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A COMPARISON OF EMPIRICAL MODELS AND ANN METHOD FOR ESTIMATION OF MONTHLY GLOBAL SOLAR RADIATION AT VIJAYAWADA, INDIA

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Abstract : Evaluation of Sun's radiation is really an important aspect for evaluating the global solar radiation of sun, as it gives the entire solar availability at a given location and can be calculated by using different empirical models as well by using measuring equipments. Unfortunately, many areas cannot measure solar radiation due to maintenance issues and the high cost of the equipment used for measuring it. Hence, empirical models were established as a substitute to roughly calculate the solar radiation datas. 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 are 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

I. INTRODUCTION

India is endowed with rich solar energy resources. The average solar radiation intensity is 200MV/km2 but effectively using this energy is an important challenge. Earth radiation information from the sun is important for optimal system performance planning, and solar radiation data are the best source for determining the true value of solar radiation. The correct way to measure this is to use a pyranometer, which is expensive and requires a high degree of maintenance. The second best method was to develop empirical models so that the estimated radiation could be measured for areas where it is difficult to measure. This work focuses on estimating the Sun's irradiance data on a parallel flat surface for the city of Vijayawada in India. Radiation data is obtained from the National Solar Radiation Base. The measured monthly terrestrial radiation comes from the National Solar Radiation Database and the regression constants for b and a are 0.47 and 0.28 respectively (Sukhatme & Modi) [5].

The measured data were compared between the following models:
i. Rietveld [2], ii. Ogleman [9], iii. Akinoglu [4], iv. Glover [16], v. Gopinathan [3], vi. Linear Regression [1], vii. ANN (Artificial Neural Network) model, to find out what is most effective for global solar radiation models on a parallel surface. There are many models that can compare the average of each month and day in the solar system over several regions using different combinations of measurement parameters. And the availability of a solar pattern in a particular area proves valuable in predicting the total value of energy produced by a particular solar system. The area used for our research is Vijayawada, located in India, the most populous city in Andhra Pradesh. It is located at 16.5062^{0}N, 80.6480^{0}E and 11 m above the surface of the sea. It has a humid and dry climate and the average temperature varies between 24.8 and 34.0°C. The climatic conditions in this study area are tropical savanna type and close to the Bay of Bengal the temperature remains unchanged (average 28.2 ° C). Average value of solar radiation extends to the Earth's surface as direct solar radiation, diffuse solar radiation and reflected radiation. The solar radiation received on the outer surface of the Earth's aerosphere is called extraterrestrial radiation. The average value of irradiance is 1361 watts/meter^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).

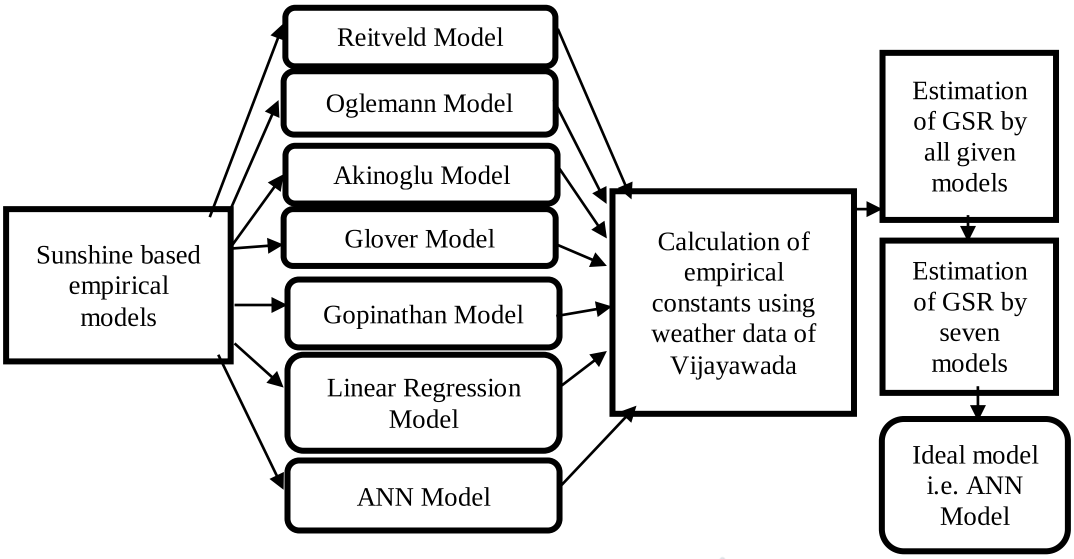

Figure 1 Outline of procedure followed to evaluate best suitable model

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

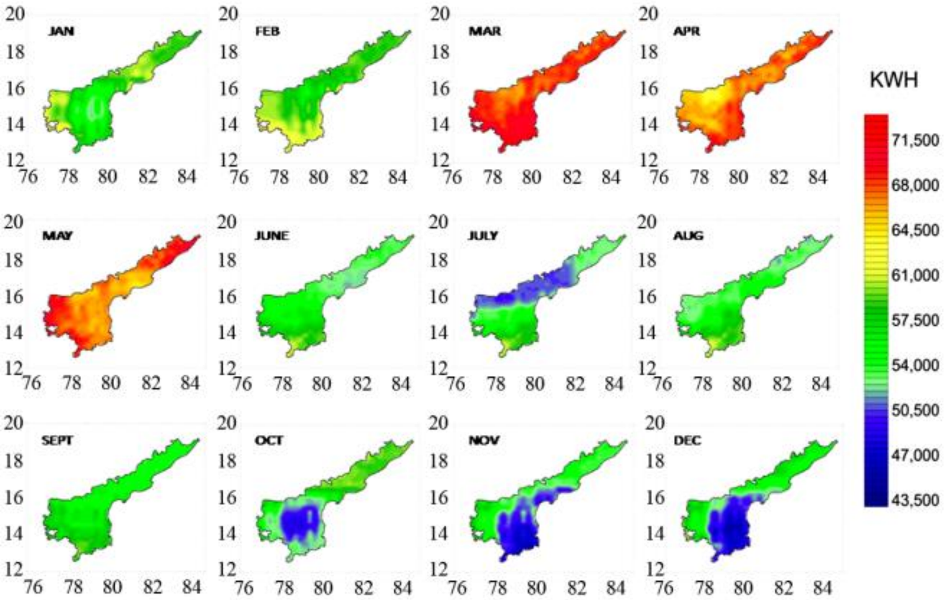

Figure 2 Solar energy generation per month for Andhra Pradesh state, India, showing the variation in different months [source: Solar GIS]

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

2. ESTIMATING SUN'S GLOBAL RADIATION

The monthly mean daily radiation, I_0 is calculated by

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

Here I_{sc} is equal to 1.367 kW/m^2 and is known as solar constant, [10], 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 [6]

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

The sunshine hour angle (ω_s) for a particular site depends upon the angle of declination and the latitudinal location and is represented by [7]

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

The mean daily radiation (on a monthly basis) on a parallel plane surface I_d , as described by Angstrom (1924) [8] is:

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

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) [5] for Vijayawada.

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

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

S is the mean daily sunshine hours, S_0 is the possible sunshine duration.

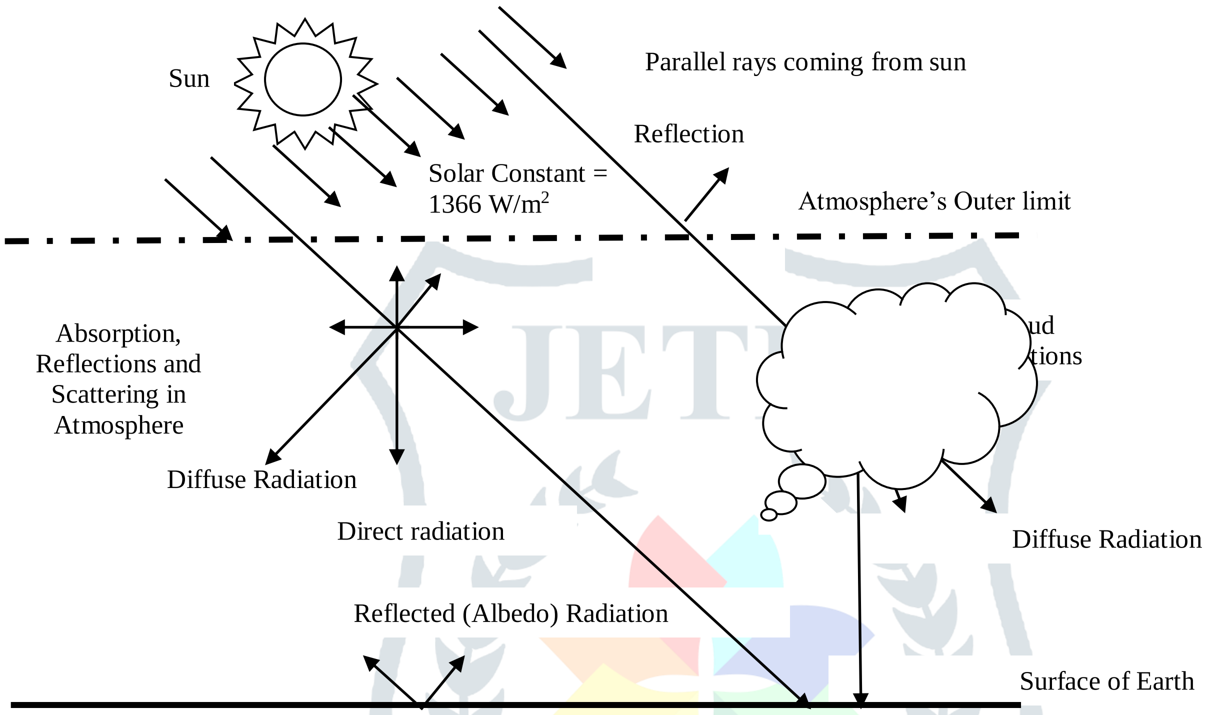

Figure 3 Total Sun's Global Radiation [source: Solar radiation handbook-2008]

2. Various models' description 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 Vijayawada:

2.1 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: $\frac{S}{S_0} < 0.4000$.

$$\frac{I_d}{I_0} = (\frac{S}{S_0})b + a \quad (6)$$

2.2 Ogleman model [9]

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

$$\frac{I_d}{I_0} = \left(\frac{S}{S_0}\right)b + a - (\frac{S}{S_0})^2 c \quad (7)$$

2.3 Akinoglu model

Ecevit and Akinoglu (1990) [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:

$$\frac{I_d}{I_0} = \left(\frac{S}{S_0}\right)b + a - (\frac{S}{S_0})^{-2} c \quad (8)$$

2.4 Glover model

Glover and McCulloch [16] presented the variation by latitude of the regression coefficients, b and a in the conventional equation of Angstrom type:

$$\frac{I_d}{I_0} = (\frac{s}{s_0})b + a \quad (9)$$

$$\frac{I_d}{I_0} = 0.52(\frac{S}{S_0}) + 0.29cos\phi \quad (10)$$

2.5 Gopinathan model

Gopinathan [3] presented the variation as latitudinal location, air temperature, the site's elevation and the average relative humidification.

$$\frac{I_d}{I_o} = \left(\frac{S}{S_0}\right) b + a \quad (11)$$

2.6 Linear Regression model

Linear Regression model [1] is developed from Angstrom, (1924) and Prescott (1940) [17] equation modifies as

$$\frac{I_d}{I_0} = a + b\,(\frac{S}{S_0}) \quad (12)$$

2.7 Artificial Neural Network (ANN) model

Artificial neural networks mimic the exact functionality of biological neural networks. Artificial Neural Networks are built with neurons, which in well-defined terms are identical clusters of interconnected 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. Applications of Artificial Neural Network models are applied for prediction, simulation, forecasting bankruptcy situations, diagnosis of tumor issues, pattern recognition, classification and non-linear mapping. Input parameters are the neurons which form the input layer. The mean Sun's daily global solar radiation on a monthly basis depicts a single neuron in the output layer.

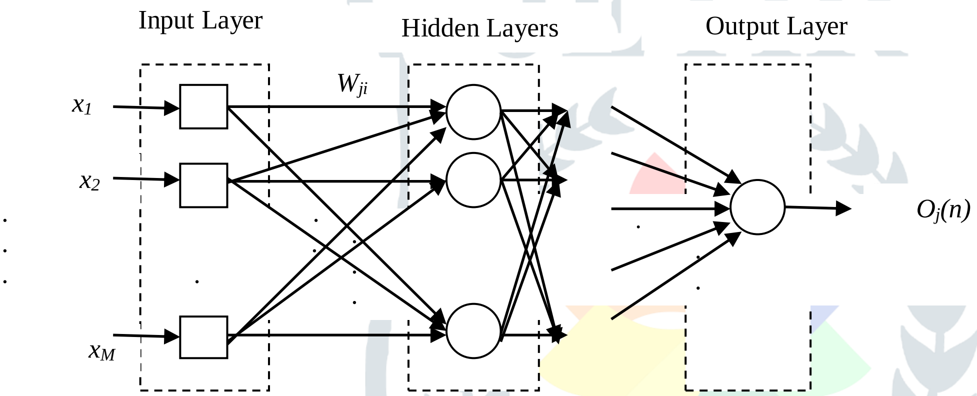

Figure 4 Basic Architecture of ANN model [32]

3. VALIDATION OF MODELS WITH STATISTICAL ERRORS

For assessing, comparing and analyzing all the average global radiation approximation models, there are various parameters [18].

3.1 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 over rated result and a negative value shows under rated 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.

$$MBE = \frac{1}{S}\sum_1^S I_{i,calc} - I_{i,meas} \quad (13)$$

3.2 Mean Percentage Error (MPE)

The difference of 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 also used in forecast errors. A MPE r between −10% and +10% is considered acceptable.

$$MPE = \frac{1}{S}\sum_1^S \left[\frac{(I_{i,calc} - I_{i,meas})}{I_{i,meas}}\right] x\ 100 \quad (14)$$

3.3 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.

$$RMSE = \left[\frac{1}{S}\sum_1^S (I_{i,calc} - I_{i,meas})^2\right]^{1/2} \quad (15)$$

3.4 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 is also opted as an evaluation criterion.

$$NSE = 1 - \frac{\sum_1^S (I_{i,calc} - I_{i,meas})^2}{\sum_1^S (I'_{meas} - I_{i,meas})^2} \quad (16)$$

3.5 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.

$$MAPE = \frac{1}{S}\sum_1^S \left|\frac{I_{i,meas} - I_{i,calc}}{I_{i,meas}}\right| \quad (17)$$

3.6 t-Statistics test

The t - test was introduced by 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. 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 value.

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

4. RESULT ANALYSIS

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

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

The figure 5 shows the graphic presentation of the measured and approximated value of mean global solar radiation per month of each individual models under consideration at study area.

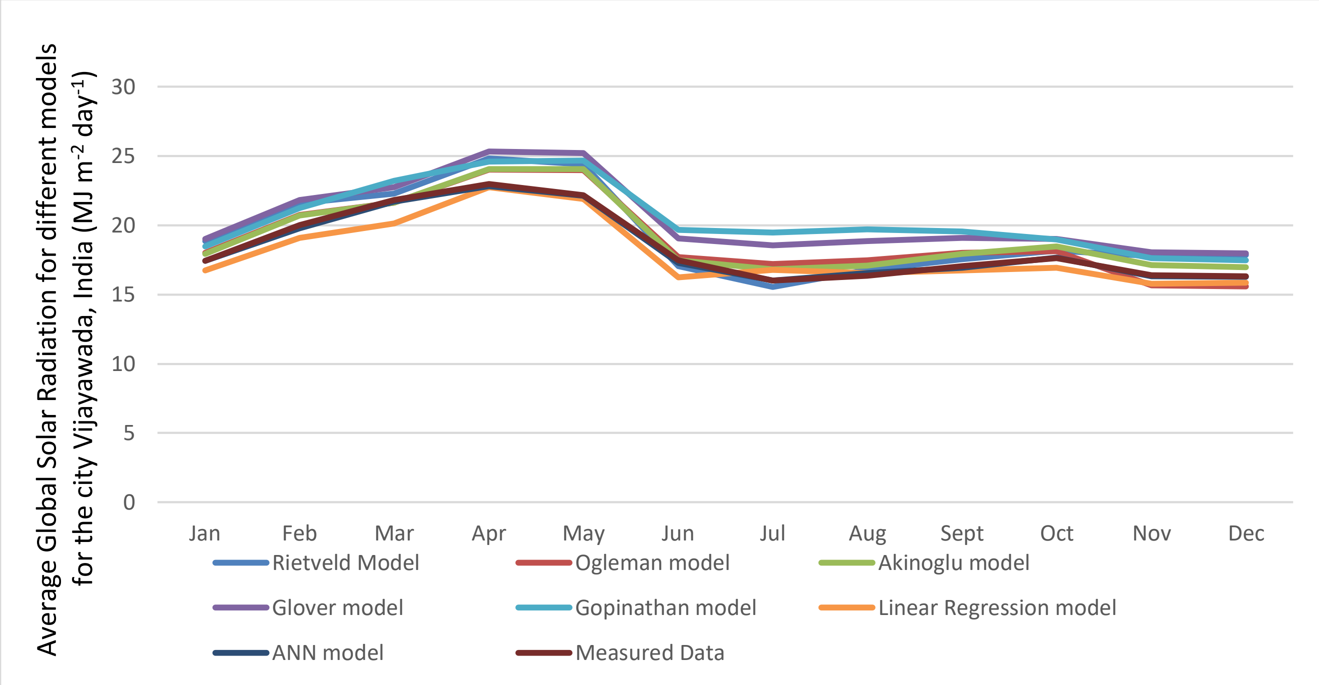

Figure 5 The approximated & measured mean Sun's global radiation on a monthly basis for city Vijayawada, India

The below given table shows the calculated data of the statistical error parameters (MBE, MPE, NSE, MAPE, RMSE and t-stat) for each individual models under consideration at the mentioned area of study i.e., Vijayawada.

Table 2. The calculated data of the statistical parameters for all models at Vijayawada, 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

The 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.

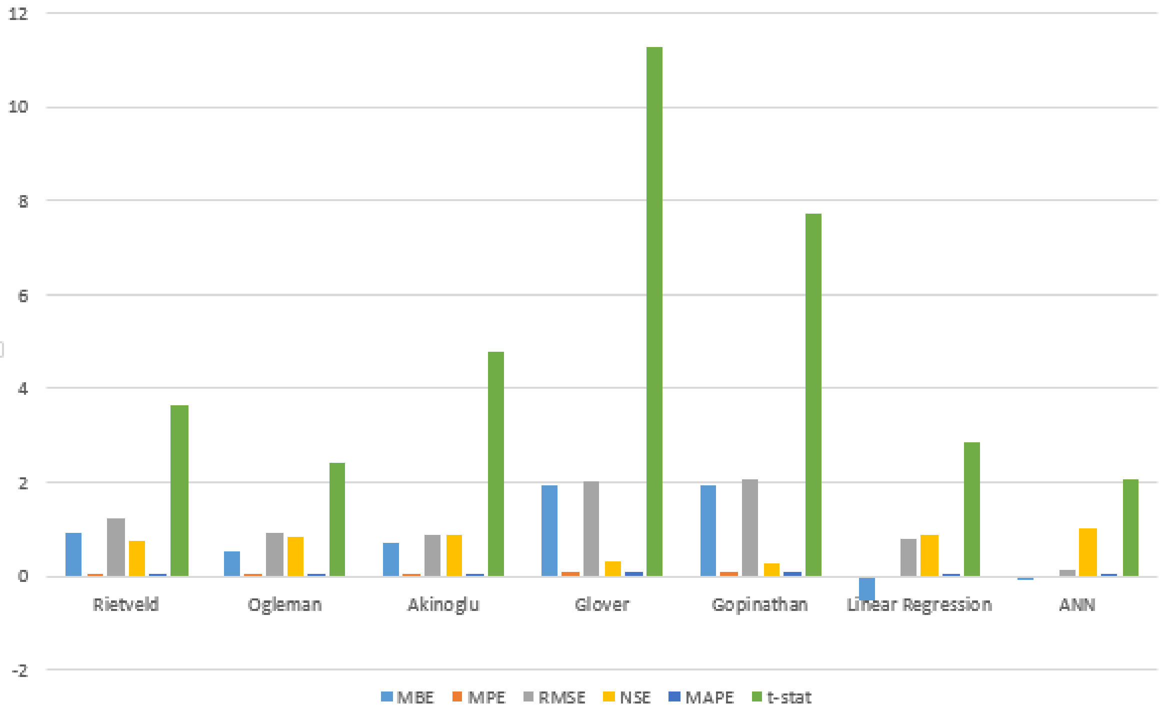

Figure 6 Estimation of MBE, MPE, NSE, MAPE, RMSE & t-stat for all prescribed models

5. CONCLUSION

In order to design and implement solar energy in an efficient and affordable way, global data of the sun's solar radiation is essential. Atmospheric parametric values are being utilised to calculate the global solar radiation due to unavailability of measuring instruments in many locations. Here in this research work we have considered seven empirical models along with ANN method to estimate & validate the mean monthly global solar radiation received on a parallel plane surface in Vijayawada, India. And the most appropriate model is selected for the above given location.

Considering the available climatic parameters of sunlight hours, lowest and highest temperature, and relative humidification these models were studied. As per the statistical evaluation of the empirical models, ANN was found to be far more accurate and advanced in comparison to the other models; hence it could be utilised in approximation of global solar radiation in Vijayawada and also for the places having similar weather conditions.

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