Estimation and Comparison of Monthly Global Solar Radiation Between Empirical Models and ANN Method at Visakhapatnam, India

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Abstract The sun's global radiation is a crucial aspect for evaluating the radiation of sun, as it gives the entire solar availability at a given place and can be calculated by the equipment. However, it is unfeasible to measure solar radiation in many areas due to maintenance and high price of the equipment used for measurement. Unfortunately, every place can't spare the price for the equipment attributable to the above factors. Hence, empirical models were established as a substitute to roughly calculate the data. This work is to compare the empirical models and find the suitable one to approximate the global monthly sun's radiation on parallel plane surfaces in the city, Visakhapatnam. The value of measured global solar radiance data facilitates the approximation of global radiation. And the execution of the empirical models is assessed using statistical error tests and in the end following the observations, it's declared that ANN model was reliable and accurate.

Keywords Sun's global radiation · Statistical error · Empirical models · ANN model

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1 Introduction

India is blessed with rich resources of solar energy. The mean intensity of the sun's radiation received is 200 MV/km^2 but utilizing this energy efficiently is a crucial challenge. Sun's global radiation data is vital for optimal design of the prediction of system performance and measured sun's radiation data is the best source for accurate values of sun's global radiation. The precise way to measure this is by using pyranometers but they are expensive and require high maintenance. The second best method was to develop empirical models to approximate the radiation for locations where measurement was difficult. This work focuses on estimating the sun's radiation data on a parallel plane surface for city Visakhapatnam located in India. The data for irradiance was taken from national solar radiation database. The measured monthly global radiation was taken from national solar radiation database and the regression constants for b and a are taken as 0.47 and 0.28, respectively (Sukhatme and Modi) [1]. Measured data is compared between the following models: (i) Rietveld [2], (ii) Ogleman [3], (iii) Akinoglu [4], (iv) Glover [5], (v) Gopinathan [6], (vi) Linear Regression [7], (vii) ANN (Artificial Neural Network) model, to find out which is the uttermost efficient for modelling of sun's global radiation on the parallel plane surface. There are several models to approximate the monthly and daily mean sun's global radiation in various regions by various combinations of measured parameters. And the accessibility of a solar radiation model, in a specific region, proves to be worthy in predicting the aggregate value of power that would be generated from a particular solar energy system. The area used for our study is Visakhapatnam, located in India, which is the most populated city of Andhra Pradesh. Next to Chennai, Visakhapatnam is the largest city in the eastern coast of South India. It is located at 17.68 N, 83.21 E and is 28 m above sea level. Since it's a coastal area it has higher temperatures than the other parts of the state. It has a wet and dry climate and the mean temperature varies between 24.7 and 30.6 °C. The weather conditions of this study area is tropically savanna type and its temperature remains unchanged (avg. 30 °C) due to proximity of the ocean Bay of Bengal. Basic ideology: Solar radiation extends out to the earth's surface in the manner of direct solar radiation, diffuse solar radiation and reflected radiation. Sun's radiation received over the external surface of the earth's aerosphere is called as extraterrestrial radiation. The average solar irradiance value is 1361 W/m^2. The angle formed between the plane, the perpendicular to a line between earth's axis, sun and the earth is acknowledged as the sun's angle of decline. On a clear sunny day at noon, around 25% of sun's radiation is dispersed and absorbed as it progresses through into the atmosphere. Hence, only 1000 W/m^2 of incident radiation arrives at the earth's surface. The source of the radiation occurs straight from one of the biggest stars, i.e. the sun and so it's known as direct irradiance (or beam irradiance).

Figure 1 shows the outline of the measures followed to estimate the almost suitable model for estimating the global radiation.

Figure 2 shows the variance in generation of solar energy for the state of Andhra Pradesh, India for all months.

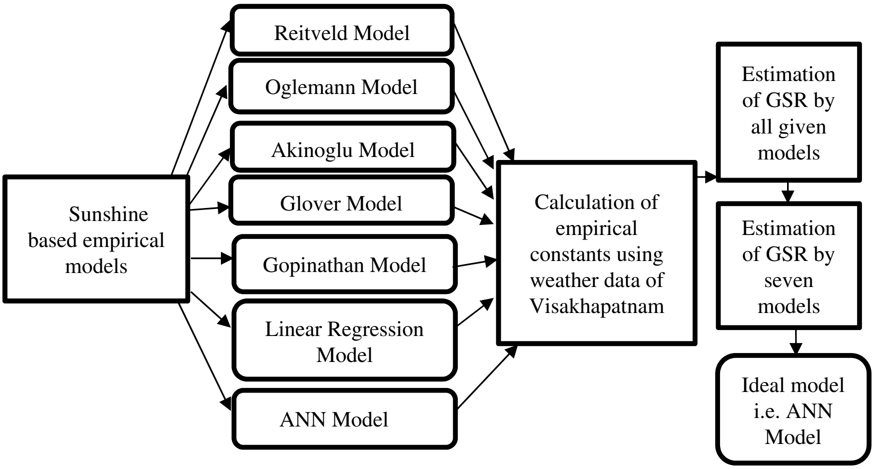

Fig. 1 Outline of procedure followed to evaluate best suitable model

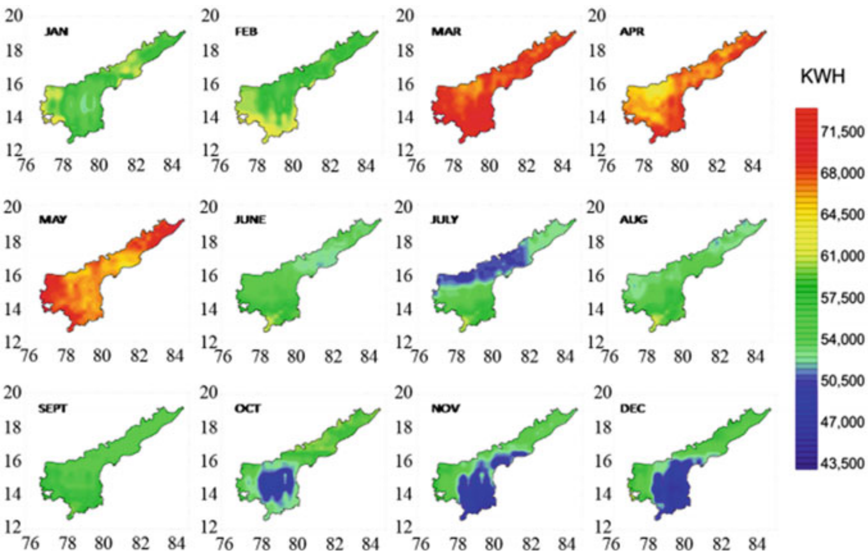

Fig. 2 Solar energy generation per month for Andhra Pradesh state, India, showing the variation in different months. *Source* Solar GIS

2 Estimating Sun's Global Radiation

The monthly mean daily radiation, I_0 is calculated by

$$I_0 = \frac{24 \times 3600}{\pi} I_{sc}\left[1 + 0.033\cos\left(\frac{360D}{365}\right)\right] \times \left(\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right)\text{kWh/m}^2\,\text{day}^{-1} \quad (1)$$

Here I_{sc} is equal to 1.367 kW/m^2 and is known as solar constant, [8], D is the day, ω_s is the sunshine hour angle of an average day of the month (in degrees), ϕ is the latitude angle (in degrees) and δ (in degrees) is the angle of declination.

The angle of declination, δ can be represented by Cooper's equation [9]

$$\delta = 23.34\sin\frac{360}{365}(284 + D) \quad (2)$$

The sunshine hour angle (ω_s) for a particular site depends upon the angle of declination and the latitudinal location and is represented by [10]

$$\omega_s = \cos^{-1}(-\tan\delta\,\tan\phi) \quad (3)$$

The mean daily radiation (on a monthly basis) on a parallel plane surface I_d, as described by Angstrom [11] is:

$$\frac{I_d}{I_0} = a + b\left(\frac{S}{S_o}\right) \quad (4)$$

S represents the average sunshine hours on a monthly basis, S_0 is the maximum probable sunshine hours, b and a are two-angstrom constants, familiarly noted as regression coefficients.

Here $a = 0.28$ and $b = 0.47$ (Modi and Sukhatme) [1] for Visakhapatnam.

S_0 is the highest probable monthly mean sunshine hours, can be derived from

$$S_0 = \left(\frac{2}{15}\right)\omega_s \quad (5)$$

S is the mean daily sunshine hours, S_0 is the possible sunshine duration (Fig. 3).

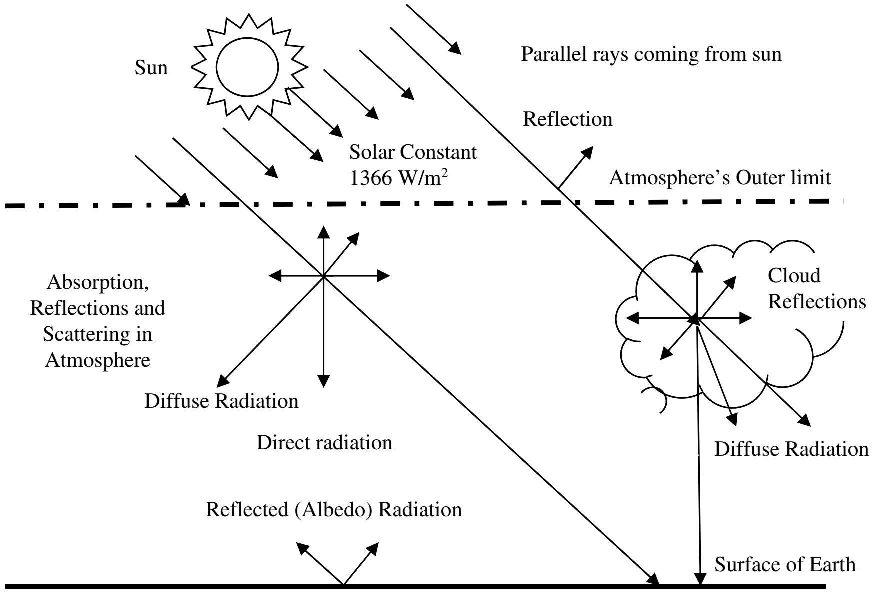

Fig. 3 Total Sun's global radiation. *Source* Solar Radiation Handbook [12]

3 Various Models' Descriptions for Predicting Sun's Global Radiation

The following seven models are being used for the study to predict the monthly mean sun's global radiations on a parallel plane surface for the city Visakhapatnam.

3.1 Reitveld Model

Reitveld [2] observed that a relationship exists amongst the regression coefficients (b, a) and the mean relative sunshine duration. He stated that his model gave an estimation that is twice as accurate for $\frac{S}{S_0}$, with the condition: $\frac{S}{S_0} < 0.4000$.

$$\frac{I_\mathrm{d}}{I_0} = \left(\frac{S}{S_0}\right) b + a \tag{6}$$

3.2 Ogleman Model [3]

The model described by Ogleman observed that standard deviation of sunshine duration for better model parameter estimation and formulated a quadratic relation for solar radiation:

$$\frac{I_\mathrm{d}}{I_0} = \left(\frac{S}{S_0}\right)b + a - \left(\frac{S}{S_0}\right)^2 c \tag{7}$$

3.3 Akinoglu Model

Ecevit and Akinoglu [4] formulated a correlation in quadratic equation form to predict the values of sun's radiation and took same values for a and b. The equation is as:

$$\frac{I_\mathrm{d}}{I_0} = \left(\frac{S}{S_0}\right)b + a - \left(\frac{S}{S_0}\right)^{-2} c \tag{8}$$

3.4 Glover Model

Glover and McCulloch [5] presented the variation by latitude of the regression coefficients, b and a in the conventional equation of Angstrom type:

$$\frac{I_\mathrm{d}}{I_0} = \left(\frac{s}{s_0}\right)b + a \tag{9}$$

$$\frac{I_\mathrm{d}}{I_0} = 0.52\left(\frac{s}{s_0}\right) + 0.29\cos\phi \tag{10}$$

3.5 Gopinathan Model

Gopinathan [6] presented the variation as latitudinal location, air temperature, the site's elevation and the average relative humidification.

$$\frac{I_\mathrm{d}}{I_o} = \left(\frac{S}{S_0}\right)b + a \tag{11}$$

3.6 Linear Regression Model

Linear Regression model [7] is developed from Angstrom [11] and Prescott [7], Angstrom [11] equation modifies as

$$\frac{I_{\mathrm{d}}}{I_0} = a + b\left(\frac{S}{S_0}\right) \quad (12)$$

3.7 Artificial Neural Network (ANN) Model

ANN imitates the exact nature of the biological neural networks functioning in the brain. Neurons are the basic blocks of any Artificial Neural Network and in well-defined terms are known as the interconnected identical processing units which are countless in number. Global radiation was estimated by Emad using Artificial Neural Network (ANN) method based on the location coordinates, number of days and sunshine hours. A basic neural network has an input layer, a hidden layer and lastly an output layer. Other than these they also have transfer function, weight and a neuron. ANN models using Artificial neural networks are applied for prediction, simulation, forecasting bankruptcy situations, diagnosis of tumour issues, non-linear mapping, pattern recognition, classification and non-linear mapping. Input parameters are the neurons that form the input layer. The mean sun's daily global radiation on a monthly basis depicts a single neuron in the output layer (Fig. 4).

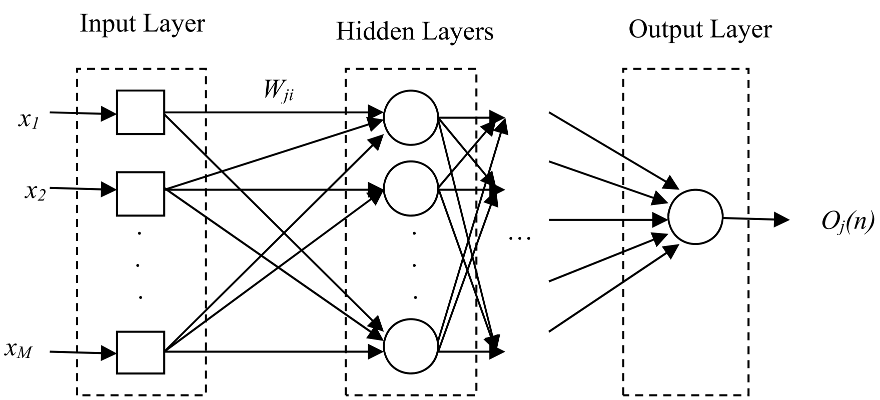

Fig. 4 Basic architecture of ANN model [13]

4 Validation of Models with Statistical Errors

For assessing, comparing and analyzing all the average global radiation approximation models, there are various parameters [14].

4.1 Mean Bias Error (MBE)

MBE test is applied for finding out the error between the calculated and measured data and provides information on long-lived performance. A positive value shows overrated result and a negative value shows underrated result and ideally, it should always be zero. One negativity of the MBE test is that underestimation in one observation gets cancelled by the overestimation in another observation.

$$\text{MBE} = \frac{1}{S}\sum_{1}^{S} I_{i,\text{calc}} - I_{i,\text{meas}} \tag{13}$$

4.2 Mean Percentage Error (MPE)

The difference in the mean daily sun's global radiation data, being approximated by the models taken from the measured values is known as mean percentage error. Deviation is in percentage form and is also used in forecast errors. An MPE *r* between −10% and +10% is considered acceptable.

$$\text{MPE} = \frac{1}{S}\sum_{1}^{S}\left[\frac{\left(I_{i,\text{calc}} - I_{i,\text{meas}}\right)}{I_{i,\text{meas}}}\right] \times 100 \tag{14}$$

4.3 Root Mean Square Error (RMSE)

RMSE measures the average mismatch amid the measured and calculated data and produces results on short-lived performance. It gives a value of the level of disperse produced by the model of regression and explains the repeatability and readability of the model. The RMSE value should be closer to zero and is always positive [15].

$$\text{RMSE} = \left[\frac{1}{S}\sum_{1}^{S}\left(I_{i,\text{calc}} - I_{i,\text{meas}}\right)^2\right]^{1/2} \tag{15}$$

4.4 The Nash–Sutcliffe Equation (NSE)

Any model is highly functioning when the value of NSE is closer to 1. For enhanced results and reformed comparison, this parameter has also opted as an evaluation criterion [16].

$$\mathrm{NSE} = 1 - \frac{\sum_{1}^{S}\left(I_{i,\mathrm{calc}} - I_{i,\mathrm{meas}}\right)^2}{\sum_{1}^{S}\left(I'_{\mathrm{meas}} - I_{i,\mathrm{meas}}\right)^2} \tag{16}$$

4.5 Mean Absolute Percentage Error (MAPE)

To overcome the drawback of MBE test, MAPE is conducted. The MAPE avoids the error cancellation problem which is frequently observed in MBE. The accuracy is been shown in percentage form. It represents the absolute mean deviation in percentage form between the calculated and measured values [17].

$$\mathrm{MAPE} = \frac{1}{S}\sum_{1}^{S}\left|\frac{I_{i,\mathrm{meas}} - I_{i,\mathrm{calc}}}{I_{i,\mathrm{meas}}}\right| \tag{17}$$

4.6 t-Statistics Test

The *t*-test was introduced aby Stone (1993) and allows the comparison of models at the same time as MBE and RMSE may not be sufficient for assessing the outcome of the model [18]. It determines the statistical importance of the approximated value on a more accurate level. The analytical *t* value is to be estimated from standard statistical tables. The approximated *t* value must be less than the analytical value as the model will perform better for smaller values [19].

$$t = \left[\frac{(S-1)\mathrm{MBE}^2}{\mathrm{RMSE}^2 - \mathrm{MBE}^2}\right]^{1/2} \tag{18}$$

Table 1 Comparison between measured and approximated mean Sun's global radiation data (MJ m^{-2} day^{-1}) on a monthly basis for city Visakhapatnam, India

Month	Rietveld model	Ogleman model	Akinoglu model	Glover model	Gopinathan model	Linear regression model	ANN model	Measured data
Jan	18.871	18.022	17.949	18.996	18.479	16.758	17.432	17.422
Feb	21.599	20.747	20.7	21.819	21.237	19.092	19.77	20.01
Mar	22.293	21.623	21.647	22.756	23.198	20.13	21.72	21.82
Apr	24.831	24.038	24.045	25.332	24.578	22.73	22.81	22.99
May	24.421	23.991	24.073	25.215	24.678	21.92	22.14	22.18
Jun	17.064	17.713	17.458	19.062	19.685	16.25	17.28	17.49
Jul	15.561	17.203	16.802	18.562	19.472	16.777	16.01	16.02
Aug	16.764	17.464	17.07	18.865	19.705	16.534	16.53	16.35
Sept	17.568	18.02	17.921	19.106	19.547	16.728	16.94	17.06
Oct	18.153	18.132	18.481	19.011	18.988	16.931	17.65	17.62
Nov	17.771	15.668	17.121	18.039	17.629	15.781	16.31	16.4
Dec	17.851	15.588	16.963	17.964	17.485	15.841	16.26	16.32

5 Result Analysis

Table 1 given represents a comparison between the measured and approximate data of mean sun's global radiation per month of each individual model.

Figure 5 shows the graphic presentation of the measured and approximated value of mean global solar radiation per month of each individual model under consideration in study area.

The below-given Table 2 shows the calculated data of the statistical error parameters (MBE, MPE, NSE, MAPE, RMSE and *t*-stat) for each individual model under consideration at the mentioned area of study, i.e. Visakhapatnam [22–25].

Figure 6 shows the graphical representation of the statistical error parameters (MBE, MPE, NSE, MAPE, RMSE and *t*-stat) for each individual model under consideration at study area [26–28, 29].

6 Conclusion

Accessing global data of sun's solar radiation has become a necessity for affordable design and efficient implementation of solar energy. However, in many locations, measuring instruments are unavailable, so atmospheric parameters are being used to estimate the global radiation in that particular region. Seven empirical models in addition to ANN are considered in the paper and validated to approximate the mean global radiation received per month on a parallel plane surface in Visakhapatnam,

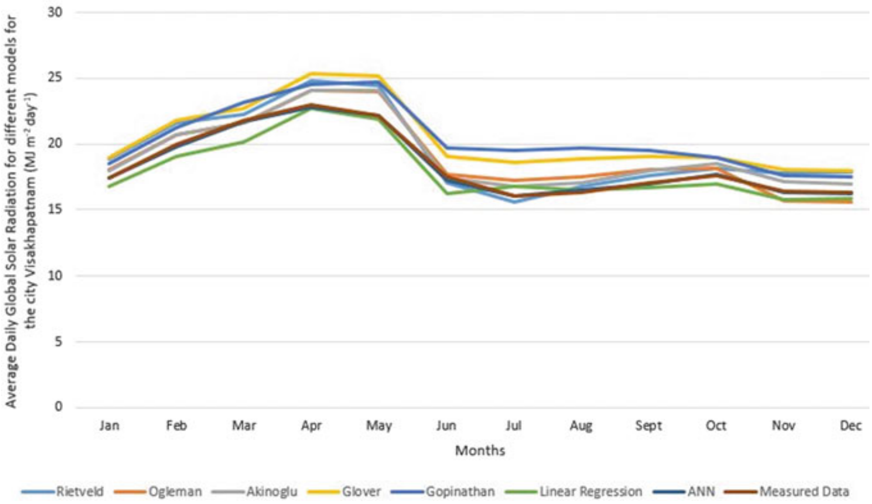

Fig. 5 The approximated and measured mean Sun's global radiation on a monthly basis for city Visakhapatnam, India [20, 21]

Table 2 The calculated data of the statistical parameters for all models at Visakhapatnam, India

Statistical errors	Rietveld model	Ogleman model	Akinoglu model	Glover model	Gopinathan model	Linear regression model	ANN model
MBE	0.9221	0.5439	0.7123	1.9204	1.9166	−0.5180	−0.0690
MPE	0.0479	0.0283	0.0385	0.1054	0.1069	−0.0270	−0.0030
RMSE	1.2446	0.9249	0.8673	2.0019	2.0856	0.7967	0.1308
NSE	0.7417	0.8573	0.8746	0.3317	0.2746	0.8942	0.9971
MAPE	0.0568	0.0448	0.0401	0.1054	0.1069	0.0366	0.0057
t-stat	3.6583	2.4115	4.7746	11.2680	7.7282	2.8334	2.0664

situated in Andhra. And most appropriate model is selected for the above-given location.

On the basis of available climatic parameters of sun-light hours, lowest and highest temperature and relative humidification these models were studied. As per the statistical evaluation of the empirical models, ANN was determined to be far more accurate and advanced in comparison with the other models; hence it could be utilized in approximation of global solar radiation in Visakhapatnam and also for the places having similar weather conditions.

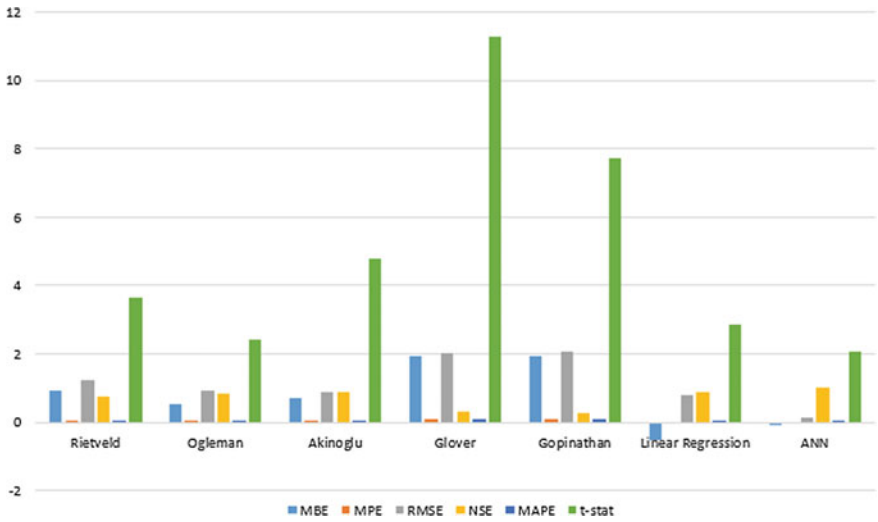

Fig. 6 Estimation of MBE, MPE, NSE, MAPE, RMSE and *t*-stat for all prescribed models [30–34]

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