JSER

Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Evaluation of optimal model for estimating solar radiation in a moderate and mountainous area based on climatical data (Case Study: Kermanshah, Iran)

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ARTICLE INFO

Received: 28 Jun 2018
Received in revised form: 15 Jul 2018
Accepted: 3 Aug 2018
Available online: 8 Aug 2018

Keywords:
Angstrom equation, solar radiation, sunshine hours,Climatic data

A B S T R A C T

The solar radiation received by earth surface is one of the most applicable parameter that is usable in hydrology, agriculture, architecture and passive houses, climatology and meteorological modeling. Many different experimental equations had been suggested by researchers to estimate this parameter in different climates. This study aimed to calibrate existing model and develop a new model for estimating global solar radiation data using commonly and available measured meteorological records such as two well-known solar radiation models Angstrom-Prescott and Allen were calibrated and eight new empirical global solar radiation models were developed. Three statistical parameters Root Mean Square Error (RMSE), Nash-Sutcliffe equation (NSE) and Mean Bias Error (MBE) have been used to estimate error and model validation. The results showed that, the value of RMSE, NSE, MBE and Rs2 for Rs3 model got the highest rank with 44.59, 43.36, -594.92 and 0.9933, respectively. All models were calibrated based on available meteorological data and sunshine hours and validated using daily measured solar radiation

1. Introduction

It is a well-known fact that solar resource or solar radiation varies spatially as well as temporally across the face of the earth [1]. Hence, resource assessment is a preliminary step for all solar applications. Information about solar radiation on the earth's surface is required for many applications. In many applications of solar energy [2], by solar engineers, architects, meteorologists, agriculturists and hydrologists a reasonably accurate information about the availability of solar resources is a requirement at any desired site [3]. Solar Radiation and Sunshine duration are two of the most important variables in the energy budget of the earth. They play an important role in the performance evaluation of renewable energy systems [4]. In many applications of solar energy, the most important parameters that are often required are the daily short and long wave solar radiation. In spite of its importance, solar radiation is not widely measured compared to other meteorological data [5]. For this reason, there have been attempts at estimating it from theoretical models. Many empirical solar radiation models based on meteorological data have been discussed for estimation of global solar radiation it is Depending on the latitude, altitude and many meteorological factors [6]. The solar radiation modeling has shown significant progress in recent decades, reaching at present integration in geographic information systems that allow quantification at its spatial distribution [7].

Several empirical models have been used to calculate solar radiation, utilizing available meteorological, geographical and climatologically parameters such as sunshine hours, latitude, relative humidity, air temperature, precipitation, cloudiness. The most commonly used parameter for estimating global solar radiation is sunshine duration [8] and sun shine hours [9]. There is a range of estimation methods, the firsts uses formulations that seek empirical parameterization of the local physical conditions, using measurements in this field, from which quantitatively describes the optical characteristics of the air by simple equations and attenuation of solar radiation on the surface [10]. This study evaluating of optimal model to find the best intensity of solar radiation in Kermanshah [11], The reason for this approach comes from the fact that the air temperature and humidity is worldwide measured meteorological parameters, and is used by several authors in solar radiation estimation techniques. The objectives of this study were to compare, calibrate and validate existing solar radiation models to predict solar global radiation from available meteorological data [12].

2. Study Area

Kermanshah province is located in the middle of western part of Iran with an area of 25008 km 2 within 45º 24' and maximum 48º 07' of east longitude and 33º 40' and maximum 35º 18' of north latitude [13] the fig .1 shows Location of Kermanshah province in Iran. Kermanshah has a climate which is heavily influenced by the proximity of the Zagros mountains, classified as a hot dry summer Mediterranean climate [14]. The city's altitude and exposed location relative to westerly winds makes precipitation a little bit high (more than twice that of Tehran) [15], but at the same time produces huge diurnal temperature swings especially in the virtually rainless summers, which remain extremely hot during the day [16]. Kermanshah experiences rather cold winters and there are usually rainfalls in fall and spring. Snow cover is seen for at least a couple of weeks in winter. This province meets Kurdestan province from north, Lorestan and Ilam provinces from south and Hamadan province from east and has 330 km of common border with Iraq [17]. All data were calculated using observations from Kermanshah airport regional station was coincides with those obtained by using in situ automatic weather station [18]. For this purpose, the amounts of incoming solar radiation on a daily basis were estimated considering local in Station No. 40766 (altitude, latitude and longitude) and climatic (Humidity, temperature, pressure, length of day, sunshine hours, solar angle, sky albedo, absorption by aerosols, ground albedo, air mass, absorption by ozone, and Rayleigh distribution) characteristics [19].

3. Studied Models

The first correlation between the global solar irradiation and the sunshine duration was first exhibited by Angstrom using a simple linear model [20], but later, Prescott [21] put this equation in a

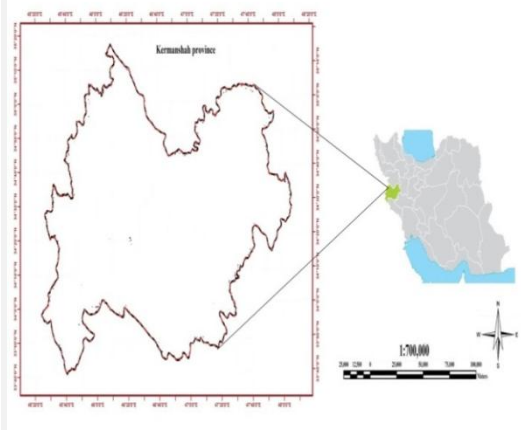

Fig. 1. Location of Kermanshah province in Iran

more convenient form by replacing the monthly global irradiation on a clear day by the monthly average daily extraterrestrial radiation, The Angstrom - Prescott model [22] is the most commonly used model as given by:

$$R_s = R_a\left[a + b\left[\frac{n}{N}\right]\right] \quad (1)$$

where Rs is the monthly average daily global radiation, Ra is the monthly average daily extraterrestrial radiation, n is the day length, N is the maximum possible sunshine duration, and a and b are empirical coefficients. The values of the monthly average daily extraterrestrial radiation (Ra) are calculated for days giving average of each month [23], These ratios (Rs/Ra) vary between zero and one [24]. Ra Was calculated from the following equation:

$$R_a = \frac{24*ISC}{\pi}\left[1+0.33\cos\left[\frac{360n(day)}{365}\right]\right](2)*$$
$$\left[\cos\phi\cos\delta\sin Ws + \left[\frac{2\pi.Ws}{360}\right]\sin\phi\sin\delta\right] \quad (2)$$

where I_{sc} is the solar constant (1367 Wm-2) which is calculated in this study, Ø is the altitude of the site, δ is the sun declination and is the mean sunrise hour angle for the given month, $n_{(day)}$ is the average day of each month. The regression models proposed in the literature based on Angstrom and Prescott and other Parameters are listed in Table 1. The Allen model is the most commonly used methods given as follows:

$$R_s = R_a \times a\sqrt{T_{\max} - T_{\min}} \quad (3)$$

Whereas Tmax and Tmin are the actual sunshine hours and maximum possible sunshine hours, maximum daily air temperature and minimum daily air temperature, respectively Calibration of all the models showed the values of "a", "b" and "a+b" coefficients are 0.2204, 0.5307 and 0.7511, respectively. These findings are in agreement with results of [25] and [26] in which they recommended "a+b" equal to 0.75 and 0.76, respectively. The value of Rs1 coefficient ("a") calibrated equal to 0.1665 for our study station. This amount is in agreement with finding of Allen, Pereira, Raes, & Smith, (1998) in which they recommended it in the range of 0.16-0.19.

In table 1, eight empirical global solar radiation models based on meteorological data and relative sunshine hours ($\frac{n}{N}$) were generated and validated as follows:

Table. 1 Regression models proposed in the literature

Regression equation	Model symbol	Source
$R_s = R_a \times a\sqrt{T_{max} - T_{min}}$	R_{S1}	(Allen, Pereira, Raes, & Smith, 1998)
$R_s = R_a\left[a + b\left[\frac{n}{N}\right]\right]$	R_{S2}	(Prescott, 1940)
$R_s = R_a \times a \times \exp\left[b\frac{n}{N}\right]$	R_{S3}	Alagib and Mansel (2000)
$R_s = R_a\left[a + b\frac{n}{N} + C\left(\frac{n}{N}\right)^2\right]$		
$R_s = R_a\left[a \times Ln(T_{max} - T_{min}) + b\left(\frac{n}{N}\right)^2 + d\right]$	R_{S4}	(Akinoğlu & Ecevit, 1990)
$R_s = R_a\left[a \times Ln(T_{max} - T_{min}) + b\left(\frac{n}{N}\right)^2 + d\right]$	R_{S5}	(Zhang, Qin, & Chen, 2004)
$R_s = R_a\left[a + b\frac{n}{N} + c \times RH + d(T_{max} - T_{min})\right]$	R_{S6}	(Bahel, Bakhsh, & Srinivasan, 1987)
$R_s = R_a\left[a + b\frac{n}{N} + c\left(\frac{n}{N}\right)^2 + d\left(\frac{n}{N}\right)^2\right]$	R_{S7}	Abdullah (1994)
$R_s = R_a \times a \times \left[1 - \exp\left(-b(T_{max} - T_{min})^c\right)\right]$	R_{S8}	Bristol and Kemble (1984)

Various models have been developed to estimate global solar radiation using sunshine hour data which are discussed for estimation of global solar radiation, in early 1954 Black found the regression model that coefficient ‘b’ was more or less constant, whereas the value of ‘a’ showed marked variation [27]. Also, for all practical purposes the coefficient ‘b’ was considered constant [28]. Page in 1988 had also noted that the clearer the atmosphere, the higher the value of $\left(\frac{Rs}{Ra}\right)$ obtained for a given value of $\left(\frac{n}{N}\right)$ and that affected the values of ‘a’ and ‘b’ found by regression analysis. The method used [29] for the estimation of monthly mean values of daily solar radiation on vertical and inclined surfaces from sunshine recorders, in conjunction with the method proposed and used for determination of the constants ‘a’ and ‘b’ of the Angstrom formula, was selected for the calculation of monthly and annual total values of global solar radiation over Greece [30].

Macris in 1976 use the model that distributed solar energy in Greece with using a form of the Angstrom type equation for the National Observatory of Athens with a=0.32 and b=0.68 [31]. These values compared to the results of other investigators mentioned above and to the values of ‘a’ and ‘b’ obtained were in excess of the latter. Similar values (a=0.31 and b=0.66) were used in overall regression equation [32].

Rietveld Model in 1978 was based on the well-known Kimbell-Angstrom-Page equation, which related the monthly average daily values of the global solar radiation G to the fraction of possible sunshine hours [33]. This model was expected to have an extended validity as shown in the later studies. Rietveld’s correlation was believed to be applicable anywhere in the world.

Flocas in his model said that despite the importance of global radiation, many meteorological stations recorded only the duration of sunshine and only a few of them recorded accurate measurements of solar radiation. A graphical relationship between the constants ‘a’ and ‘b’ and the annual average of $\left(\frac{n}{N}\right)$ had been proposed. The solar radiation in Brazil, applying the Angstrom formula and using the method proposed has been estimated. It was used for the determination of the constants ‘a’ and ‘b’.

Hutchinson Model found in his research 458 monthly values from 6 Australian stations with observations ranging from 3 to 10 years [34]. It was in agreement with the study made by Hounam [35]. A correlation was developed in Fagbenle’s Model which was believed to be suitable for the rain forest climatic zone of Southern Nigeria [36].The effect of the latitude and the altitude of the location to calculate regression coefficients ‘a’ and ‘b’ were included in Chandel Model (2002). Comparison with other models showed that it gave best results and can be used for the estimation of global solar radiation with greater accuracy [37]. Akpabio and Etuk’s Model state that The global solar radiation and sunshine duration data reported were supplied by the International Institute of

Tropical Agriculture station of Onne, Nigeria, a high rainfall station located at latitude 40 46' N, Longitude 70 10' E with an altitude of 10 m [38]. The method of least squares was used to obtain the constants 'a' and 'b'.

3. Results and Discussion

Model constants were estimated by minimizing the sum of square errors from measured and predicted values. Performance of the models were evaluated by statistical error tests including coefficient of determination (R2), root mean square error (RMSE), mean bias error (MBE) and the Nash-Sutcliffe
equation (NSE) [39] as follows:

$$MBE = \frac{\sum_1^n (P_i - O_i)}{n} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_1^n (P_i - O_i)^2}{n}} \quad (5)$$

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \overline{O})^2} \quad (6)$$

Where, n is the total number of measurements, i is the measurement number, O and P are the measured and estimated values, respectively and $\bar{O}$ is the average of measured values. A model is more efficient when NSE is closer to one [40]. The mean bias error value provides information on the long-term performance. A low MBE is desired. A positive value gives the average amount of over-estimation of an individual measurement, which will cancel under-estimation in separate measurements. The RMSE gives information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the predicted and measured data. The smaller the value, the better is the model's performance. However, a few large errors in the sum can produce a significant increase in the RMSE [41]. The calibrated constants for the eight models of Regression equation in the study station are shown in table 2.

The values of statistical indices including RMSE, MBE, NSE and R^2 are shown in table 3 for all 8 models. For statistical analysis, it was assumed that the best methods were those that yielded the lowest RMSE and Absolute value of (MBE) and highest value of NSE and R^2 .Based on Table 3, all recommended models except Rs2, Rs4 and Rs7 show an acceptable accuracy. The minimum amounts of RMSE belong to Rs1, Rs5 and maximum amount of R2 belong to model Rs2 and model Rs8, respectively.

Rs3 was found to be the most accurate model for the prediction of global solar radiation in study station with RMSE, MBE, NSE and R2 values of 44.59069778 MJ/m2/d, 43.36049724 MJ/m2/d, -594.920777 and 0.9933, respectively. Results confirmed that meteorological variables such as precipitation, daily mean air temperature, square root of the maximum and minimum air temperature differences, daily averaged relative humidity, saturation deficit and relative sunshine durations could be used to reasonably estimate the daily global solar radiation. After the Rs3, model Rs8 could estimate the daily global radiation with relatively high accuracy and is therefore recommended to estimate the global solar radiation when the T_{max} and T_{min} are available [42]. The values of measured and predicted global solar radiation by all models during 2008 to 2015 are compared as shown in Figure 2. As it can be seen from this figure 3, the estimated values of solar radiation using model Rs3 are very close to the measured values.

Temperature, square root of the maximum and minimum air temperature differences, daily averaged relative humidity, saturation deficit and relative sunshine durations could be used to reasonably estimate the daily global solar radiation. Results of statistical analysis suggest that models Rs3 (Alagib and Mansel model) and Rs8 (Bristol and Kemble model) presented in this paper are the most accurate models amongst the solar radiation models, which are based on meteorological data and sunshine hours. Therefore, these models are recommended to be used in Kermanshah region for estimation of solar radiation with higher accuracy.

4. Conclusion

Results confirmed that meteorological variables such as precipitation, daily mean air temperature, square root of the maximum and minimum air temperature differences, daily averaged relative humidity, saturation deficit and relative sunshine durations could be used to reasonably estimate the daily global solar radiation. After the Rs3, model Rs8 could estimate the daily global radiation with relatively high accuracy and is therefore recommended to estimate the global solar radiation when the Tmax and Tmin are available. The values of measured and predicted global solar radiation by all models during 2008 to 2015 are compared as shown in Figure 2. As it can be seen from this figure 3, the estimated values of solar radiation using model Rs3 are very close to the measured values.

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Table. 2 Calibrated constants for the models in the study station				
Model	a	b	c	d
Rs1	0.1665			
Rs2	0.2204	0.5307		
Rs3	0.1514	0.0299	0.4831	
Rs4	0.2165	0.0044	0.4356	
Rs5	0.1958	0.0043	0.0099	0.4224
Rs6	0.2097	0.0090	0.2446	0.0585
Rs7	0.2059	0.0066	0.4614	-
Rs8	0.4470	0.294	0.1085	0.0031

Table. 3 The Statistical indices of investigated models				
MODEL	INDEX			
	RMSE	MBE	NSE	R2
Rs1	19.00263451	17.2478252	2.350368039	0.5691
Rs2	36.23751665	29.96742223	2.348294659	0.0673
Rs3	44.59069778	43.36049724	-594.920777	0.9933
Rs4	266.6251161	27.67733081	0.009343001	0.0016
Rs5	5.276582773	2.134656189	0.816701064	0.8488
Rs6	28.11407417	21.50101795	0.353602395	0.4845
Rs7	243.7821446	28.36905557	0.012157604	0.0017
Rs8	45.90367268	59420.81074	892.5444798	0.9679

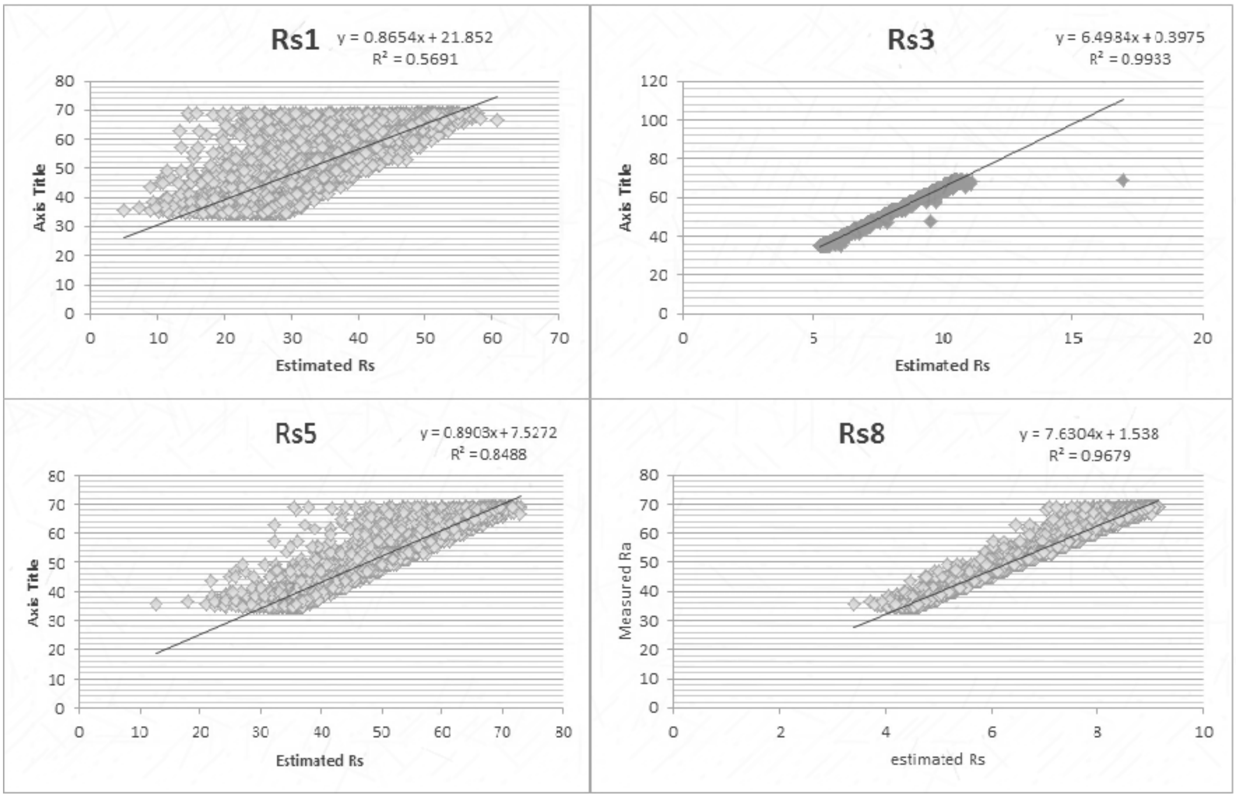

Fig. 2. Correlation of measured and estimated radiation data by selected models

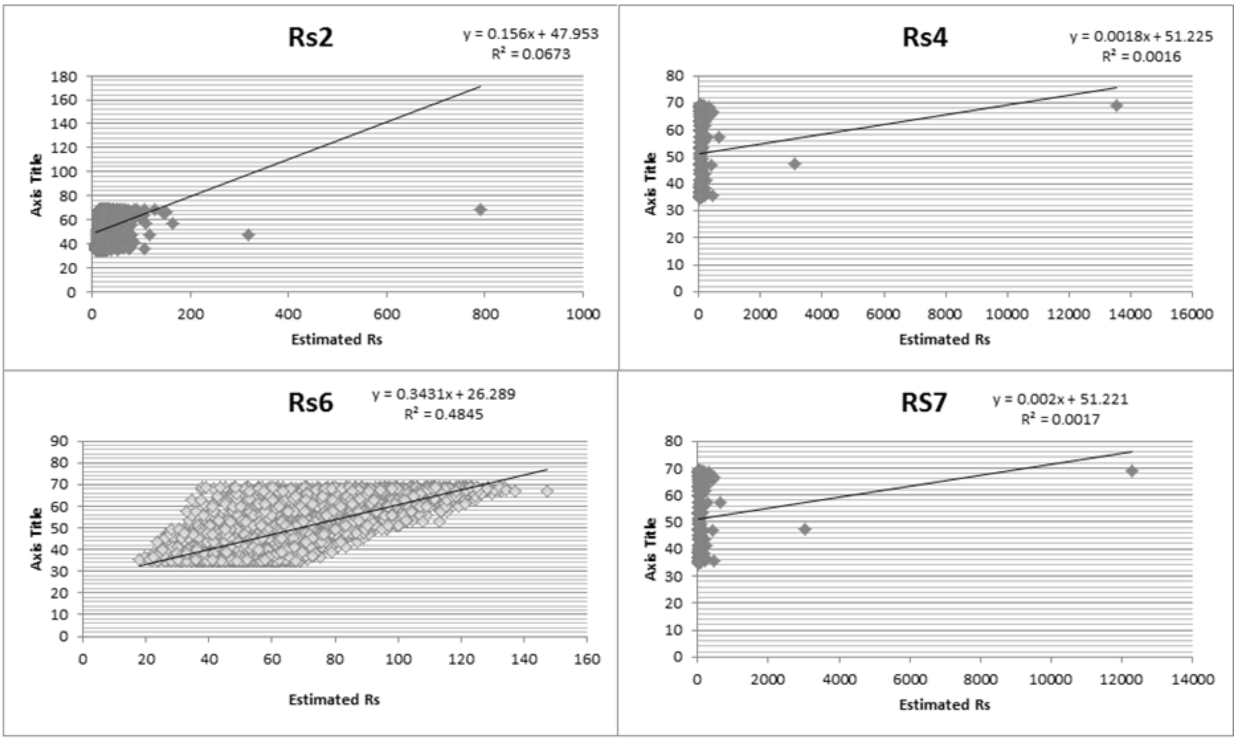

Fig. 3. Correlation of measured and estimated radiation data by rejected models

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