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RESEARCH ARTICLE

DEVELOPMENT NEW MODEL for FORECASTING SOLAR RADIATION by USING RATIONAL APPROACH

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ABSTRACT

In this study, solar energy potential of south region of Turkey was assessed statistically by using the Solar Energy Potential Map of Turkey data for one year. A new model was developed by using rational approach for global solar radiation (SR) estimation. Calculations was performed in Matlab program. To demonstrate the efficiency of new model the four different statistical indicators were used. The obtained results reveal that the new proposed model give very appropriate results for SR estimation for mentioned region.

Keywords: *Solar energy, Solar radiation, Rational approach, Statistical indicators.*

1. INTRODUCTION

The globalizing energy need and the updating of the world population cause the demand for new energy sources to increase continuously. The increase in the need for energy used in the world day by day proves that the energy used is not at a sufficient level. Fossil fuels used today, etc. With the increasing population and technological developments around the world, the need for energy is constantly increasing due to the use of many technological devices. In order to meet this increasing need for electrical energy, renewable energy sources should be used more effectively [1]. Both the use of other non-renewable energy sources and the increase in their costs at the point of production have led the world community to seek new sources that can provide more efficient energy. Renewable energy sources, on the other hand, have been seen as a solution point for this search and their use has increased day by day. It has been observed in the projects carried out today that renewable energy sources can produce high-efficiency energy thanks to the right system and engineering service. Solar energy, which is the most important of renewable energy sources, has started to appear in every aspect of our lives. When we look at fossil fuels and the progress of our world today, solar energy emerges as a solution option against the negative environmental conditions created by climate changes. Developed countries are constantly supporting this source in order for solar energy to potentially reach the most efficient production values. At this point, our country has shown how important this energy

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is to every individual of the society by providing the right investments and incentives. When the global solar radiation values are examined at the point of production of solar energy, our country has a very strong potential in this regard. Today, the need for energy is constantly increasing due to the increasing population and developing technology. All countries around the world have sought new energy sources in order to meet their energy needs. Due to the fact that fossil fuel resources are too limited to meet the need in the near future, as well as environmental problems in the form of greenhouse effect as a result of air pollution and acid rain, renewable energy sources are met with increasing interest all over the world and are seen as an important alternative in meeting energy needs. The amount of energy consumption is one of the most important parameters that show the technological and economic development level of countries [2]. Solar energy (SE), which is one of the renewable energy sources, is an important alternative to fossil fuels thanks to the rapidly developing technology as well as being a clean source in terms of environment. Many solar applications require accurate information on solar availability and sufficiency in operating areas. However, long-term SR intensity measurements can only be made in certain locations. For places where no measured meteorological data is available, a practical method is to develop forecast models using empirically accepted correlations using data measured at some selected location. By using these correlations, desired models from meteorological, seasonal and geographical parameters such as latitude, sunshine duration, temperature can be developed with different methods and approaches. These developed methods can be used successfully in SR intensity estimation [3, 4, 5]. The solar map of Turkey is shown in Figure 1. For this study, the city of Gaziantep was chosen. The chosen area was within the spectrum of favourable provinces in terms of SE potential because to its geographic proximity to Turkey's South Coast. The fact that the global radiation and sunshine duration are located above the Turkey average has potential utility. Figure 1 details the SE potential of the location chosen for this investigation. The selected region is a SE-efficient region, as can be seen from the detailed figure.

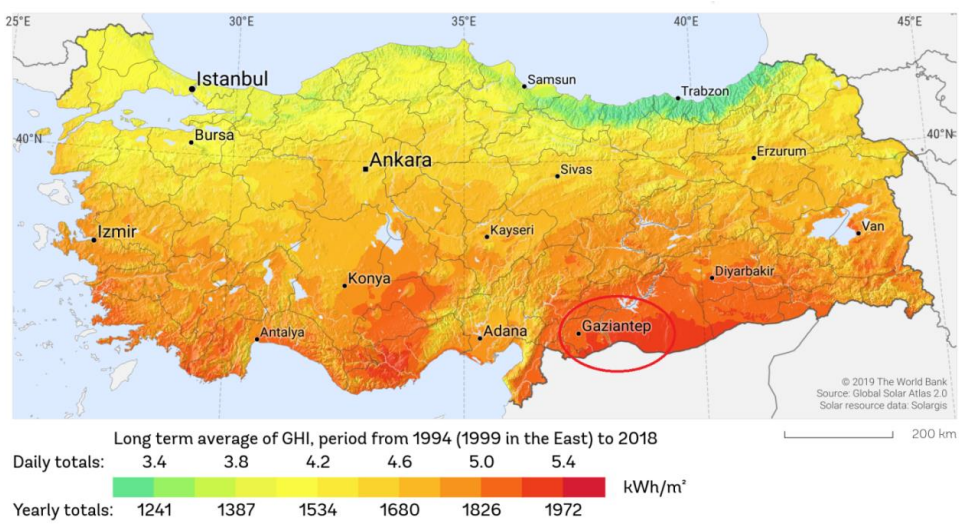

Figure 1. Solar map of Turkey (kW h/m^2 year) [6].

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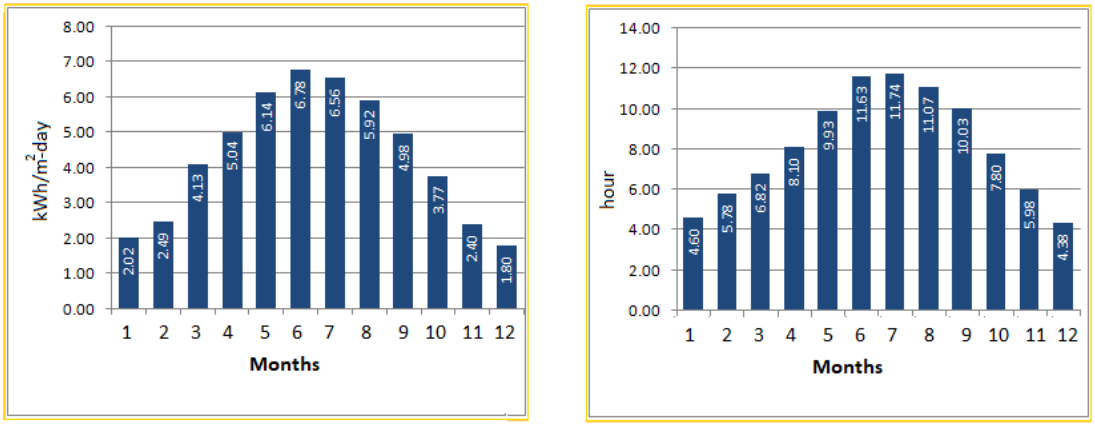
In this study, new model was developed by using rational approach for estimating SR. The Matlab software was used to perform the calculations. They were looked at in various statistical tests to demonstrate the efficacy of the developed model. The obtained results shown that the developed model is effective and trustworthy. The average SR values of the region selected for this study and the average sunshine duration of the region are shown in Figure 2.



a-) b-)

Figure 2. SR and sunshine duration for selected region [6].

There are many studies in the literature on developing SR estimation models using different algorithms and approaches. Zang et al. [7] developed a total of 14 year-based diurnal models using data collected between 1994 and 2015 at 35 meteorological sites across six different climate areas of China to estimate the daily global SR. The comparison results demonstrated the new models' outstanding climatic adaptation and forecast accuracy. Husain and Khan [8] developed six machine learning models, including random forest, k-nearest neighbors, Gaussian process regression, support vector machine, multilayer detection, and XGBoost for GSR prediction using simply air temperature as input for several climate zones in India. The effectiveness of machine learning models was also contrasted using a few well-known experimental models. Feng et al. [9] compared different ML and empirical models for estimating global SR using only air temperature as input. The findings demonstrated that when compared to current ML and empirical models, the hybrid mind evolutionary algorithm and neural network model offered improved predictions. Almorox et al. [10] claimed that numerous values for the solar constant (SC) and total solar irradiance (TSI) had been provided and used in the literature. They stressed the crucial role that the TSI value has in engineering and academic studies of energy. They conducted a review to look at the ideas of TSE and SC in this study. . The impact of three distinct TSI values for various places was examined using the angstrom-prescott (a-p) equation to forecast global radiation over Spain.

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2. MATERIAL and METHOD

2.1. Rational Polynomials

In approximation theory, besides the problems in which linear parameters come into play, it is possible for the parameters to appear in a non-linear way. It is very difficult to develop a theory for such problems. General theories can be given under very limited conditions. These theories have certain features of polynomial approximations. Rational approaches are examples of these. Ratios of polynomials are what are known as "rational models," and they are given by [11]

$$y = \frac{\sum_{i=1}^{n+1} p_1 x^{n+1-i}}{x^m + \sum_{i=1}^{m} q_i x^{m-1}} \tag{1}$$

where n is the degree of the polynomial in the numerator and $0 \leq n \leq 5$, and m is the degree of the polynomial in the denominator and $1 \leq m \leq 5$. x^m 's coefficient is always 1. When the polynomial degrees are the same, the numerator and denominator are unique because of this.

The degree of the numerator and the degree of the denominator are used here to describe rationals. As an illustration, the rational equation given by

$$y = \frac{p_1 x^2 + p_2 x + p_3}{x^3 + q_1 x^2 + q_2 x + q_3} \tag{2}$$

Rationals are frequently employed when a straightforward empirical model is required, much like polynomials. Rationals' key benefit is its adaptability to data with complex structures. The biggest drawback is that when the denominator is close to zero, they become unstable.

2.2. Rational Models

In this section, the data set used in the article study explained and the method used is examined in detail. Insolation time is easily and reliably measured and data is widely available. With the correlation obtained based on these measured values, monthly average total daily solar radiation can be estimated. The sunshine time is measured easily and reliably and its data is widely available. Based on these measured values, the mean daily average daily SR can be estimated by the correlation obtained. Statistical models for estimating the monthly mean daily Diffuse SR are given based on measured sunshine duration, Global SR, and calculated pre-atmospheric SR. The most commonly used of these models is Angström-type equations. The equation of rational approach is expressed for $n = 1, m = 1$ and $n = 1, m = 2$ as follows, respectively [11, 12, 13]:

$$\frac{H}{H_0} = \frac{p_1 \frac{S}{S_0} + p_2}{\frac{S}{S_0} + q_1} \tag{3}$$

$$\frac{H}{H_0} = \frac{p_1 \frac{S}{S_0} + p_2}{\left(\frac{S}{S_0}\right)^2 + q_1 \frac{S}{S_0} + q_2} \tag{4}$$

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Here $p_i$and q_i, $i = 1,2$ values are constants calculated in Matlab program.

In this context, firstly, the radiation data used in the study is presented, and the details of extraterrestrial radiation and sunshine duration calculations are explained. The general formula of the model equations based on the sunshine duration is Eq. 5: the monthly average daily total solar radiation H, the monthly average extra-atmospheric solar radiation Ho, the sunshine duration S, the maximum possible monthly average daily sunshine duration S_0. In order to calculate the H_0 value, declination and hour angles must be calculated first. The declination angle is the angle between the plane on which the earth rotates around the sun and the equatorial axis. Various forecasting models have been developed in Turkey and many parts of the world to find the monthly average daily total solar radiation. Many of these developed models have been specific to a certain location since they contain the parameters of the region to be calculated.

Day length in hours 'S_o' changes according to different time periods in the year related to hour angle 'ω_s' [5]

$$H_0 = \frac{24}{\pi} I_{sc} \left(1 + 0{,}033cos\frac{360n}{365}\right)\left(cos\emptyset cos\delta sinw_s + \frac{\pi w_s}{180} sin\emptyset sin\delta\right) \quad (5)$$

where $\emptyset$ the latitude of the site, δ the solar declination hour angle, I_{sc} is the solar constant 1353 W/m^2 and n the number of days of the year [14, 15, 16].

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

$$S_0 = \left(\frac{2}{15}\right) arccos(-tan\delta tan\emptyset) \quad (7)$$

2.3. Statistical Error Tests

In general, they are the methods that are used to analyze the radiation coming from the sun statistically and to subject it to error tests in the literature, and which are used to reveal the errors of these models. These methods are given below [2, 3, 17].

2.3.1. The sum of squared error (SSE)

$$SSE=\sum_{i=1}^{n}(m_i - c_i)^2 \quad (8)$$

2.3.2. The analysis of variance (R^2)

$$R^2=\frac{\sum_{i=1}^{n}(c_i-c_a)\times(m_i-m_a)}{\sqrt{[\sum_{i=1}^{n}(c_i-c_a)]\times[\sum_{i=1}^{n}(m_i-m_a)^2]}} \quad (9)$$

2.3.3. The adjusted analysis of variance (R^2_{adj})

$$R^2_{adj}=1-\left[\frac{(1-R^2)x(n-a)}{n-a-1}\right] \quad (10)$$

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2.3.4. The root mean square error

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(m_i - c_i)^2} \tag{11}$$

Error analysis methods are used to determine the error difference between the estimation result and the real result of the models found as a result of the rational approach. The specified error analysis method formulas are used to control more than one error analysis result of the model by giving different results. The R^2 equation used for error analysis is between 0 and 1 value. The fact that the value obtained as a result of the coefficient of determination is close to 1 indicates the accuracy of the model found as a result of machine learning to the real value. In other error tests, if the result is close to zero, it means that it performs better.

3. RESULTS

In this section, detailed expressions of the developed models are given. The graph of the model developed for $n = 1, m = 1$ is shown in Figure 3, and the graph of the model developed for $n = 1, m = 2$ is shown in Figure 4, respectively. Four different statistical error tests were used to evaluate the performance of the developed models. These statistical test results are given in Table 1 for both models.

The rational model equation for $n = 1, m = 1$ was developed as;

$$\textbf{Model 1: } \frac{H}{H_0} = \frac{0.9435\frac{S}{S_0} - 0.1369}{\frac{S}{S_0} + 0.2688} \tag{12}$$

The rational model equation for $n = 1, m = 2$ was developed as;

$$\textbf{Model2: } \frac{H}{H_0} = \frac{-0.2975\frac{S}{S_0} + 0.2824}{\left(\frac{S}{S_0}\right)^2 - 2.083\frac{S}{S_0} + 1.102} \tag{13}$$

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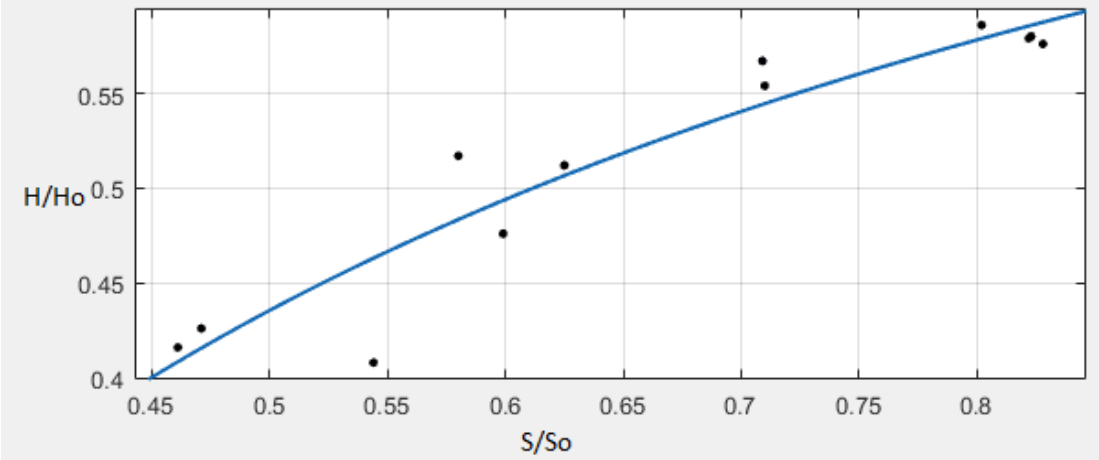

Figure 3. The graph of developed model by using rational polynomial for $n = 1,\ m = 1$.

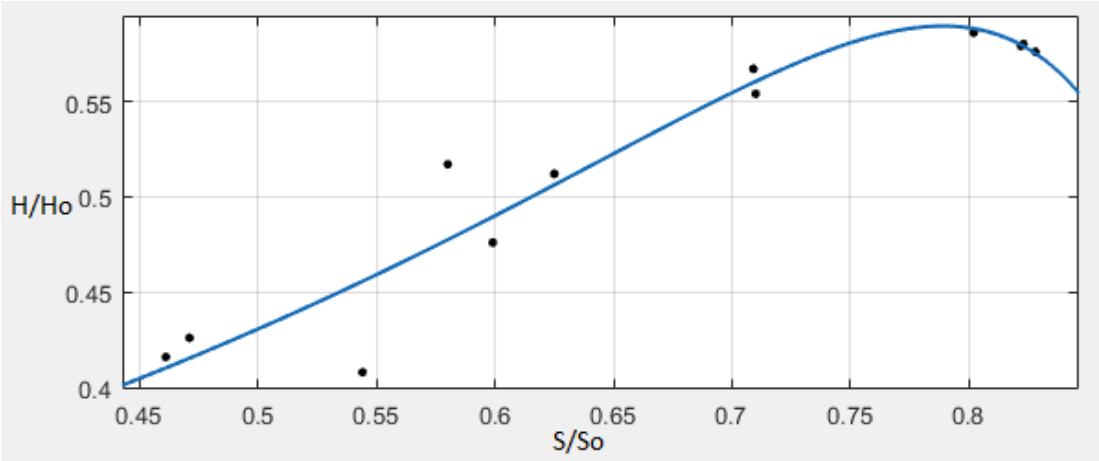

Figure 4. The graph of developed model by using rational polynomial for $n = 1,\ m = 2$.

Table 1. The statistical test results of the rational models.

Models	**Statistical Error Tests**			
	SSE	R^2	R^2_{adj}	**RMSE**
Model 1	0.00553	0.8936	0.87	0.0279
Model 2	0.00429	0.9174	0.8865	0.0232

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In this study, the performances of the two models developed using the Rational approach were examined using different statistical tests. SSE statistics test results in both models were very close to the zero value. These results are an important indicator that the developed models give values very close to the real values. When the estimation results in terms of R^2 are examined, it is seen that the developed two models exhibit successful results. The R^2 values of the algorithms in the study vary between % 89.36 and % 91.74 according to different degrees. Considering the results of all developed models are examined in terms of R^2_{adj}, it is seen that the result of model 1and model 2 are 0.87 and 0.88, respectively. When all the results are evaluated in terms of the RMSE test, it is seen that these test results 0.0279 and 0.0232 for two models. Therefore, the prediction success of all algorithms was evaluated as "good" in terms of this metric. When the results are examined in general, it can be said that both methods developed are very successful in solar radiation estimation. However, according to the results obtained, it was seen that model 2 performed better than model 1.

4. CONCLUSIONS

In this study, a new model are developed to estimate the SR value using rational approach in the matlab program. In order to develop new model, a region with high SE potential was selected. The results were analyzed in different statistical error analysis tests. It can be seen from the obtained results that the developed model is quite effective. It is possible to obtain advanced versions of these models by using genetic algorithm, fuzzy logic and artificial intelligence to make predictions and create new models with a rational approach. With these models, optimum levels of results can be obtained and these results can be systematically improved and a great contribution can be made to the SE production sector. It is known that the solar power plant to be installed will provide great convenience before the investment is made. These models, which form the basic structure of online applications used for energy production globally, are open for continuous self-development and adapting to all kinds of innovative projects. Rational approach, thanks to some methods used in the photovoltaic sector today, SR intensity, sunshine duration, etc. It is a method that can be used in the solution of photovoltaic formulations and is constantly evolving thanks to the artificial intelligence logic with a high level of learning feature. As a result, with the rational approach, a prediction model can be developed for each province-based region by using SR intensity and sunshine duration, and it is seen that realistic data estimation is possible in SE production by using these models. The most important and distinctive feature of this study is that an SR prediction model has not been developed using a rational approach before. In this study, two new models were developed using different degrees of rational approaches. For this reason, it is expected that this study will make very important contributions to the literature. This study can provide an important motivation for future academic studies on SR estimation with a rational approach.

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