Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 2 (No. 2), pp. 45-50, 2022
doi: 10.54569/aair.1139183
Published online: Sept 15, 2022

Determination of Angstorm Coefficients with curve fitting method by using Matlab Program

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Abstract

For the sustainable development of nations and to lessen the negative environmental effects of fossil fuels, more clean and renewable energy sources are now required. One of the most significant energy sources is solar energy. To utilize solar energy more efficiently in a particular area, it is crucial to be aware of the solar radiation levels. Furthermore, it's critical to accurately calculate solar energy for study into climate change, one of the biggest global challenges. Systems that utilize solar energy are frequently used nowadays to address the rising global need for energy. The high geographical and temporal resolution, global, diffuse, and direct sunlight data needed for the design and effective operation of solar power plants are now provided by satellite-based solar radiation predictions. In this work, satellite-based forecasting models were used to estimate diffuse solar radiation for the chosen region. In this study, the solar radiation irradiance values of the chosen region were estimated using the curve fitting approach. Angstorm coefficients were determined using the Matlab program for this investigation. Various statistical error analysis tests were used to evaluate how well the constructed model performed. The findings collected unequivocally demonstrate that the provided prediction models perform well.

Keywords: *Solar energy; solar radiation; solar radiation models; statistical indicators.*

1. Introduction

The main causes of global warming and climate change, which are one of the main problems of today's world, are of human origin. The activities carried out by people to meet their needs harm the nature and the quality of life of future generations. Rapid increase in world population, industrialization activities, technological innovations, rising living standards and rapidly increasing consumption expenditures lead to an intense energy demand. In energy production, which is carried out to meet the increasing demand day by day, it is more easily available and less costly traditional fossil fuels (non-renewable resources) are largely preferred. Resources such as coal, oil and natural gas, which are called fossil fuels, are not renewable, have great harm to the environment and cause air pollution, especially since they reduce the amount of oxygen in the air. Such as oil, gas and coal carbon dioxide from fossil fuel-based energy use and similar greenhouse gases cause an increase in the average surface temperature. This situation, inevitably lead to climate change and biodiversity reduction. For such reasons, the increasing human sensitivity towards environmental issues has drawn attention to renewable energy sources. Because renewable energy sources are environmentally friendly compared to fossil sources and they constantly renew themselves. Renewable energy is indispensable for healthy development and meeting basic human needs. The argument that energy is one of the basic inputs of economic growth and social welfare and even the foremost is accepted at the global level. It is possible to characterize the concept of "sustainable energy", which includes the objectives of using energy without causing irreversible environmental destruction, without disturbing the ecological balance, and in accordance with the understanding of intergenerational justice, as a common policy principle adopted by the international community. To prevent global warming caused by the ever-increasing energy demand and fossil fuel use international studies reveal that the use of renewable energy resources, which are considered to be cleaner, is mandatory. This energy source is free, clean and available in most places throughout the year. Fossil fuels can run out, pollutes, and when they decrease, energy costs increase. Therefore, today, many countries are turning to renewable energy sources in order to meet their increasing energy needs and to reduce the negative effects of fossil fuels. With the use of renewable energy sources, electricity needs will be met on the one hand, and on the other hand, it will be possible to help prevent climate change in a global sense. In this sense, solar energy; high potential, ease of use and it comes to the fore among renewable energy sources due to its environmental friendliness. The sun is without a doubt the world's primary energy source. Electromagnetic waves are how the sun's energy travels throughout space. Total solar radiation that reaches the surface of the Earth changes as a result of the Earth's geometry, extra-atmospheric solar radiation, and atmospheric characteristics. For the examination of solar systems in any place, precise determination of the sun's overall radiation and its constituent parts is crucial. On the surface of the planet, direct and diffuse solar radiation, which make up global solar radiation,

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Received: 01/Jul/2022; Received in revised form: 26/Aug/2022; Accepted: 31/Aug/2022.

can be measured [1]. In addition to being a renewable, clean home source, solar energy technologies are also a key element of the generation of sustainable energy in the future. Turkey is in the medium sun belt and experiences roughly 2640 hours of sunshine annually. 3,6 KWh/m2 is the daily average solar energy density (S). The annual maximum total solar radiation in sunny hours is 299 hours and 1460 KWh/m2 with Southeast Anatolia, while the annual minimum total solar radiation in bright hours is 1971 hours and 1120 KWh/m^2 with the Black Sea region [2]. Turkey's overall gross solar energy potential is 8,8 MTEP. When the number of weather stations is taken into account, the data on solar radiation are low. In such circumstances, it is typical to estimate the required data by using a solar radiation model for solar radiation application. Some parameters are utilized to develop a number of empirical models that are used to calculate the solar radiation on a worldwide scale. These variables include evaporation, cloudiness, total precipitation, extraterrestrial radiation, sunshine, duration, temperature, soil temperature, relative humidity, number of wet days, altitude, latitude, and longitude [3, 4, 5].

In this study; linear, quadratic and cubic polynomial approaches were used to develop a model for solar radiation estimation, and three different new models were developed. the polynomial approaches were developed by using Matlab program to obtain Angström-type equations. For this study, the city of Kahramanmaraş was chosen and the geographical properties of selected region were given Table 1. The hourly values of wind speed data were provided by the Meteorological stations of Turkey for one year. Table 1 provides the geographical coordinates of the meteorological station.

Table 1. *The study area geographical coordinates.*

Variable	Value
Latitude	37,58 ° N
Longitude	36,93 ° E
Level of sea	568 m
Measurement height	10 m

2. The Curve Fitting Method

The process of creating a curve or mathematical function that best fits a group of data points is known as curve fitting. One of the most effective and popular analysis tools for engineering problems is curve fitting. In order to determine the "best fit" model for the connection between one or more predictors (independent variables) and a response variable (dependent variable), curve fitting is used [6].

Most commonly, a curve of the shape y=f(x) is fitted to the data points. The first degree polynomial equation is a line with slope a.

$$y=ax+b \tag{1}$$

If the order of the equation is increased to a second degree polynomial, the following results:

$$y=ax^2+bx+c \tag{2}$$

If the order of the equation is increased to a third degree polynomial, the following is obtained:

$$y=ax^3+bx^2+cx+d \tag{3}$$

3. Calculation method and new model description

Global radiation measurements are made regularly around the world, but widespread radiation measurements are not made. Therefore, global and widespread solar radiation estimations are obtained by developing experimental prediction models using the climatic parameters of the region. Solar radiation calculations are a subject that has been studied for years and still continues to be studied. These studies, which started with monthly solar radiation model calculations, were followed by daily solar radiation calculations. Angstrom-based solar radiation models have been applied for years to develop solar radiation irradiance estimates.

The sun-shining duration function equations are the ones that are most frequently employed. The term "H" stands for "total solar radiation," " H_o " for "solar radiation from beyond the atmosphere," "S" for "sunshine duration," and "(S_o) " for "day length." The following is how the "Angstrom Equation" is written out [7]:

$$\frac{H}{H_0} = a + b\,\frac{S}{S_0} \tag{4}$$

Here, "a" and "b" values are referred to as regression constants by the term Angstrom coefficient. According to different seasons of the year associated to hour angle "s," day length in hours " S_o " varies [7].

$$H_0 = \frac{24}{\pi} I_{sc} \left(1 + 0{,}033 Cos\frac{360n}{365}\right)\left(Cos\emptyset Cos\delta Sinw_s + \frac{\pi w_s}{180} Sin\emptyset Sin\delta\right) \tag{5}$$

where $\emptyset$ the latitude of the site, δ the solar declination, I_{sc} is the solar constant 1353 W/m^2 and n the number of days of the year [7].

$$\delta = 23{,}45 Sin\left[\frac{360(n+284)}{365}\right] \tag{6}$$

$$S_0 = \left(\frac{2}{15}\right) arcCos(-Tan\delta Tan\emptyset) \tag{7}$$

This section uses the aforementioned formulae to calculate the Angstrom coefficients for chosen location. The models created were provided by;

The equation for the linear model was developed as;

Model 1: $\frac{H}{H_0}$=0.1105+0.6967$\frac{S}{S_0}$ (8)

Second order equation was given as;

Model 2: $\frac{H}{H_0}$=-0.7035+3.1561$\left(\frac{S}{S_0}\right)-1.8023\left(\frac{S}{S_0}\right)^2$ (9)

Third degree of polynomial equation was obtained as;

Model 3: $\frac{H}{H_0}$=-4.0131+18.6152$\left(\frac{S}{S_0}\right)-25.4352\left(\frac{S}{S_0}\right)^2$+11.8241$\left(\frac{S}{S_0}\right)^3$ (10)

4. Calculating the total radiations and comparing the models

The models stated above have been compared with actual solar radiation values in this section. The one-year data on sunlight hours and monthly average daily solar radiation on a horizontal plane were used in this study in a particular region. The General Directorate of State Meteorology provided the data that was based on measurements of solar radiation. Figure 1 makes it abundantly evident that the newly constructed models produce results that are closer to the measured solar radiation data for the chosen region.

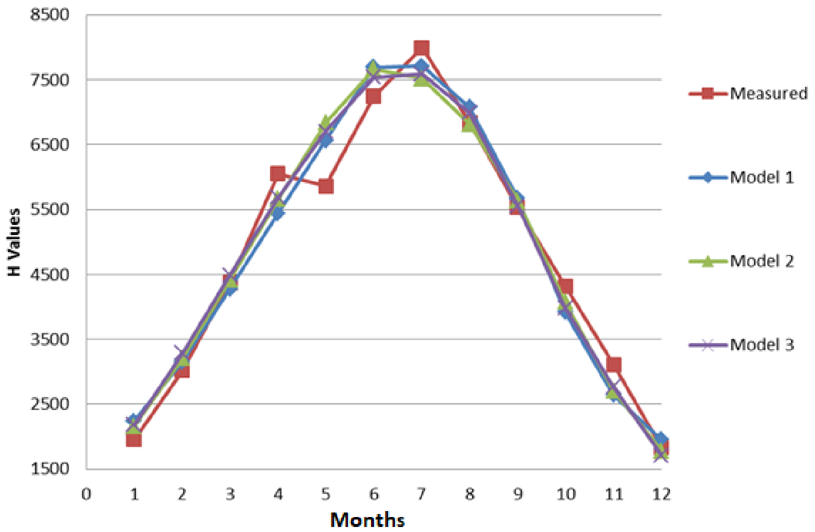

Figure 1. *The graph of monthly-average hourly global radiation of all developed models.*

5. Statistical Analysis Methods

Numerous statistical test methods are utilized in the literature to assess the effectiveness of solar radiation estimation models. The most popular statistical techniques for comparing the results among these are the relative percentage error (RPE), mean percentage error (MPE), Analysis of variance (R^2), mean absolute percentage error (MAPE), squared relative error (SSRE), total relative standard error (RSE), average bias error (MBE), and T-statistic (t-stat) [8, 9].

5.1. The Relative Percentage Error (RPE)

The percentage of relative error is defined as follows [10].

$$RPE = \left(\frac{m_i - c_i}{m_i}\right) \times 100 \tag{11}$$

Here, c_i shows the calculated values and m_i shows the measured values. The ideal value for RPE is equal to zero.

5.2. Mean Percentage Error (MPE)

Mean percentage error can be defined as the measured values of proposed equation and the percentage deviation of estimated monthly daily radiation.

$$MPE = \frac{\sum_{i=1}^{n} \left|\frac{m_i - c_i}{m_i}\right| x100}{n} \tag{12}$$

Here n is the number of calculated and measured values [11].

5.3. The analysis of variance (R^2)

The coefficient of determination can be used to determine the linear relationship between calculated and measured values [12].

$$R^2 = \frac{\sum_{i=1}^{n} (c_i - c_a) \times (m_i - m_a)}{\sqrt{[\sum_{i=1}^{n} (c_i - c_a)] \times [\sum_{i=1}^{n} (m_i - m_a)^2]}} \tag{13}$$

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

5.4. Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error is expressed as the average absolute value of the percentage deviation between predicted and measured solar radiation [12].

$$MAPE = \frac{\sum_{i=1}^{n} \left|\frac{(m_i - c_i)}{m_i}\right|}{n} \times 100 \tag{14}$$

5.5. The Sum of Squared Relative Error (SSRE)

The sum of the squares of the relative error is given as follows [11].

$$\text{SSRE} = \sum_{i=1}^{n} \left(\frac{m_i - c_i}{m_i}\right)^2 \tag{15}$$

SSRE must be equal to the ideal value of zero.

5.6. The t-statistic Test (t-stat)

A model performs better when the t value is smaller. Therefore, it is advantageous to employ t-statistic, or t, together with MBE and RMSE to evaluate the performance of models. The formula for t is given as follow [12, 13];

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^{n} (m_i - c_i) \tag{16}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (m_i - c_i)^2} \tag{17}$$

$$t - stat = \sqrt{\frac{(n-1) MBE^2}{RMSE^2 - MBE^2}} \tag{18}$$

The compatibility of estimated values with newly designed models and some models from the literature with real data was examined using the six different error analysis methods. Table 2 provides the statistical test results for one year for all the generated models. The outcomes of all the statistical techniques employed demonstrate that the proposed models' performance is satisfactory.

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

Model	RPE	MPE	R^2	MAPE	SSRE	t-stat
Model 1	-0,36843991	-0,83217	0,982489	7,515021	0,091064	0,156706
Model 2	-0,57817504	-0,62617	0,981403	6,263185	0,073767	0,239858
Model 3	-0,56598179	-0,58809	0,984649	6,658054	0,072469	0,25905

It can be clearly seen from the table that the performances of the developed models vary according to different tests. When we examine the results in general, it is seen that all the models developed show acceptable performance.

6. Conclusions

In order to properly examine every solar energy system, it is crucial to understand the worldwide and typical solar radiation. Studies on solar radiation determination mostly involve global solar radiation measurement and estimation. Knowledge of the incoming solar radiation in the area under study is necessary for the design and evaluation of solar energy systems. Based on this idea, a few models that employ empirical correlations to calculate the monthly average daily solar radiation on a horizontal surface were proposed. Three distinct models were created for this study utilizing the data on solar radiation for the chosen area. Six different statistical error tests were used to analyze the developed models performances. In conclusion, current findings have demonstrated that countrywide forecasting using precise satellite data is possible for both diffuse and global solar radiation. Three new models will be contributed to the literature, and the models created in this study will be crucial in estimating the region's potential for solar energy. This work can help future research on the solar energy problem because the measurement of solar radiation is currently regarded as one of the most crucial areas of renewable energy research.

Declaration of interest

The authors declare that there is no conflict of interest. It was presented as a summary at the ICAIAME 2022 conference.

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