheric solar radiation, and atmospheric characteristics. For any analysis of solar systems, a precise assessment of the elements of global solar radiation is required. On the surface of the planet, the direct and diffuse solar radiation that make up global solar radiation can be measured (Kaplan, 2015). Solar energy technologies are domestic, clean, and renewable energy sources that will be crucial in the production of sustainable energy in the future. Turkey receives roughly 2640 hours of sunshine annually due to its location in the medium solar belt. The solar energy density (S) is 3,6 KWh/m2 on a daily basis. Turkey has an overall gross solar energy potential of 8,8 MTEP with an annual maximum total solar radiation of 299 hours and 1460 KWh/m2 in Southeast Anatolia and an annual minimum total solar radiation of 1971 hours and 1120 KWh/m2 in the Black Sea region (Ozturk, Bezir & Ozek, 2009).

When the number of weather stations is taken into account, the statistics on solar radiation are few. A solar radiation model is typically employed in these circumstances to forecast the necessary data for solar radiation applications. Some parameters are used to construct a variety of empirical models for estimating global solar radiation. Extraterrestrial radiation, daylight, duration, temperature, soil temperature, relative humidity, number of wet days, altitude, latitude, and longitude, as well as total precipitation, cloudiness, and evaporation are among the factors that are examined (Togrul & Onat, 2000)(Jin, Yezheng & Gang, 2005)(Menges, Ertekin & Sonmete, 2006).

This work used the sum of sine model to create a novel solar radiation estimation model. The city of Antalya served as the study's setting, and Table 1 contains information on its geography.

Table 1. The study area geographical coordinates.

Variable	Value
Latitude	36,07 ° N
Longitude	29,20 ° E
Level of sea	39 m
Measurement height	10 m

2. Material and Method

2.1. Sum of Sine Model

The sum of sines model fits periodic functions and is given by

$$y = \sum_{i=1}^{n} a_i \sin(b_i x + c_i) \quad (1)$$

where a is the amplitude, b is the frequency, and c is the phase constant for each sine wave term. n is the number of terms in the series and $1 \leq n \leq 8$. This equation is closely related to the Fourier series described in Fourier Series. The main difference is that the sum of sines equation includes the phase constant, and does not include a constant (intercept) term (MathWorks Help Center).

In this section, the coefficients of Eq. 1 for selected region were calculated in Matlab program for $n = 1$, $n = 2$, $n = 3$ respectively. The used regional solar radiation data based on measured hourly one year and the developed model was given by;

Sum of Sine Model for $n = 1$

$$\frac{H}{H_0} = 2.026 \sin(0.1678 \frac{S}{S_0} + 6.479) \quad (2)$$

Sum of Sine Model for $n = 2$

$$\frac{H}{H_0} = 1.306 \sin\left(4.127 \frac{S}{S_0} + 4.634\right) + 0.676 \sin\left(6.401 \frac{S}{S_0} + 6.157\right) \quad (3)$$

Sum of Sine Model for $n = 3$

$$\frac{H}{H_0} = 0.99 \sin\left(7.11 \frac{S}{S_0} + 3.25\right) + 0.46 \sin\left(13.23 \frac{S}{S_0} + 2.44\right) + 0.14 \sin\left(13.23 \frac{S}{S_0} + 2.44\right) \quad (4)$$

In this study, a specific region's one-year data on sunlight hours and monthly average daily solar radiation on a horizontal plane were employed. The information was provided by the General Directorate of State Meteorology and was based on observations of sun radiation. The graphs of the developed models are shown in Figure 1, Figure 2, and Figure 3 for $n = 1$, $n = 2$, $n = 3$ respectively.

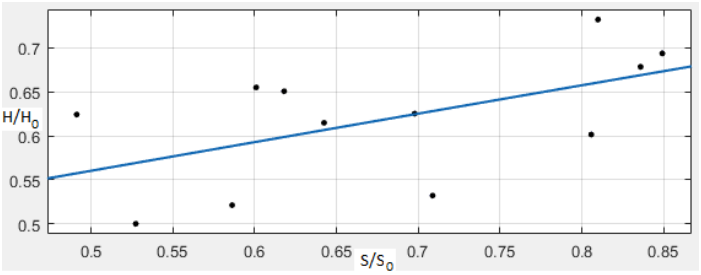

Figure 1. The graph of developed model by using sum of sine for $n = 1$

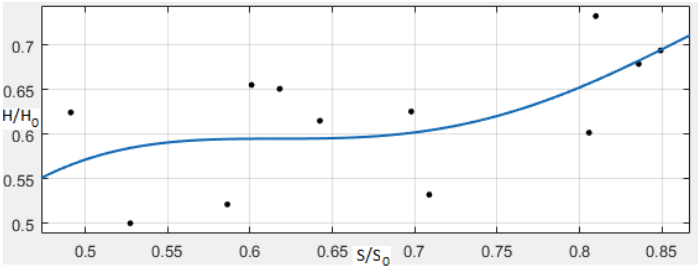

Figure 2: The graph of developed model by using sum of sine for $n = 2$

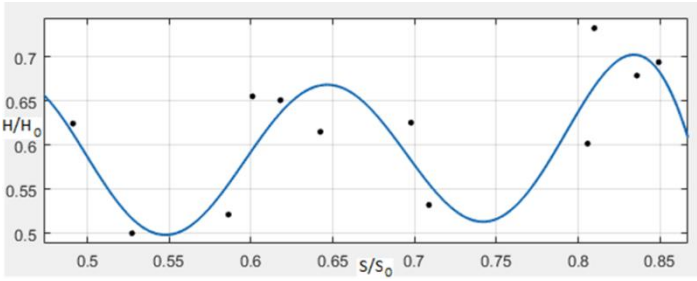

Figure 3. The graph of developed model by using sum of sine for $n = 3$

2.2. Statistical Error Tests

In the literature, the efficacy of solar radiation estimation models is evaluated using a variety of statistical error tests. In this investigation, three different statistical error tests were used (Kallioglu, 2014)(Aras, Balli & Hepbasli, 2006)(Ulgen & Hepbasli, 2004).

2.2.1. The sum of square of error (SSE)

The sum of square of error is calculated as follows (Oztürk, Ozek & Berkama, 2012). SSE must be equal to the ideal value of zero.

$$SSE=\sum_{i=1}^{n}(m_i - c_i)^2 \quad (5)$$

2.2.2. The analysis of variance (R^2)

The coefficient of determination indicates the extent to which one variable is bound to another. It is used to determine the linear relationship between the calculated and measured values. The value of this coefficient ranges from 0 to 1 and its ideal value is close to 1 (Khorasanizadeh, Mohammadi & Mostafaeipour, 2014).

$$R^2=\frac{\sum_{i=1}^{n}(c_i-c_a)\times(m_i-m_a)}{\sqrt{[\sum_{i=1}^{n}(c_i-c_a)]\times[\sum_{i=1}^{n}(m_i-m_a)^2]}} \quad (6)$$

Here, c_a and m_a are respectively average of the measured and calculated values.

2.2.3. The root mean square error (RMSE)

The root mean square error is calculated as follows (Khorasanizadeh, Mohammadi & Mostafaeipour, 2014)(Sabzpooshani & Mohammadi, 2014). The ideal value for RMSE is equal to zero.

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_i - c_i)^2} \quad (7)$$

3. Results and Discussion

In this study, new models was developed by using sum of sine model for $n = 1$, $n = 2$, $n = 3$ in Matlab program for solar radiation estimation of selected region. Three different statistical error tests were used to evaluate the effectiveness of the models that was developed.

The statistical error test results of developed models are given in Table 2. When the results are evaluated in general, it is seen in Table 2 that the statistical error test results change depending on n. When the results are generally evaluated, it has been observed that the performance of the developed model improves as the number of n increases.

Table 2. The statistical error test results of developed models.

n	SSE	R^2	RMSE
1	0.0386	0.3102	0.06549
2	0.03715	0.336	0.07869
3	0.01844	0.6704	0.0784

4. Conclusions and Recommendations

For the purpose of estimating the solar radiation of a chosen location, new models were developed in this study utilizing the sum of sine model for $\boldsymbol{n = 1}$, $\boldsymbol{n = 2}$, $\boldsymbol{n = 3}$ in the Matlab software. Three different error analysis tests were applied to show the effectiveness of the developed models. According to the results obtained, the developed models have been shown to be quite effective.

The models developed for this study will be useful in determining the region's solar energy potential and will introduce a brand-new model to the literature. Because solar radiation measurement is currently one of the most important fields of renewable energy research, this work can help with future studies on the topic.

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