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An Estimation of Solar Characteristic in Kelantan using Hargreaves Model

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Abstract

One of the famous models in statistical analysis for predicting the solar radiation is using Hargreaves model. In any prediction of the solar radiation, the specific site accurately over the long term is needed. This study presents an estimation of the solar radiation in Kelantan, Eastern Malaysia for the year of 2011 using Hargreaves model. This estimation is based on latitude and daily minimum and maximum temperature in Kelantan. The measured and estimated solar radiation data were compared for the year 2011 and analyzed using coefficient of residual mass (***CRM***), root mean squared error (***RMSE***), coefficient of determination ($\boldsymbol{R}^2$) and percentage error (***e***). The results showed that the value of ***CRM*** is 0.09, it indicates the tendency of the estimation model to under-estimate the measure solar radiation. Meanwhile, the value of ***RMSE*** is 8.21%. and the value of $\boldsymbol{R}^2$ is 0.8661, closed to 1 indicates that about 86.61% of the total variation is explained in the data. For the ***e***, the value is 7.98%, it indicates that the model estimation is good.

Keywords: Solar radiation; air temperature; Hargreaves model

1. Introduction

Solar radiation at the earth's surface is important for the development and utilization of solar energy. It is needed for designing collectors for solar heaters and other photovoltaic equipment that depend on solar energy. Over the last two decades, the interest in modelling solar radiation data has increased widely. This demand has been reflected in the numerous methods, developed for suitable radiation data, that have already been reported. These methods range from simple empirical formulas to complex numerical models that depend on the availability of input data.

The simple relationships for estimating solar radiation, involving such factors as cloud cover, percentage of specific cloud types, evaporation, humidity, number of days with dust or smoke, air temperature, precipitation, latitude and elevation, have been widely reported [7-8][22]. Simple relationships are practical because in remote areas weather data is rare and furthermore fully instrumented meteorological stations are costly to set up and maintain. Since the solar radiation data is the most important component to estimate output of photovoltaic systems [23-25], therefore, the best way to obtain the solar radiation data of a particular place of interest (POI) is to measure at the specific site continuously and accurately over the long term. References comparing a variety of simple methods can be found in [9][11][13-16][22].

The various models have been explored in order to estimate the solar radiation from other available meteorological data. Hence, the aim of this work is to propose a simple method for estimating daily solar radiation, from the daily maximum and minimum air temperatures in Kelantan using Hargreaves model [12].

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This method requires daily maximum and minimum air temperatures as input data. The Kota Bharu weather station was selected to test the methods and the data were recorded by Meteorological Station in Kota Bharu, Kelantan for the year 2011.

2. Data and Methods

2.1 Climate Data

The data used in this study was obtained from Meteorological Station in Kota Bharu, Kelantan (6.13° N, 102.25° E), . The population of Malaysia is about 904450 people. Kelantan's climate is Northeast monsoon, where it brings heavy rainfall. Its temperature is relatively uniform within the range of $21-32°C$ throughout the year. During the months of April-September, the weather is generally dry and warm. Humidity is consistently high on the lowlands ranging between 82% and 86% per year. The average rainfall per year is 2062–2543 mm and the wettest months are from November to March. The Kota Bharu Station is set to record daily solar radiation, maximum, minimum and average temperature.

Fig. 1. Meteorological Station in Kota Bharu, Kelantan

2.2 Hargreaves Model

Hargreaves and Samani (1982) first suggested that the solar radiation (R_s) can be estimated from the difference between maximum and minimum air temperature using a simple equation [17-18][21]:

$$R_s = a.R_a\left(T_{\max} - T_{\min}\right)^{0.5} \tag{1}$$

where R_s is in MJ.m^{-2}.d^{-1}; $T_{\max}$ and $T_{\min}$ are daily maximum and minimum air temperature, in $°C$, respectively, R_a is extraterrestrial radiation, in MJ.m^{-2}.d^{-1} which is a function of latitude and day of the year; and a is an empirical coefficient, the value of a to be 0.16 for interior regions and 0.19 for coastal regions.

The value of R_a is given by

$$R_a = (1440/\pi).SC.DF.(\cos\phi.\cos\delta.\sin W_s + W_s.\sin\phi.\sin\delta) \quad (2)$$

where SC is solar constant (1367 W/m2 or 0.082 $MJ.m^{-2}.min^{-1}$), DF is eccentricity correction factor of the earth's orbit, can be calculated by the expression:

$$DF = 1.0 + 0.033.\cos(2\pi.(JulianDay/365)) \quad (3)$$

where ϕ is latitude of the site, can be calculated by the expression:

$$\phi = latitude.\pi/180 \quad (4)$$

and δ is solar declination, can be calculated by the expression:

$$\delta = (23.45\pi/180).\sin(2\pi(284 + JulianDay/365)) \quad (5)$$

W_s is mean sunrise hour angle, can be calculated by the expression:

$$W_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (6)$$

The value of R_a depends on julian day, and the value of R_s is proportional to the difference between maximum and minimum air temperature (T_d). if the value of (T_d) increase, so value of R_s will increase.

3. Statistical Analysis

Daily estimated solar radiation (R_{sest}) values were compared with measured (R_{smea}) values. To assess the predictive accuracy for daily solar radiation estimation, four performance indicator were used, namely, coefficient of residual mass (***CRM***), root mean squared error (***RMSE***), Nash–Sutcliffe equation (***NSE***) and percentage error (***e***) expressed as a percentage of the arithmetic mean of the measured solar radiation [17-20][26-28] is given as follows:

- The ***CRM*** indicates overall under- or over estimation. For perfect estimation, the value of ***CRM*** would be zero. A positive value of ***CRM*** indicates the tendency of the estimation model to under – estimate the measured solar radiations, whereas, a negative ***CRM*** indicates a tendency to over-estimate the measured solar radiations. The calculation of ***CRM*** is given by

$$CRM = \frac{\sum_{i=1}^{n} R_{smea,i} - \sum_{i=1}^{n} R_{sest,i}}{\sum_{i=1}^{n} R_{smea,i}} \quad (7)$$

  where $R_{smea,i}$ is the measured daily solar radiation at *i* day, $R_{sest,i}$ is the estimated daily solar radiation at *i* day, $\overline{R}_{smea,i}$ is the average measured solar radiation and n is the day number of estimated solar radiation.

- The ***RMSE*** is expressed as percentage to make it dimensionless, a lower value of it indicates better performance. The calculation of ***RMSE*** is given by

$$RMSE(\%) = \frac{\sum_{i=1}^{n} R_{sest,i} - \sum_{i=1}^{n} R_{smea,i}}{\sum_{i=1}^{n} \overline{R}_{smea,i}} \quad (8)$$

- The ***NSE*** is also known as coefficient of determination (R^2), a model is more efficient when ***NSE*** is closer to 1 when all the estimated solar radiations match perfectly with the measured ones. A lower value (close to zero) of ***NSE*** indicates poor performance of the estimation model used and a negative value indicates that the estimated solar radiations are worse than simply using measured mean. The calculation of ***NSE*** is given by

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(R_{smea,i} - R_{sest,i}\right)^2}{\sum_{i=1}^{n}\left(R_{smea,i} - \overline{R}_{smea,i}\right)^2} \quad (9)$$

- A relative percentage error between -10% and +10% is considered acceptable. The mean percentage error can be defined as the percentage deviation of the estimated and measured monthly average daily solar radiation. The calculation of e is given by

$$e(\%) = \frac{R_{smea,i} - R_{sest,i}}{R_{smea,i}} \quad (10)$$

4. Result And Discussion

4.1 Temperature and Solar Radiation for the Year 2011

Solar radiation (R_s) is effected by the difference between maximum and minimum air temperature (T_d). R_s is proportional to T_d, if the value of T_d increase, so value of R_s will increase. The temperature throughout the year of 2011 recorded by Kota Bharu Station is shown in Fig. 2. Based on the Fig. 2, the lowest minimum temperature is 18.8 $^\circ C$ on 24 January and average value of the minimum temperature is 23.41 $^\circ C$. Meanwhile, for the maximum temperature, the highest value is 36.6 $^\circ C$ on 10 March and the average value is 30.36 $^\circ C$. Based on the difference of temperature graph (difference between maximum and minimum temperature), the lowest, highest and average value are 1.60 $^\circ C$ on 20 May, 13.20 $^\circ C$ on 22 January and 13 March and 8.04 $^\circ C$, respectively.

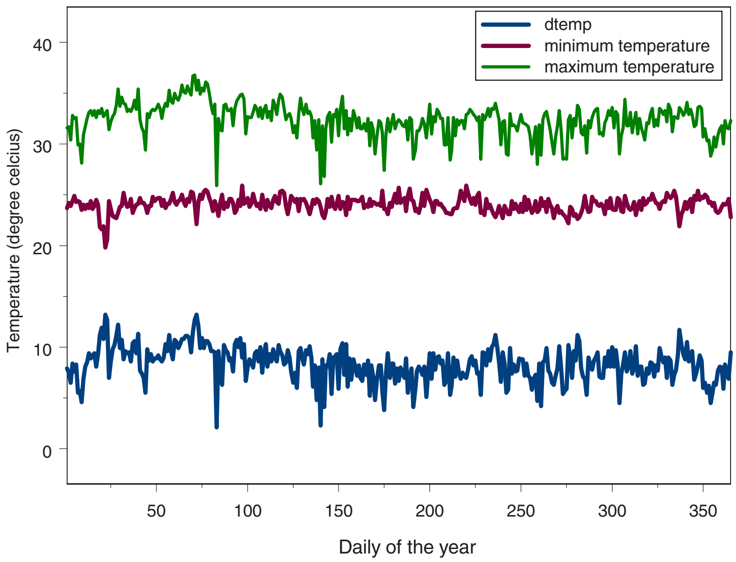

Fig. 2. Temperature throughout the year of 2011 recorded by Kota Bharu Station in Kelantan.

The solar radiation for the year 2011 is estimated using Hargreaves model in eq (1), as shown in Fig. 3. Then the comparison of measured and estimated solar radiation from the daily measured temperature is expressed by ***CRM***, ***RMSE***, R^2 and e, as shown in Table 1. The results show that the value of ***CRM*** is 0.09, it indicates the tendency of the estimation model to under-estimate the measure solar radiation. Meanwhile, the value of ***RMSE*** is 8.21%, shows that the percentage of error is small. The value of R^2 is 0.8661, closed to 1 indicates that about

86.61% of the total variation is explained in the data and the value of ***e*** is small, about 7.98%. It indicates that the model estimation is good.

Table 1. Comparison of measured and estimated solar radiation from the daily measured temperature

Station	***CRM***	***RMSE* (%)**	***R^2***	***e* (%)**
Kota Bharu	**0.09**	**8.21**	**0.8661**	**7.98**

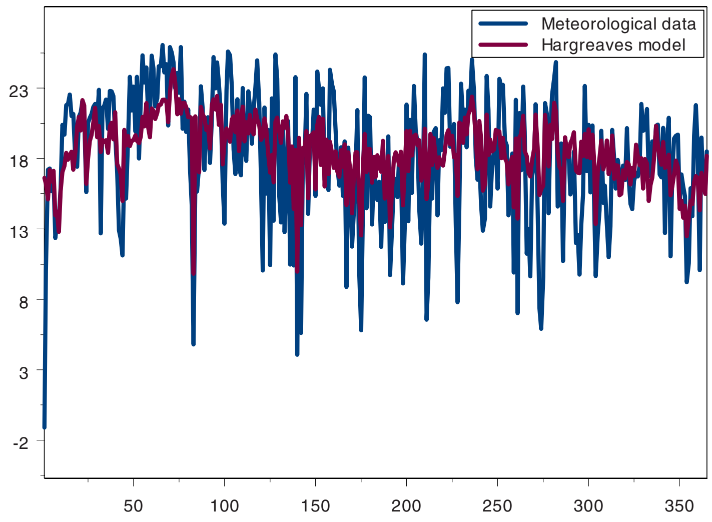

Fig. 3. Daily solar radiation recorded by Kota Bharu Station throughout the year 2011.

5. Conclusion

According to the results above, the Hargreaves model can be used to estimate the solar radiation in Kelantan, East Malaysia. The comparison of measured and estimated solar radiation from the daily measured temperature using ***CRM***, ***RMSE***, ***R^2*** and ***e***. The minimum, maximum and average daily estimated solar radiation throughout the year of 2011 were 5.02 MJ/m2 on 22 November, 20.25 MJ/m2 on 20 February and 16.25 MJ/m2, respectively. The monthly minimum and maximum estimated solar radiation were 12.28 MJ/m2 on December and 17.29 MJ/m2 on April, respectively. The total estimated solar radiation in a year were 5.75 GJ/m2 .

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