ESTIMATION OF GLOBAL SOLAR RADIATION USING SUNSHINE AND TEMPERATURE BASED MODELS OVER ANANTAPUR REGION

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Abstract: The measurement of the different meteorological parameters such as wind speed, direction, air temperature, relative humidity, rainfall and sunshine hour was collected from MOSDAC (Meteorological and Oceanographic Satellite data Archive Center) and the instrument Phyranometer gave the incoming global solar radiation (GSR) data on the horizontal surface over a period of January 2015 to August 2016 at Anantapur (Latitude 14.62° N, Longitude 77.65° E and altitude 331 m asl). The objective of this study is to performance of sunshine, air temperature dependent models for the estimation of global solar radiation and comparison assessment of the models was carried out using measured global solar radiation over Anantapur region. Sunshine and temperature models have been employed to estimate the monthly average global solar radiation on horizontal surface using monthly mean sunshine hour data and minimum and maximum temperatures. The result showed that all the models could predict very well pattern of the measured monthly daily mean global solar radiation. Estimated global solar radiation values were compared with measured values based on statistical indicators such as mean bias error (MBE), mean percentage error (MPE), root mean square error (RMS), coefficient of correlation (R), coefficient of determination (R^2) and coefficient of residual mass (CRM). Nevertheless, a very good agreement was found between the measured radiations and the proposed models with a coefficient of determination within the range 0.7–0.86 for both sunshine and temperature models.

Keywords: Global solar radiation, meteorological parameters, temperature, sunshine hour.

I. Introduction

Solar energy is primarily derived from solar radiation reaching the surface of the earth. Solar radiation is an electromagnetic radiation of varying wavelengths ranging from 10^{-6}µm (γ-rays) to10^{8} µm (radio waves) (**Adeyefa and Adedokun, 1991)**. The terrestrial solar spectrum deviates from extra-terrestrial spectrum because of various absorptions in the earth's atmosphere **(Ugwuoke and Okeke, 2012)**. Radiation from the sun views life on earth and determines climate it means the sun is the primary source of the energy for earth climate system and energy balance. The sun warms the planet, initiatives the hydrologic cycle and makes life on earth possible **(Ramamohana reddy, 2017, Ramamohana reddy, 2018)**. The amount of sunlight received on earth surface is exaggerated by the reflectivity of the surface, the angle of the sun, the output of the sun and the cyclic variations of the earth's orbit around the sun. The energy flow within the sun results in a surface temperature of around 5800 K, so the spectrum of the radiation from the sun is similar to that of a 5800 K blackbody with fine structure due to absorption in the cool peripheral solar gas.

Sunshine duration is the length of time that the ground surface is irradiated by direct solar radiation. The World Meteorological Organization (WMO) defined sunshine duration as the period during which direct solar irradiance exceeds a threshold value of 120 watts per square meter (W/m2). This value is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions. The global solar radiation reaching the earth's surface is made up of two components, direct and diffuse. The total quantity of short wave radiant energy emitted by the suns disc as well as that scattered diffusively by the atmosphere and cloud, passing through a unit area in the horizontal in unit time is referred generally as global solar radiation. Monitoring the daily global solar radiation will help in assessing the total solar energy at any location considering diurnal and seasonal variations. Near noon on a day without clouds, about 25% of the solar radiation is scattered and absorbed as it passes through the atmosphere. Therefore about 1000 W/m^2 of the incident solar radiation reaches the earth's surface without being significantly scattered. This radiation, coming from the direction of the sun, is called direct normal irradiance (or beam irradiance). Some of the scattered sunlight is scattered back into space and some of it also reaches the surface of the earth. The radiation which is scattered by the atmospheric constituents such as molecules, aerosols and clouds is called diffuse radiation. Solar radiation incident on the earth's surface in the visible and near - infrared wavelength range 0.3 µm – 2.0 µm is measured on the ground by means of Pyranometer. Unfortunately, the solar radiation measurements are not always available due to the cost of the measuring equipment. Thus solar radiation models are desired to predict the solar radiation by using models and empirical correlations **(Prescott, 1940)**. Several empirical models have been proposed to estimate the global solar radiation, using meteorological, climatological parameters such as sunshine hour, minimum and maximum temperature, relative humidity, cloud cover, precipitation and rain fall. The most commonly used method for estimating the global solar radiation is the sunshine hour because it is easily measured and widely available **(Teke et al., (2014), Mecibah et al., (2014), Khorasanizadeh (2013), Gana etal., 2013b, Li et al., (2010), Bakirci et al., (2009), Bannani et al., (2006), Angstrom (1924))**. Another model to estimating the global solar radiation was to proposed by using minimum and maximum temperatures (Muhammad **and Darma (2014), Kaltiya**

et al., (2014), Medugu and Yakubu (2011), Agbo et al., (2010), Paulescu et al., (2006), Falayi and Rabiu (2005), Allen (1997), Bristow and Campbell (1984), Hargreaves and Samani (1982)).

This objective of the paper was to assess the suitable of both sunshine hour and maximum and minimum temperature dependent empirical models for the estimation of global solar radiation in Anantapur region. The reliability and usability of these models mainly depends on the correlation between the measured and estimated values. The data obtained from these models were tested for errors using Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE).

II. METHODOLOGY

Meteorological parameters such as wind speed, wind direction, temperature, relative humidity and sun shine hour data were collected from MOSDAC (Meteorological and Oceanographic Satellite data Archive Center) and incoming global solar radiation measurements were carried out from the pyranometer which was installed at our university premises. The actual measurements were carried out at Sri Krishnadevaraya University (SKU, 14.62°N, 77.65°E, 331m asl), from January 2015 to August 2016. Anantapur represents the very dry continental region of Andhra Pradesh, India. Most of the rainfall occurs during monsoon and post monsoon from south-west and north-east monsoons respectively. This region receives very little rainfall, and the average annual rainfall is of order of 450mm (which is about 300mm due to south-west monsoon and 150 mm from north - east monsoon).

The first model is use to estimate the global solar radiation on a horizontal surface based on sunshine model is described by the equation as (**Prescott 1940, Ahmed et al., 2009 and Medugu and Yakubu, 2011)**

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \qquad (1)$$

H is the monthly mean of daily global solar radiation (W/m^2), H_0 is the monthly mean of daily extraterrestrial solar radiation (W/m^2), S is the monthly average daily hours of bright sunshine, S_0 is the monthly average day length and S/S_0 is the relative sunshine, it is found to vary daily and seasonality **(Shears et al., 1981)** and a, b are regression coefficients.

The global solar radiation and sunshine duration vary from day to day, the monthly daily averaged values are used to derive the a and b values. While it is not easy about estimating the daily total amount of global solar radiation on a particular day, by using the sunshine duration method it allow the rough estimation of monthly value.

The estimated values of the monthly mean global solar radiation (H_c) and the regression coefficients are substituted in equation (1) to get the clearness index.

In this research, the global solar radiation models are classified according to the basis of their input parameters employed in correlating with the clearness index (k_t) **(Rama Gopal et al., 2016)**. It point outs the depletion of the incoming global solar radiation by the atmosphere and therefore it gives both the level of availability of solar irradiance at the surface of the earth and the changes in atmospheric conditions **(Nwokolo et al 2017)**.

$$k_t = \frac{H}{H_0} \qquad (2)$$

The monthly daily extraterrestrial solar radiation on a horizontal surface (H_0) (MJm^{-2}day^{-1}) can be computed from the model of **Deffie and Beckman (1991)** as follows,

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \qquad (3)$$

where H_o extraterrestrial radiation [MJm^{-2}day^{-1}], G_{sc} solar constant = 0.0820 MJm^{-2} min^{-1}, d_r inverse realtiave distance Earth-Sun, ω_s sunset hour angle (rad), φ latitude (rad), δ solar declination (rad).

H_o is expressed in the above equation in MJm^{-2} day^{-1}. The corresponding equivalent evaporation in W/m^2 is obtained by multiplying H_o by 11.6.The latitude; φ expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$[\text{Radians}] = \frac{\pi}{180}[\text{decimaldegree}] \qquad (4)$$

The inverse relative distance Earth-Sun, d_r and the solar declination, δ are given by:

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \qquad (5)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \qquad (6)$$

The sunset hour angle, ω_s is given by:

$$\omega_s = \arccos[-\tan\varphi\tan\delta] \qquad (7)$$

Monthly average day length (S_0) is:

$$S_0 = \frac{2}{15}\omega_s \qquad (8)$$

Estimation of global solar radiation using sunshine based models

The sunshine duration is a most commonly used parameter to estimating the global solar radiation. This is because sunshine hours can be easily and reliably measured and data are widely available. Most of the models for estimating solar radiation use sunshine ratio for prediction of monthly average daily global solar radiation. The models are **(Prescott 1940, Ogelman et al., 1984, El-Metwally, 2004 and Bakirci, 2009).**

(1) Angstrom- Prescott model

This model (Prescott, 1940) is the most commonly used model and it is given by

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \qquad (9)$$

Where H is the monthly mean global solar radiation (W/m^2), H_0 is the extraterrestrial solar radiation (W/m^2), S is the actual sunshine duration (hours), S_0 is the maximum day length (hours) and the values a and b are regression coefficients obtained from the graph of H/H_0 against S/S_0.

(2) Ogelman et al model

Ogelman developed following model for estimating global solar radiation **(Ogelman, 1984)**.

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 \qquad (10)$$

Where a, b and c are regression coefficients.

(3) El-Metwally model

The following model was developed by El-Metwally for estimating global solar radiation **(El-Metwally, 2005)**.

$$\frac{H}{H_0} = a^{\left[\frac{1}{\frac{S}{S_0}}\right]} \qquad (11)$$

where a is regression coefficient.

(4) Bakirci exponential model

Bakirci developed the following model for estimating global solar radiation **(Bakirci,2009).**

$$\frac{H}{H_0} = a\left(\frac{S}{S_0}\right)^b \qquad (12)$$

Where a and b are regression coefficients.

Estimation of global solar radiation using temperature based models

The Hargreaves and Samani (1982) and the Garcia (1994) models are both temperature based models as they employ maximum and minimum temperatures (temperature range) as the required meteorological data.

(1) Hargreaves and Samani model

This model gives relation between clearness index and thermal amplitude ΔT based on the specification of an empirical coefficient of proportionality (k_r) and depends on the location and altitude of the station **(Allen et al., 1998)**.This is given by the relation

$$\frac{H}{H_0} = k_r\left(T_{max} - T_{min}\right)^{0.5} \qquad (13)$$

$$k_r = k_{r_0}\left(\frac{p}{p_0}\right)^{0.5} \quad \text{and} \quad \frac{p}{p_0} = Exp(-0.0001184 \ * h)$$

where H is the estimating global solar radiation (W/m^2), H_0 is the daily mean value of extraterrestrial solar radiation (W/m^2), T_{max} and T_{min} are the daily mean values of maximum and minimum temperatures (^0c), k_r is the adjustment coefficient , k_{ra} is the empirical coefficient for arid and semi-arid regions it is initially taken as 0.17 and P and P_0 are mean atmospheric pressure at site (k pa)and mean atmospheric pressure at sea level (101.3k pa) and h is the altitude of the site in meters **(Chandel et al., 2005)**.

(2)Garcia model

Garcia model (1994) is one of the single parameter for estimating global solar radiation. This model is an adaptation of the Angstrom- Prescott model, clearness index or global solar radiation is correlated with difference between maximum and minimum temperatures (ΔT) is expressed in the form of **(Abdulsalamet al.2014)**

$$\frac{H}{H_0} = a + b\left(\frac{\Delta T}{S_0}\right) \qquad (14)$$

Here a and b are regression constants and S_0 is the maximum day length (hours).

(3)Olomiyesan and Oyedum model

In 2016, a multilinear regression model was developed for the estimation of global solar radiation. Olomiyesan and Oyedum model is on the new model with three regression constants **(Olomiyesan et al., 2016)**. In this model, Garcia model was incorporated into Angstrom-Prescott model is in the form of

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{\Delta T}{S_0}\right) \qquad (15)$$

where a, b and c are the regression constants determined for given location.

Model evaluation schemes

The accuracy and applicability of these models were determined based on analysis of different statistical indicators. These are mean bias error (MBE), mean percentage error (MPE), root mean square error (RMS), coefficient of correlation (R) and coefficient of determination (R^2). The arrangement of the estimated values against the measured values of monthly means of daily global solar radiation were evaluate the fundamental error analysis schemes described by **Muzathik et al.,(2011) and Maghrabi et al., (2009)**.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_c - H_m\right) \qquad (16)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_c - H_m}{H_m}\right) * 100 \qquad (17)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_c - H_m\right)^2\right]^{\frac{1}{2}} \qquad (18)$$

The Coefficient of Residual Mass (CRM) was calculated according to the equation presented by **Ezekoye et al., 2011**.

$$CRM = \frac{\sum\left(H_m - H_c\right)}{n\overline{H_m}} \qquad (19)$$

$$R = \frac{\sum\left[\left(H_c - \overline{H_c}\right)\times\left(H_m - \overline{H_m}\right)\right]}{\sqrt{\sum\left(H_c - \overline{H_c}\right)^2 \times \sum\left(H_m - \overline{H_m}\right)^2}} \qquad (20)$$

where H_m is the measured solar radiation, H_c is the calculated or estimation solar radiation and n is the total number of observations. MBE is an indicator for the average deviation of the calculated values from the measured values. It provides the given model has a tendency to under or over predict, with ideally zero value is preferred Almorox et al., 2005 and Chen et al., 2004. The MPE test gives long term performance of the examined regression equations, percentage deviation of the predicted and measured monthly average daily global solar radiation values. The positive values of MPE and MBE values provide the measured values are overestimated in the calculated values, while the negative values gives underestimated. The RMSE test indicates the level of scatter that a model produces and it allows the term-by-term comparison of the estimated and measured values with low values of RMSE is desirable. For better data modeling, the coefficient of correlation and coefficient of determination should be closely one as possible. A positive value of CRM indicates the measured values are underestimated while a negative value indicates the measurement values are overestimated **(Bandyopadhyayetal., 2008)**. $\overline{H_c}$ and $\overline{H_m}$ are the average values of calculated and measured global solar radiation.

III. RESULTS AND DISCUSSION

3.1. General meteorology for Anantapur station

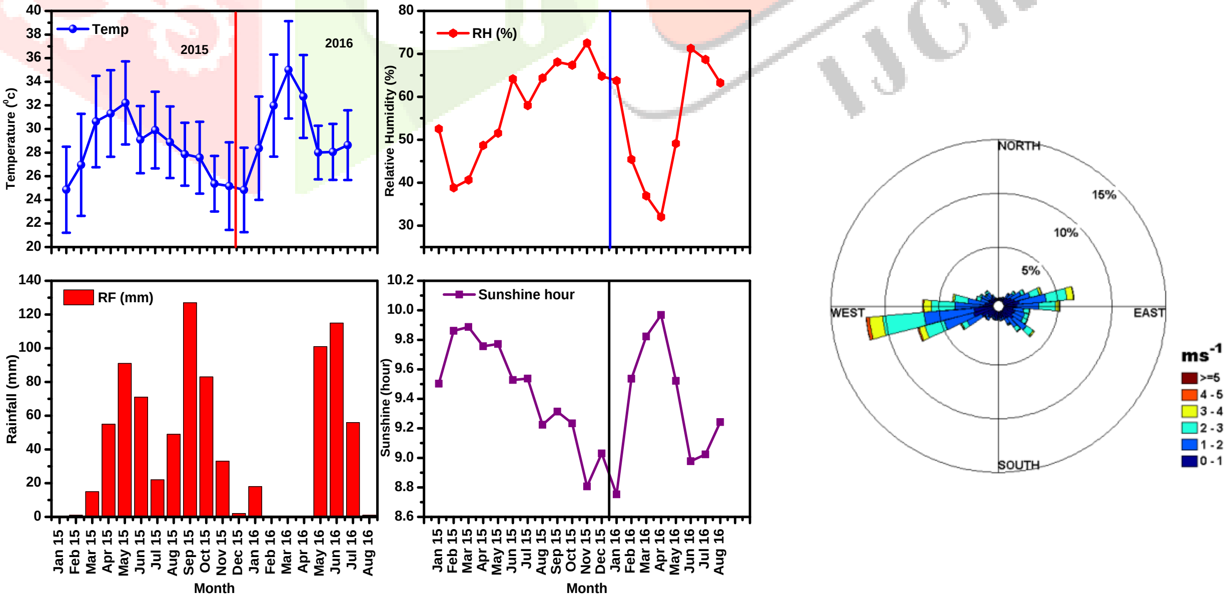


Fig 1. General meteorological parameters for Anantapur station

The monthly variation of general meteorological parameters; the atmospheric temperature, relative humidity, rainfall, sunshine hour, wind speed and wind direction for Anantapur station are shown in fig 1. for January 2015 to August 2016 obtained from automatic weather station established at the observation site. Monthly mean maximum temperature of 35±4.12ºc was observed in April 2016 and maximum relative humidity (RH) of 73% was observed in November 2015. The minimum temperature of 24.83±3.57ºc in January, and a minimum RH of 32% were observed in April 2016. The total rainfall for the study period across the site was 840 mm for January 2015 to August 2016. The sunshine duration is a climatologically indicator, measuring duration of sunshine in given period usually a day or a year for a given location on the earth, typically expressed as an averaged value perseveres years. The sunshine of a position is the duration from sun rise to sunset. The sunshine is expressed as the average number of hours of sunshine per month or per year, and tabulating the actual hours of sunshine, as a percentage possible duration of sunshine for the particular location indicates the relative sun shines of climate **(Russell, 1934)**. Based on the statement of **WMO (2003)**, the sunshine duration for a given period is defined as the sum of the sub period for which the direct solar irradiance exceeds 120 W/m^2. The amount of bright sunshine is badly affected by cloudiness, humidity, dustiness, latitudinal and altitudinal location, physical relief, length of day and night. It measures the total energy delivered by the sunlight over a given period. The sunshine duration of Anantapur, maximum in April 2016 (9.97) and minimum in January 2016 (8.75) during the observation period.

The wind rose diagram showed that the variation of wind speed and wind direction for the study period of January 2015 to August 2016. The wind speed and wind direction are important for predicting and monitoring weather patterns and global climate. The wind rose shows that the winds at Anantapur during the period blow from the south west direction.

3.2. Monthly variation of H_{mea}/H_0 and S/S_0 for Anantapur (ATP) station

The Fig 2(a), (b) shows the monthly variation and correlation of measured clearness index, sunshine fraction for Anantapur for the period of January 2015 to August 2016.The In Anantapur, the clearness index and relative sunshine are minimum in June (0.43±0.10 and 0.70±0.24) and maximum in February (0.62±0.01 and 0.85±0.02) with an annual average of 0.55±0.03 and 0.78±0.24. In sky conditions classification, the clearness index is often used because it depends mainly on global solar irradiance **(Li et al., 2004; Muneer, 1995)**. According to **Kuye and Jagtap (1992)** the clearness index varies for cloudy sky it is in the range between 0.12 to 0.35, for partly cloudy sky its varies 0.35 to 0.65 and for clear sky it is greater than 0.65. In 2008, the world meteorological organization proposed and classified the sky condition based on sunshine hour, for cloud sky the relative sunshine is in between 0 to 0.3, for scattered clouds sky it is in between 0.3 to 0.7 and for clear sky it is in between 0.7 to 1 **(Yusuf, 2017)(WMO, 2006; Adam, 2012)**. From the above observations in Anantapur the clear sky will obviously fell within the summer season and partly cloudy sky in monsoon and post monsoon seasons.Table.1 shows the average of measured global solar radiation (H_{mea}), extraterrestrial solar radiation (H_0), bright sunshine hour (S), monthly averaged day length (S_0) and measured clearness index (H_{mea}/H_0) respectively.

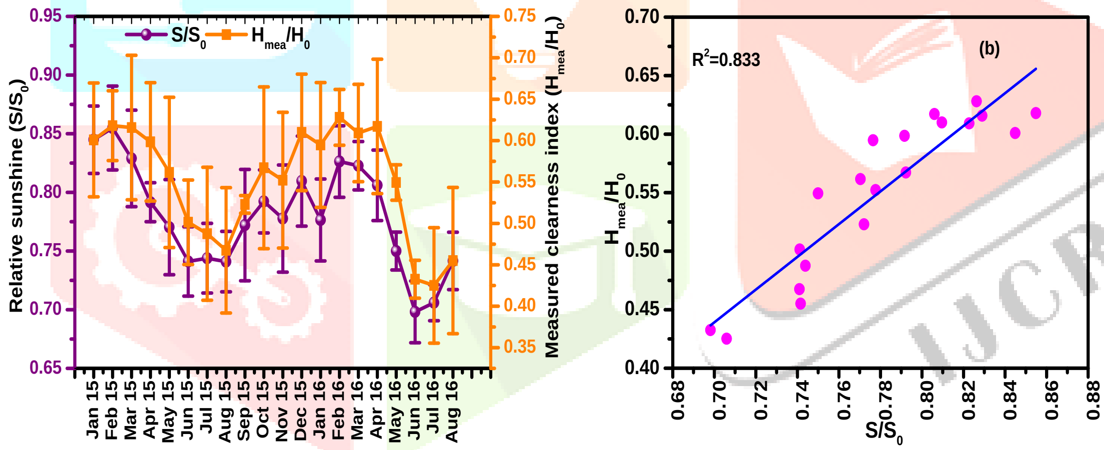


Fig 2 (a), (b). Monthly variation of relative sunshine and measured clearness index and their correlation.

Table 1: Input meteorological parameters for Anantapur during January 2015 to August 2016.

Month	S	S_0	H_{mea}	H_0	S/S_0	H_{mea}/H_0
Jan-15	9.50	11.25	207.94	345.59	0.84	0.60
Feb-15	9.86	11.54	235.95	380.27	0.85	0.62
Mar-15	9.89	11.93	256.88	417.78	0.83	0.62
Apr-15	9.76	12.34	264.07	441.19	0.79	0.60
May-15	9.77	12.69	250.58	446.25	0.77	0.56
Jun-15	9.53	12.86	222.72	444.08	0.74	0.50
Jul-15	9.54	12.78	216.19	443.40	0.74	0.49
Aug-15	9.22	12.48	205.86	440.25	0.74	0.47
Sep-15	9.31	12.07	221.30	423.33	0.77	0.52
Oct-15	9.23	11.66	220.14	389.22	0.79	0.57
Nov-15	8.81	11.32	194.68	351.86	0.78	0.55

Dec-15	9.03	11.16	203.07	333.11	0.81	0.61
Jan-16	8.75	11.25	205.47	345.59	0.78	0.59
Feb-16	9.54	11.54	238.74	380.95	0.83	0.63
Mar-16	9.82	11.94	254.47	418.86	0.82	0.61
Apr-16	9.97	12.36	273.13	441.61	0.81	0.62
May-16	9.52	12.70	245.17	446.23	0.75	0.55
Jun-16	8.98	12.86	200.46	444.02	0.70	0.43
Jul-16	9.02	12.77	188.51	443.39	0.71	0.43
Aug-16	9.24	12.46	200.43	439.97	0.74	0.46

3.3. Determination of regression constants

In the sunshine based models, there are four models were used to estimating global solar radiation to show the validation of relative sunshine duration and clearness index for Anantapur for the period of January 2015 to August 2016. The regression constants and the coefficient of determination R^2 values for sunshine and temperature based models are shown in table 2&3. The results for the four sunshine based models were summarized below;

$$\frac{H_c}{H_0} = -0.54 + 1.3988\left(\frac{S}{S_0}\right) \qquad (21)$$

The coefficient of determination, R^2 is 0.841.
The empirical relationship for polynomial model is

$$\frac{H_c}{H_0} = -4.4083 + 12.408\left(\frac{S}{S_0}\right) - 7.0767\left(\frac{S}{S_0}\right)^2 \qquad (22)$$

The coefficient of determination, R^2 is 0.888.
The empirical relationship for exponential model is

$$\frac{H_c}{H_0} = 0.9172\left(\frac{S}{S_0}\right)^{2.0681} \qquad (23)$$

The coefficient of determination, R^2=0.845.
The empirical relationship for power model is

$$\frac{H_c}{H_0} = 0.0694e^{2.646\left(\frac{S}{S_0}\right)} \qquad (24)$$

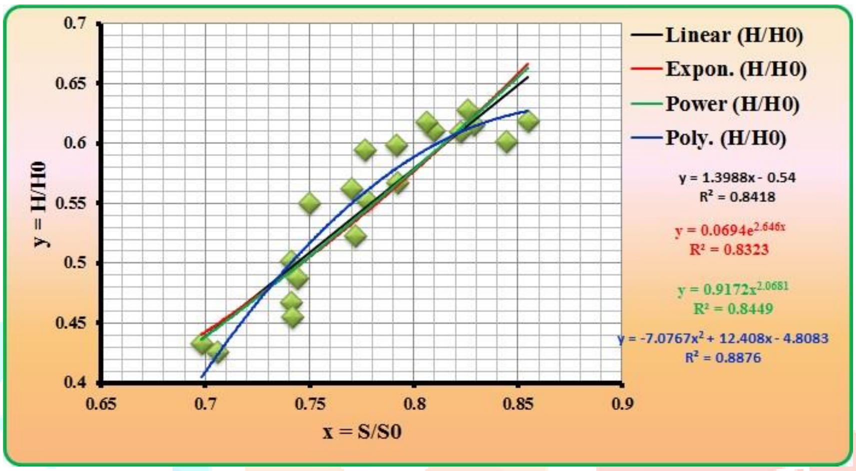
The coefficient of determination is 0.832.
From the above models, model 2 is excellently fit for data compare to model 1, 3 and 4.

Table 2: Regression equations developed based on sunshine models for the location Anantapur (14.62˚N, 77.65˚ E).

S.No	Models	Regression equations	R^2value
1.	Angstrom- Prescott model	$\frac{H_c}{H_0} = -0.54 + 1.3988\left(\frac{S}{S_0}\right)$	0.841
2.	Ogelman et al model	$\frac{H_c}{H_0} = -4.4083 + 12.408\left(\frac{S}{S_0}\right) - 7.0767\left(\frac{S}{S_0}\right)^2$	0.888
3.	El-Metwally model	$\frac{H_c}{H_0} = 0.9172\left(\frac{S}{S_0}\right)^{2.0681}$	0.845
4.	Bakirci exponential model	$\frac{H_c}{H_0} = 0.0694e^{2.646\left(\frac{S}{S_0}\right)}$	0.832

Table 3: Regression equations developed based on temperature models for the location Anantapur.

S.No	Models	Regression equations	R^2value
1.	Hargreaves and Samani model	$\frac{H_c}{H_0} = 0.167(T_{max} - T_{min})^{0.5}$	0.52
2.	Garcia model	$\frac{H_c}{H_0} = 0.276 + 0.3193\left(\frac{\Delta T}{S_0}\right)$	0.758
3.	Olomiyesan and Oyedum model	$\frac{H_c}{H_0} = -0.31557 + 0.9815\left(\frac{S}{S_0}\right) + 0.1172\left(\frac{\Delta T}{S_0}\right)$	0.869



3.4. Monthly variation of measured and estimated clearness index using sunshine based models

Fig 3. shows the comparison and correlation between measured and estimated global solar radiation using sunshine based models shown in equations (9 to12) to estimating the monthly mean global solar radiation for the study period. The measured and estimated global solar radiation values are good correlation with correlation coefficient of 0.84, 0.89, 0.85 and 0.83 for AP Model, Ogelman Model, El-metwally Model and Bakirci Model respectively. The months of January, February, June and July are overestimated to the measured radiation for all sunshine models were individually shown in Fig 4. The results for the four sunshine models were summarized below in Table 4.

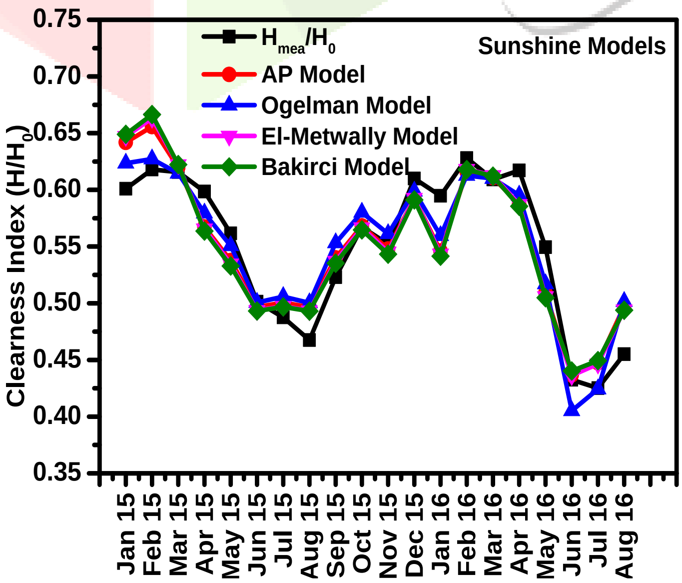


Fig 3. Monthly variation of measured and estimated global solar radiation using sunshine based models.

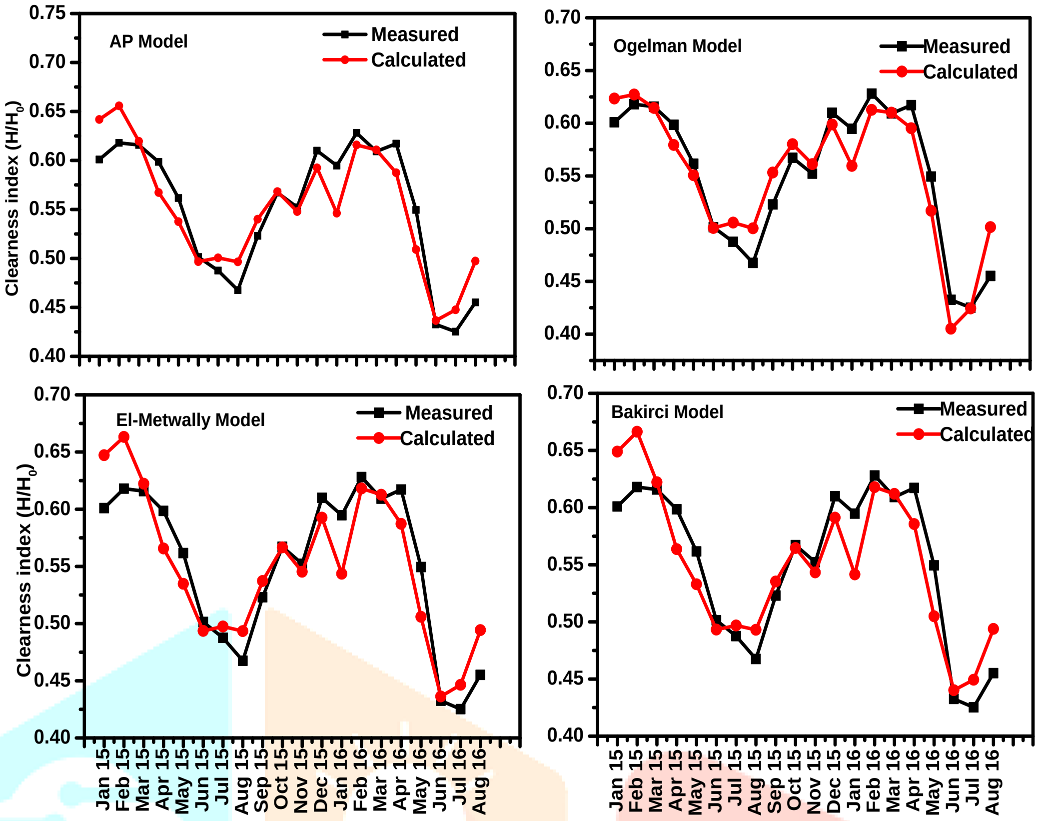


Fig 4. Correlation of measured and estimated global solar radiation using sunshine based models.

Table 4: shows the measurement and estimated global solar radiation using sunshine based models that are Angstrom-Prescott, Ogelman, El-Watman and Bakirci models.

Month	Relative sunshine (S/S_0)	H_{mea}/H_0	AP Model	Ogelman Model	El-Metwally Model	Bakirci Model
Jan-15	0.845	0.601	0.642	0.623	0.647	0.649
Feb-15	0.855	0.618	0.656	0.627	0.663	0.666
Mar-15	0.829	0.616	0.620	0.615	0.622	0.622
Apr-15	0.792	0.599	0.567	0.579	0.566	0.564
May-15	0.770	0.562	0.538	0.551	0.535	0.533
Jun-15	0.741	0.501	0.497	0.501	0.494	0.493
Jul-15	0.744	0.488	0.501	0.506	0.497	0.497
Aug-15	0.741	0.468	0.497	0.500	0.493	0.493
Sep-15	0.772	0.523	0.540	0.553	0.537	0.535
Oct-15	0.792	0.567	0.568	0.580	0.567	0.565
Nov-15	0.778	0.552	0.548	0.561	0.545	0.543
Dec-15	0.810	0.610	0.592	0.599	0.593	0.591
Jan-16	0.776	0.595	0.546	0.560	0.544	0.542
Feb-16	0.826	0.628	0.616	0.613	0.618	0.618
Mar-16	0.823	0.609	0.611	0.610	0.613	0.612
Apr-16	0.806	0.617	0.587	0.595	0.587	0.586
May-16	0.750	0.549	0.509	0.517	0.506	0.505
Jun-16	0.698	0.433	0.437	0.405	0.436	0.440
Jul-16	0.706	0.425	0.448	0.424	0.446	0.449
Aug-16	0.742	0.455	0.497	0.501	0.494	0.494

3.5. Monthly variation of measured and estimated clearness index using temperature based models

Estimation of global solar radiation by the temperature based models using maximum and minimum air temperature values from the study area is shown in Fig 5. The estimation global solar radiation using temperature models could predict the pattern of the measured monthly mean global solar radiation. The measurement and estimated global solar radiation values using temperature based models represented in Table5. According to Fig 6. the months of June, July, August are overestimated the measured radiation in HS model, in Garcia and Olomiyesan models the months of February, June, July, August are overestimated the measured radiation. The correlation between the measured and estimated radiation gave a coefficient of determination R^2 of 0.52, 0.76 and 0.87 for HS Model, Garcia Model and Olomiyesan Model respectively.

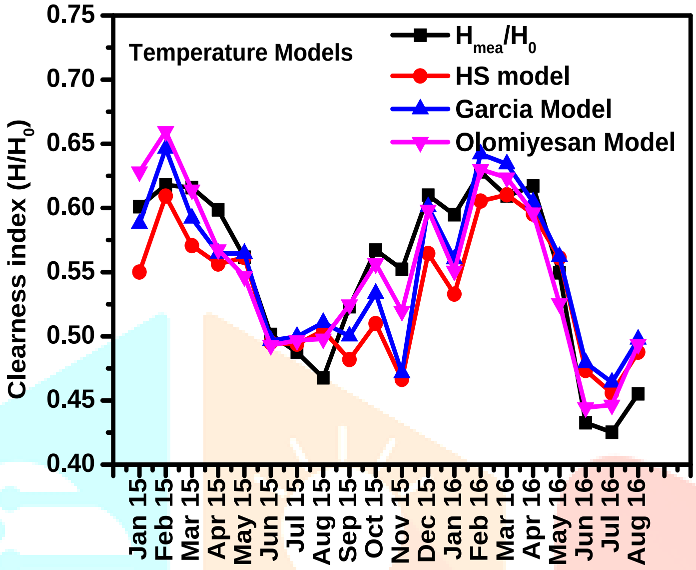


Fig 5. Monthly variation of measured and estimated global solar radiation using temperature based models.

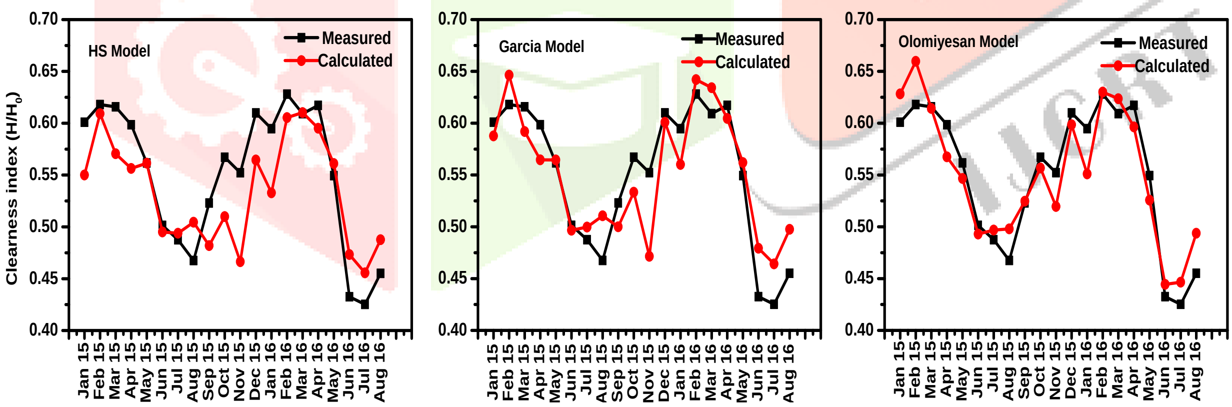


Table 5: shows the measurement and estimated global solar radiation using temperature based models that are HS Model, Garcia Model and

Fig. 6. Correlation of measured and estimated global solar radiation using temperature based models.

Olomyesan model

Month	S/S_0	$\Delta T/S_0$	H_{mea}/H_0	HS Model	Garcia Model	Olomyesan Model
Jan-15	0.845	0.977	0.601	0.550	0.588	0.628
Feb-15	0.855	1.161	0.618	0.609	0.646	0.660
Mar-15	0.829	0.990	0.616	0.571	0.592	0.614
Apr-15	0.792	0.904	0.599	0.556	0.565	0.568
May-15	0.770	0.904	0.562	0.561	0.564	0.547
Jun-15	0.741	0.691	0.501	0.495	0.497	0.493
Jul-15	0.744	0.701	0.488	0.494	0.500	0.497
Aug-15	0.741	0.735	0.468	0.504	0.511	0.498

Sep-15	0.772	0.702	0.523	0.482	0.500	0.525
Oct-15	0.792	0.807	0.567	0.510	0.533	0.557
Nov-15	0.778	0.612	0.552	0.466	0.471	0.520
Dec-15	0.810	1.018	0.610	0.565	0.601	0.599
Jan-16	0.776	0.891	0.595	0.533	0.560	0.551
Feb-16	0.826	1.147	0.628	0.605	0.642	0.630
Mar-16	0.823	1.123	0.609	0.610	0.634	0.624
Apr-16	0.806	1.030	0.617	0.595	0.605	0.596
May-16	0.750	0.896	0.549	0.561	0.562	0.526
Jun-16	0.698	0.637	0.433	0.473	0.479	0.444
Jul-16	0.706	0.590	0.425	0.456	0.464	0.447
Aug-16	0.742	0.694	0.455	0.488	0.498	0.494

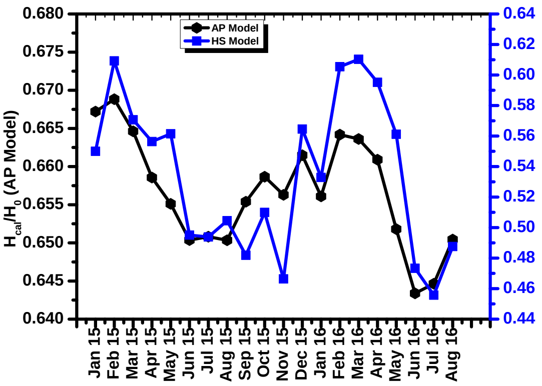
Table 6: shows the summary of the model evaluations using sunshine and temperature based models.

Sunshine based models	**MBE (W/m^2)**	**MPE (%)**	**RMSE (W/m^2)**	**R**	**R^2**	**CRM**
AP Model	-0.384	0.0464	10.63	0.90	0.81	0.001705
Ogelman	-0.264	0.0212	9.933	0.92	0.84	0.001173
El-watman	-0.668	-0.0931	11.026	0.89	0.8	0.00296
Bakirci	-0.8001	-0.1394	11.394	0.89	0.79	0.00355
Temperature based models						
HS model	-6.1883	-2.674	14.753	0.86	0.74	0.02746
Garcia model	0.142	0.1545	12.411	0.88	0.77	-0.00063
Olomysean	-0.2611	0.01027	9.431	0.93	0.86	0.001159

The required values of the MBE, MPE, RMSE and R^2 gained from the sunshine based model and temperature based models are shown in Table 6. The result showed that the values of MBE, MPE and RMSE are smallest and their CRM is approximately zero, this makes that in both evaluations models are compared to the measured global solar radiation. The Olomysean model gives the best estimation because its RMSE value is low and R^2 is 0.86 compare to other models. The HS Model shows poor performance with highest RMSE value.

3.6. Correlation of monthly mean values of clearness index for Anantapur using AP and HS models

Figure 7(a) & 7(b) represents the variation of clearness index with respect to the sunshine and temperature models. From the Fig 7 (a), we observed that both models are exhibit maximum clearness index in the summer season due to clear sky and extreme hot climate conditions whereas minimum values were observed in the monsoon season because of hazy climate conditions. Both models are correlated with a correlation coefficient of 0.61% (fig 7(b)). Table 7 showed that the predicted monthly mean values of global solar radiation for Angstrom–Prescott model, Hargreaves-Samani for each month.



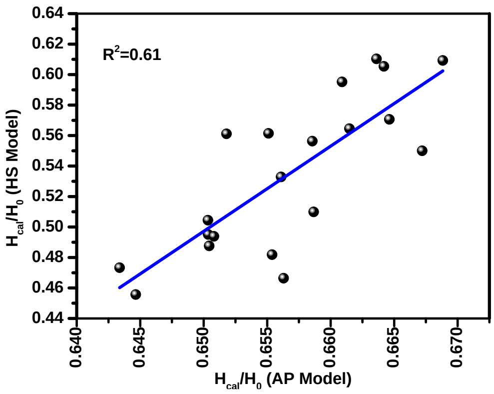


Fig 7 (a), (b). Monthly mean and correlation of clearness index for Anantapur using AP Model and HS Model.

Table 7: shows the summary of the comparison of estimated global solar radiation using AP and HS models for Anantapur during 2015 and 2016 years.

Month	S/S_0	H_{mea}/H_0	$\Delta T/S_0$	AP Model (H_{cal}/H_0=a+b(S/S_0))	HS Model (H_{cal}/H_0=Kr(T_{max}-T_{min})^0.5)
Jan-15	0.845	0.601	0.977	0.642	0.550
Feb-15	0.855	0.618	1.161	0.656	0.609
Mar-15	0.829	0.616	0.990	0.620	0.571
Apr-15	0.792	0.599	0.904	0.567	0.556
May-15	0.770	0.562	0.904	0.538	0.561
Jun-15	0.741	0.501	0.691	0.497	0.495
Jul-15	0.744	0.488	0.701	0.501	0.494
Aug-15	0.741	0.468	0.735	0.497	0.504
Sep-15	0.772	0.523	0.702	0.540	0.482
Oct-15	0.792	0.567	0.807	0.568	0.510
Nov-15	0.778	0.552	0.612	0.548	0.466
Dec-15	0.810	0.610	1.018	0.592	0.565
Jan-16	0.776	0.595	0.891	0.546	0.533
Feb-16	0.826	0.628	1.147	0.616	0.605
Mar-16	0.823	0.609	1.123	0.611	0.610
Apr-16	0.806	0.617	1.030	0.587	0.595
May-16	0.750	0.549	0.896	0.509	0.561
Jun-16	0.698	0.433	0.637	0.437	0.473
Jul-16	0.706	0.425	0.590	0.448	0.456
Aug-16	0.742	0.455	0.694	0.497	0.488

IV. Conclusions:

This paper is aimed to estimating clearness index using sunshine and temperature based models using sunshine hour and maximum and minimum temperatures. The collected data from MOSDAC and pyranometer for Anantapur station during January 2015 to August 2016. The results are briefly summarised below.

- The monthly variation of temperature was maximum in the month of April and minimum in the month of January.
- The maximum relative humidity was found in the month of August whereas low in the month of April.
- The wind speed and directions were measured and the reasons for determining the type of aerosols present over the site and direction from which region they transported are analyzed.
- The clearness index and relative sunshine are minimum in June (0.43±0.10 and 0.70±0.24) and maximum in February (0.62±0.01 and 0.85±0.02) with an annual average of 0.55±0.03 and 0.78±0.24.
- The sunshine and temperature models are good agreement with the measured global solar radiation.
- Based on the statistical error indices, the proposed model was found to have the overall best accuracy with the least RMSE values in all the studied sites as well as highest coefficient of determination, R^2 values.
- The AP Model and HS Model can be used effectively to estimating global solar radiation with relative accuracy. These two models are correlated with correlation coefficient of 0.61.

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