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Authors' contributions

Y. Nazeer Ahammed: conceptualized the experiment and edited - Original draft. S. Pavankumari,G Balakrishnaiah, designed the study, data collection and writing the original draft. Amit Awasthi, A. Ramanjula Reddy and P. Sankar Naryana carried out the scientific analysis of the data.

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Abstract

To accomplish the best operation of available solar energy, it is important to estimate the incident solar radiation over the specific region. The present study focuses on the estimation of solar radiation by using mathematical modelling. For that purpose, monthly average daily global solar radiations are estimated based on different parameters like minimum and maximum temperature, sunshine hour, and relative humidity. The location selected for this study is Kadapa ((14.47ºN, 78.87º E, and 138m asl) Southern part of India. The study period is from April 2016 to October 2018. The study focuses particularly on models based on the relative sunshine (S/S_0) and clearness index (k_t). The clearness index and relative sunshine were high in December (1.058±0.002 and 0.968±0.005) and low in July (0.952±0.05 and 0.734±0.072). The estimated clearness index based on sunshine models is best correlated with the calculated clearness index values. In temperature and relative humidity-based models the hybrid parameter-based models are better correlated with the single parameter based-models.

Keywords: Clearness index, Solar radiation, Sunshine hour, Relative humidity.

1. Introduction

Solar irradiation at the earth's surface is necessary for the growth and utilization of solar energy. Understanding of solar radiation's availability and variability is of huge significance in Atmospheric Research as well in practical consumption in electricity generation, water heating, etc. In support of designing collectors for the photovoltaic equipment and other solar heater, solar radiation is required in the form of solar energy. Measurements of solar radiation are significant as increasing number of solar heating and cooling applications and the require for exact solar irradiation data to predict performance. The energy transferred to a surface by solar radiation experimentally determined by using device which will measure the heating effect of direct solar radiation and diffuse solar radiation (Jatto et al ., 2015). Constancy in the weather-system and climate-atmosphere mechanism solar radiation plays a very important role. Direct, Global and diffuse radiation are important radiation parameters used in solar energy techniques (Hussain et al. 1999). information of global solar radiation is of primary importance for all solar energy conversion systems. Incoming global solar radiation is affected by atmospheric environment such as aerosols, air mass, water vapor, ozone and cloud distribution. The attenuation agents are changeable over time and when combined with elevation changes, they significantly influence the spatial pattern of attenuation (Ruiz-Arias et al. 2010).The is indicated by The fraction of extraterrestrial radiation that reaches the earth's surface as global radiation is indicated as the transparency of the atmosphere. It gives the measure of the degree of clearness of the sky (Akhlaque et al. 2009). The quantity of solar radiation reaching the earth's surface is ascertained by the hour of the day, the season of the year, and solar angles, amongst which are the sun's altitude angle, azimuth angle, zenith angle, and declination angle (Ghazi 2014; Fedorov 2019). The solar radiation data calculated at different regions is important in order to determine the potential of solar energy in a specific region. The instruments pyranometer, solarimeter, pyroheliometer etc are measured the components of solar radiation. Because of the expensive measurement devices and the difficult measurement methods it is not practically reasonable to place measurement devices everywhere. So that there was be deficient in of sufficient solar radiation data for establishing solar energy generation systems. The prediction of solar radiation have been more significant for energy and smart grid applications. In order to mounting the appropriate evaluation method of solar radiation is major importance for reducing electricity cost and time loss. For the solar radiation estimation, the most frequently used meteorological parameters such as Sunshine duration, air relative humidity and temperature (Zeng et al. 2011 and Khen et al. 2018). The estimation models make available Global Solar Radiation (GSR) as output. Model accuracy evaluations like Mean Bias Error (MBE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), etc. are statistically tested based on error calculations. Thus solar radiation models are desired to predict 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. These parameters include sunshine hours (Teke et al. 2014; Mecibah et al. 2014; Khorasanizadeh 2013; Gana etal. 2013b; Li et al. 2010; Koussa et al. 2009; Bakirci et al. 2009; Bannani et al. 2006; Akinoglu and Ecevit 1990 and Angstrom 1924; air temperature (Muhammad and Darma 2014; Kaltiya et al. 2014; Medugu and Yakubu 2011; Agbo et al. 2010; Fletcher and Moot 2007; Paulescu et al. 2006; Falayi and Rabiu 2005; Allen 1997; Bristow and Campbell 1984; Hargreaves and Samani 1982; relative humidity (Trabea and Shaltout 2000 and Alnaser 1993); precipitation (Rietveld 1978); and cloudiness (Kumar and Umanand 2005).

In the present study, we provide the idea behind different solar radiation estimation models with the methodology used. The most important purpose of this study is to calculate the global solar radiation using Angstrom –Prescott model and compare it with the estimation of global solar radiation using sunshine hour, minimum and maximum temperature and relative humidity (RH) based on clearness index and sunshine ratio in Kadapa region.

2.Methodology and model approach

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). The present analysis was carried out at Yogi Vemana University, Kadapa (YVU; 14.47ºN, 78.82ºE, 138 m above sea level), from April 2016 to October 2018. The study area, Kadapa is situated in the central part of Andhra Pradesh is located 8 km south of the Penna River and is surrounded by the Nallamala (40 km) and the Palakonda hills (25 km) on its three sides. Kadapa has a tropical climate and the weather conditions are generally hot. It is an active station under the Aerosol Radiative Forcing over India (ARFI) network of stations. The sampling station is located at adjacent to the highway, at a distance of 15 km west of the main Kadapa city. Several brick kilns and some small-scale cement and electrical industries around the observational site within a 30 km radius. In addition, a large number of automobile and vehicular emissions are run through the highway from morning to near-midnight. These emissions are the principal sources of air pollution. Most of the rainfall occurs during monsoon and post- monsoon from the south-west and north-east monsoons respectively.

The temperature was observed to have increased in the summer months, it decreases to its minimum in the monsoon months and the relative humidity (RH) was observed to be high in monsoon months and low in the summer months was shown in Fig. 1 (a) in all the years under study. Figure 1 (b) shows the wind rose diagram for variation of wind speed and wind direction, these are important for monitoring and predicting weather patterns and global climate. Over the study period in the Kadapa region most of the winds blows from the south east direction.

The first model used to estimate the global solar radiation on a horizontal surface based on the 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_0 is the monthly mean of daily extraterrestrial solar radiation (W/m^2), H is the monthly mean of daily global solar radiation (W/m^2), S is the monthly mean daily hours of bright sunshine, S_0 is the monthly mean 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. Their values have been obtained from the relationship given by **R. C. Srivastava and Harsha Pandey** (R.C. Srivastava & Harsha Pandey, 2013) as

$$a = -17.222\left(\frac{S}{S_0}\right)^2 + 27.18\left(\frac{S}{S_0}\right) - 10.533 \qquad (2)$$

$$b = 18.676\left(\frac{S}{S_0}\right)^2 - 29.395\left(\frac{S}{S_0}\right) + 12.098 \qquad (3)$$

The significance of this relationship lies in the information that using this correlation solar radiation can be estimated for every location in India, even at the places where we do not have a system to measure solar radiation. To compute estimated values of the monthly average daily global solar radiation, the values of *a* and *b* were used in Equation (1).

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, using the sunshine duration method allows the rough estimation of monthly value.

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 (199**1)** as follows,

$$H_0 = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right] \qquad (4)$$

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

extraterrestrial solar radiation (H_o)is expressed in the above equation in MJm^{-2} day^{-1}. The consequent equivalent evaporation in W/m^2 is obtained by multiplying H_o by 11.6. The symbol φ is latitude expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The change from decimal degrees to radians is given by:

$$[\text{Radians}] = \frac{\pi}{180}[\text{decimaldegree}] \quad (5)$$

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

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}J\right) \quad (6)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}J - 1.39\right) \quad (7)$$

The sunset hour angle, ω_s is given by:

$$\omega_s = \arccos[-\tan\varphi\tan\delta] \quad (8)$$

Monthly average day length (S_0) is:

$$S_0 = \frac{2}{15}\omega_s \quad (9)$$

The diffuse fraction of models are classified according to the basis of their input parameters such as correlations of clearness index (k_t) and relative sunshine (S/S_0). It points out the reduction of the incoming global solar radiation by the atmosphere and 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).

The clearness index (k_t) is the ratio of the global radiation at ground level on a horizontal surface to the extraterrestrial global solar irradiation. It describes the attenuation of solar radiation due to the clouds and depends on the geographical coordinates of the location.

$$k_t = \frac{H}{H_0} \quad (10)$$

Based on sky conditions, the clearness index (k_t) is used to mainly depend on global solar irradiance (Li et al., 2004). The value of k_t is in the range of 012-0.35, 0.35-0.65, >0.65 for cloudy, partly cloudy, clear sky conditions, respectively (Kuye and Jagtap 1992). In 2008, the world meteorological organization, classified and proposed the sky condition based on sunshine hour, relative sunshine (S/S_0) is in the range of 0 –0.3, 0.3-0.7, 0.7-1 for the cloudy sky, scattered clouds, clear sky, respectively (Yusuf, 2017) (WMO, 2006; Adam, 2012).

Diffuse solar radiation for daily periods

The total solar radiation consists of direct or beam radiation coming directly from the solar disc and the diffuse component scattered to the ground from the sky dome. The latter depends on the clarity of the sky and could be estimated from the correlation of (Collares-Pereira and Rabl 1979) which gives the daily average diffuse radiation, H_d as:

$$H_d = H\{0.775 + 0.0060(\omega_S - 90) - [0.505 + 0.00455(\omega_S - 90)]\cos(115k_t - 103)\} \quad (11)$$

The diffuse fraction, K_d is defined as the ratio of the daily diffuse radiation (H_d) on a horizontal surface to the daily global solar radiation (H) on that surface, that is:

$$k_d = \frac{H_d}{H} \quad (12)$$

which is the diffusion characteristics of diffuse solar radiation and hence mirrors the effectiveness of the sky in transmitting diffuse solar radiation.

Estimation of global solar radiation using sunshine, temperature and relative humidity:

To estimating global solar radiation, several models have been proposed. Page, 1964 gives a modified Angstrom type of linear regression model which correlates the global solar radiation with the relative sunshine duration. The correlation between the estimation of global solar radiation using meteorological parameters like a sunshine hour, mean daily maximum and minimum temperature, mean daily relative humidity and bright sunshine data was studied in (Trabea 2000 and Vasudeva Reddy 2018).

Sunshine based models

The sunshine duration is the most commonly used parameter for the estimation of 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 the sunshine ratio for the prediction of monthly average daily global solar radiation. The earlier studies (Souza et al. 2016; Li et al. 2012; Besharat et al. 2013; Muneer and Munawwar 2006; Ertekin and Yaldiz 1999) reported that the Angstrom-Prescott sunshine-based model yielded the best correlation on single variable basis with the clearness index. Therefore, it is the most accepted worldwide model for estimating global solar radiation based on a single variable. The models are (Prescott 1940; Ogelman et al. 1984; El-Metwally 2005; Bakirci 2009).

(1) Angstrom- Prescott model

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

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \tag{13}$$

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

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 \tag{14}$$

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)**.

$$\frac{H}{H_0} = a^{\left[\frac{1}{\frac{S}{S_0}}\right]} \tag{15}$$

Where a is regression coefficient.

(4) Bakirci exponential model

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

$$\frac{H}{H_0} = a\left(\frac{S}{S_0}\right)^b \tag{16}$$

Where a and b are regression coefficients.

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 the 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

$$\frac{H}{H_0} = k_r \left(T_{max} - T_{min}\right)^{0.5} \tag{17}$$

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

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 is mean atmospheric pressure at the site (k pa) and P_0 is the 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 parameters for estimating global solar radiation. This model is an adaptation of the Angstrom- Prescott model, the clearness index is correlated with the difference between the maximum and minimum temperatures (ΔT) is expressed in the form of **(Abdulsalam et al. 2014)**

$$\frac{H}{H_0} = a + b\left(\frac{\Delta T}{S_0}\right) \tag{18}$$

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

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{\Delta T}{S_0}\right) \quad (19)$$

Where a, b and c are the regression constants determined for study area.

Relative humidity based models

(1)Group 1

The clearness index is related with the relative humidity (RH) in the Group 1 model is the form of

$$\frac{H}{H_0} = a + b(RH) \quad (20)$$

(2)Group 2

$$\frac{H}{H_0} = a + b(RH)^2 \quad (21)$$

(3)Swartman- Ogunlade model

Swartman- Ogunlade in 1967 expressed global solar radiation in terms of relative sunshine and relative humidity (RH) as

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c(RH) \quad (22)$$

Where RH is the monthly average daily relative humidity (%) and S/S_0 is the relative sunshine.

3. Results and discussion

3.1. Monthly variation of solar radiation

Figure 2 (a), (b) ,(c) and (d) shows the monthly mean daily variation and standard deviations of the sunshine hour, diffuse solar radiation (H_d) global solar radiation (H_{cal}) and extraterrestrial solar radiation (H_0) during April 2016 – October 2018 over the study area. The monthly mean daily variation of the sunshine hour was maximum in the summer months (12.19±0.59) and minimum in the winter months (11.81±0.11) respectively over the study period. The sunshine hour for a given period is defined as the sum of the sub-period for which the direct solar irradiance exceeds 120 W/m^2 WMO (2003). The sunshine was uttered as the regular number of hours of sunshine per month or year, and tabulating the real hours of sunshine, as a percentage possible duration of sunshine for the particular location indicates the relative sun shines of climate (Russell 1934). The sunshine hour is directly affects the result of global solar radiation. It is observed that the global and diffuse solar radiation were fairly high in summer (344.77±33.24 and 84.51±5.87 W/m^2) months (March-May) and low in the winter and monsoon (326.51±6.70 and 76.89±8.22 W/m^2) months (December – February) with total average values of 335.46±26.81 and 80.36±8.68 W/m^2 respectively. The larger values of global and diffuse solar radiation during the summer months could be attributed to the maximum daily sunshine hours due to a high clearness index. In the presence of cloud and rainfall, suspension of water particles attenuates the incoming solar radiation to the earth's surface (Sansui, et al., 2015; Omondi Onyango et al. 2015) and hence the reduction in the amount of global solar radiation. Extraterrestrial solar radiation was high in May (445.92±0.016 W/m^2) and low in December (333.98±0.053 W/m^2). The sunshine duration (S), global solar radiation (H_{cal}), extraterrestrial solar radiation (H_0), and diffuse solar radiation (H_d) for Kadapa are presented in Table 1.

3.2. Monthly variation of relative sunshine and global solar radiation with clearness index

Figure 3 (a) shows the monthly variation of relative sunshine and clearness index during the period of three years (2016- 2018) for the semi- arid region Kadapa. A similarity pattern was observed in both parameters with their significance values. Both values of relative sunshine and clearness index were maximum in November 2016 (1.07±0.002 and 1.00±0.005) due to the clear sky and hence the high global solar irradiance is experienced. In sky conditions classification, the clearness index is often used because it depends mainly on global solar irradiance. In another improvement, Fig. 3 (b) shows the monthly mean K_t, including the mean global solar radiation measured for the same periods from 2016–2018. It shows that the curves of mean K_t values and the mean global solar radiation were in same pattern. Minimum values were observed in the monsoon month of July 2018 (0.89±0.05 and 0.65±0.072) due to the cloudy sky and the fairly low solar irradiance. The minimum value of k_t indicates that huge fraction of global solar radiation is diffuse in the monsoon season. The seasonal values of both relative sunshine (clearness index) was observed in winter, summer, monsoon and post-monsoon are 1.044±0.021 (0.926±0.054), 0.984±0.043 (0.787±0.072), 0.956±0.043 (0.745±0.062), and 1.004±0.057 (0.858±0.116) respectively over the study period. From the above observations in the Kadapa region, the clear sky will fell within the winter and summer seasons and partly cloudy sky in monsoon and post-monsoon seasons.

3.3. Monthly variation of clearness index and diffuse fraction

Figure. 4 shows the monthly variations of the clearness index (k_t) and a diffuse fraction (k_d) for the Kadapa region from April 2016 to October 2018. The clearness index and diffuse fraction showed the sky conditions in the method of transmitting and scattering incoming solar radiation. The location of the sun relative to the study site and the level of humidity cause the variation in clearness index . The highest clearness index was observed in November 2016 (1.001±0.048) and lowest in the monsoon month of July 2018 (0.650±0.035). High global radiation conquered by the direct component of the radiation gives the **h**igher values of clearness index, and low global solar radiation due to a cloudy sky with a high portion of diffuse components gives the lower clearness index. For the entire study period, the total average values of clearness index and diffuse index were (0.823±0.100) and (0.240±0.019) respectively. Table 2 shows the values of the monthly averaged daily sunshine hour (S), relative sunshine (S/S_0), clearness index (kt) and diffuse fraction (k_d) respectively.

3.4.Seasonal wise Frequency and Commutative Frequency Distribution of Daily clearness index and diffuse fraction Values

Figure 5(a), (b) shows the seasonal wise daily percentage frequency and cumulative frequency distributions of clearness index (k_t) with 0.2 range and the diffuse fraction (k_d) with the range of 0.05 from 2016 – 2018. From Fig. 5(a), in all seasons the percentage frequency of k_t was greater than 0.8, indicates the clear sky condition in the Kadapa region. It is clear from the figure, k_t ranged from 0.8 to 1.0 with a frequency of 76.67% in winter season followed by summer and post monsoon are 50.63% and 57.51% respectively. While it varied from 0.6 to 0.8 with that of 84.96% in monsoon season. In the case of diffuse fraction, a broad frequency distribution was observed to be 0.15 to 0.35 from 2016 - 2018. From the Fig. 5 (b), k_d indicates the dispersing direct normal irradiance. The dispersed irradiance however finds its course to the surface of the earth, which then brings about diffusion.

3.5.The correlation equation of the Models

In the sunshine, temperature and relative humidity based models, there are different models were used to estimate the global solar radiation to show the validation of relative sunshine duration, ΔT, $\Delta T/S_0$ and clearness index for Kadapa during the period of April 2016 to October 2018. The regression constants and the coefficient of determination R^2 values for sunshine, temperature and relative humidity based models were shown in table 3, 4 & 5. The results of the models were summarized below;

From the above summary, the regression equations formed due to the sunshine-based models were well correlated with the calculated values.

In summary, model 3 performed excellently in term of coefficient of determination (R^2) than model 1 and 2 while model 3 performed better than model 1 and model 2 has a 95.30% coefficient of determination.

Model 3 performed excellently in terms of coefficient of determination (R^2= 0.953) compared to model 1, 2. From the above report, the calculated and the estimated values for study location is remarkable.

3.6.Monthly variation of calculated and estimated clearness index using sunshine based models

Figure 6 shows the estimation of the monthly mean daily global solar radiation using sunshine-based models for Kadapa during the period 2016-2018. From the figure there was good agreement between the calculated and model estimated values with a coefficient of determination of 0.951, 0.971, 0.959 and 0.964 for AP Model, Ogelman Model, El-metwally Model and Bakirci Model respectively.

In the months from July to December vales are under estimated to the calculated values and the remaining months are over estimated. From the model estimation, AP model, Ogelman Model, El-metwally Model are over estimated and the Bakirci Model was under estimated to the calculated values. The calculated and estimated clearness index using sunshine models were shown in Table 6.

3.7. Monthly variation of calculated and estimated clearness index using temperature-based models

The comparison and correlation between the calculated and estimated global solar radiation using temperature-based models over the study location were shown in Fig. 7. In the temperature models, the maximum and minimum air temperature values and relative sunshine values are using during the study period. From the above figure the HS model was under estimated to the calculated values for all months with a coefficient of determination of R^2= 0.226. The Garcia and Olomyesan models were over-estimated in January to July and under-estimated in August to December with a coefficient of determination of R^2=0.334 and 0.953 respectively. The Table 7 gives the summary of the calculated and estimated clearness index using the temperature-based models. The result shows that the accuracy of hybrid-parameters-based models is better than compared to single-parameter-based models.

3.8.Monthly variation of calculated and estimated clearness index using relative humidity based models

Figure 8 shows the estimation of global solar radiation using the relative humidity (RH) and comparison with the calculated radiation. The figure shows that the months from May to September for the group I and group II models are over-estimated and the remaining months are under-estimated to the calculated values with a coefficient of determination of 0.465 and 0.426 respectively. The Swartman-Ogunlade model shows the best correlation (R^2=0.953) to the calculated radiation value. The results for the relative sunshine models were summarized below in Table 8.

4. Conclusions

The estimation of monthly global solar radiation has been calculated by several empirical models from the kinds of literature based on the sunshine, temperature and relative humidity model using sunshine hour, relative sunshine, maximum and minimum temperatures and relative humidity values. These meteorological parameters were collected from MOSDAC for Kadapa station from January 2016 to December 2018. The atmospheric temperature (relative humidity) was high (low) in the summer (winter) and low (high) in the winter (summer) months. The global solar radiation and diffuse solar radiation were high in summer months and low in monsoon months. The estimated clearness index using different models; sunshine, temperature and relative humidity are good correlated with the calculated clearness index values.

CRediT authorship contribution statement.

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Data availability:

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare that they have no competing interests.

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Figures

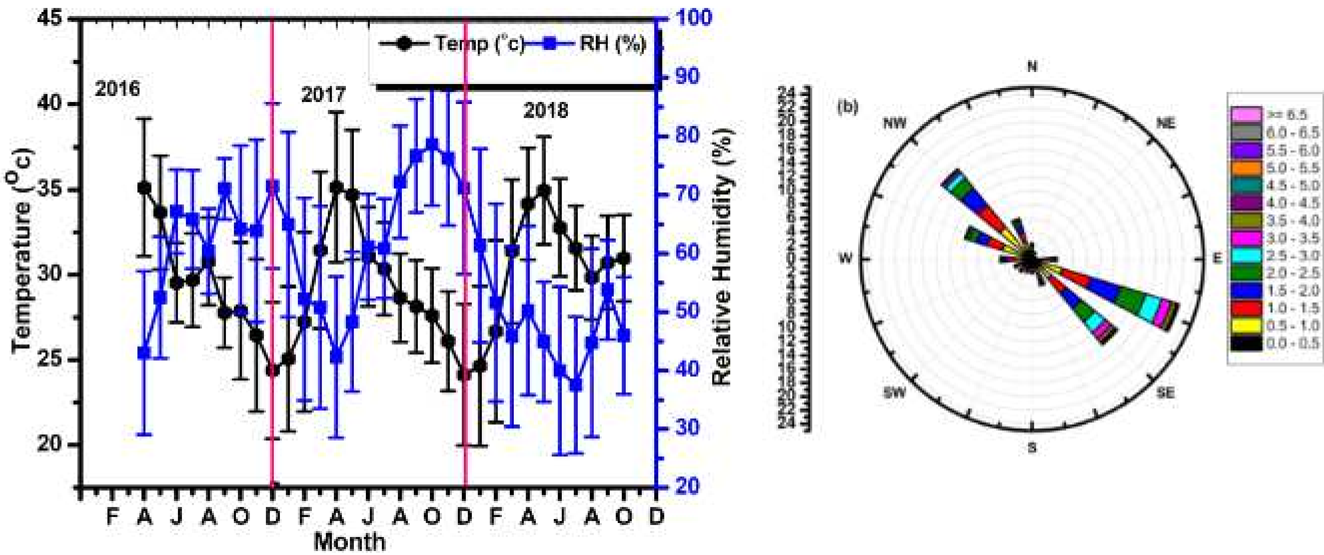

Fig. 1

Figure 1

(a) Monthly variation of atmospheric temperature and relative humidity (RH), (b) wind rose over the study location during April 2016 to October 2018.

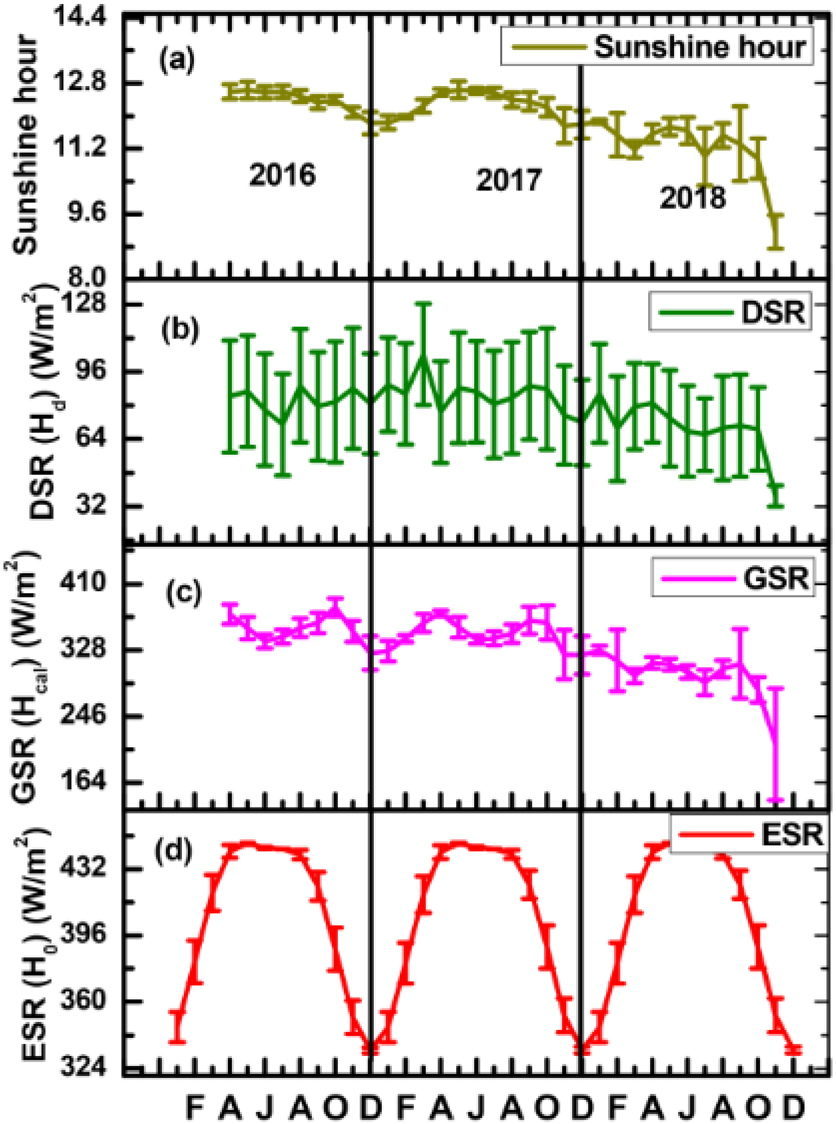

Fig. 2

Figure 2

Monthly means daily variation of sunshine hour, global, extraterrestrial and diffuse solar radiation in kadapa during the study period 2016-2018.

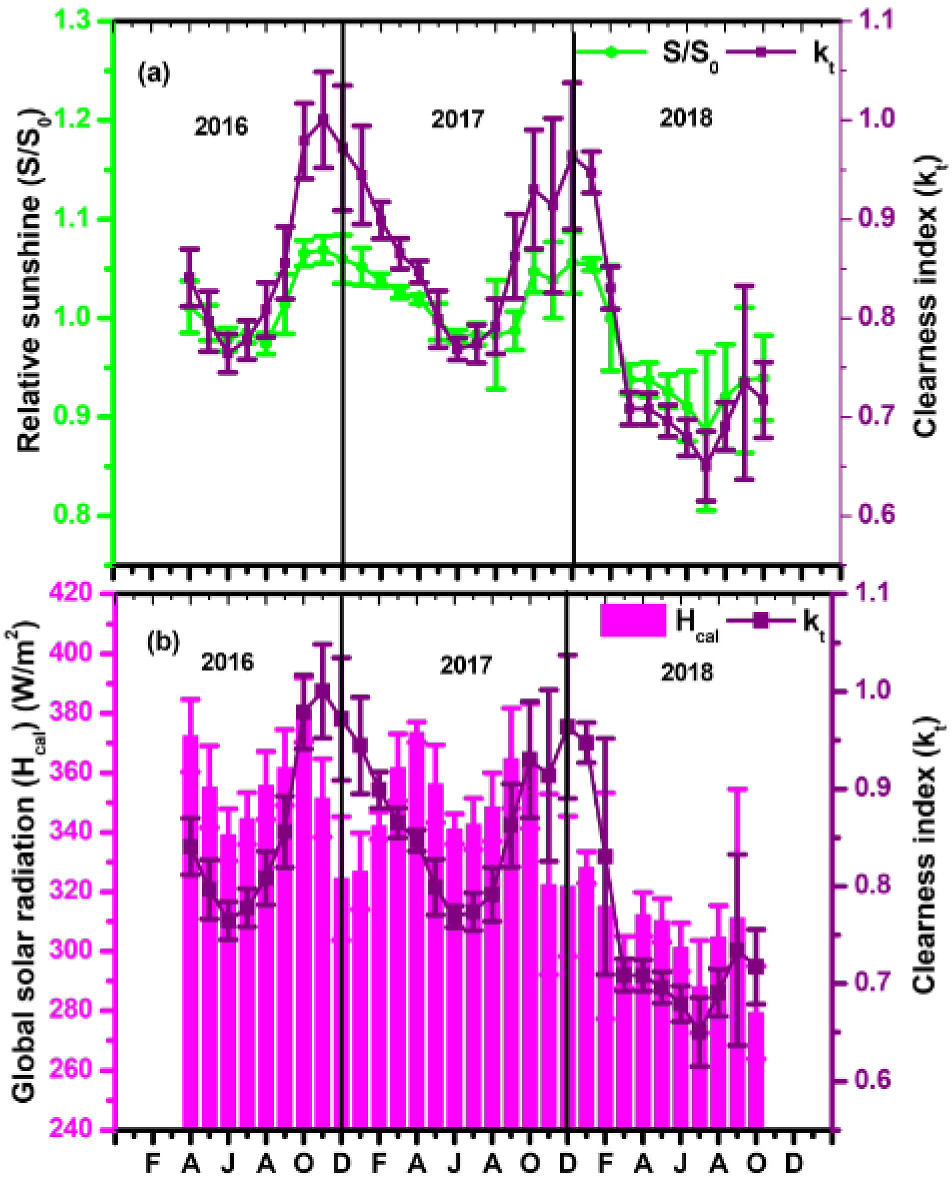

Fig. 3

Figure 3

Monthly variation of (a) relative sunshine and (b) global solar radiation with clearness index over the study location.

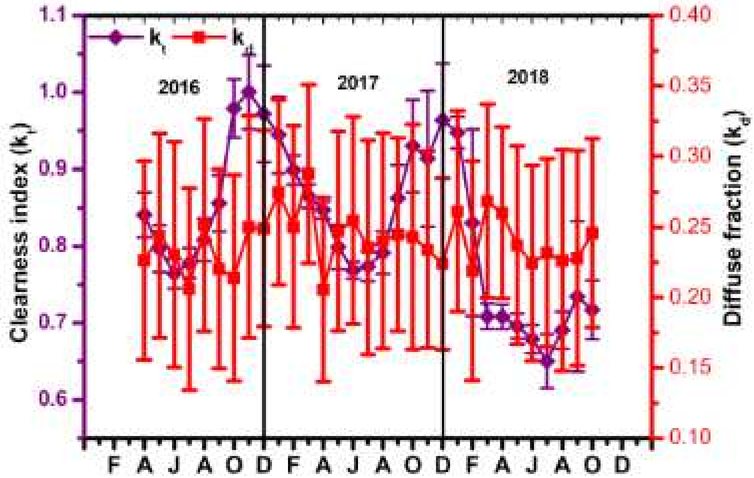

Fig. 4

Figure 4

Monthly variation of clearness index (k_t) and diffuse fraction (k_d) over the study.

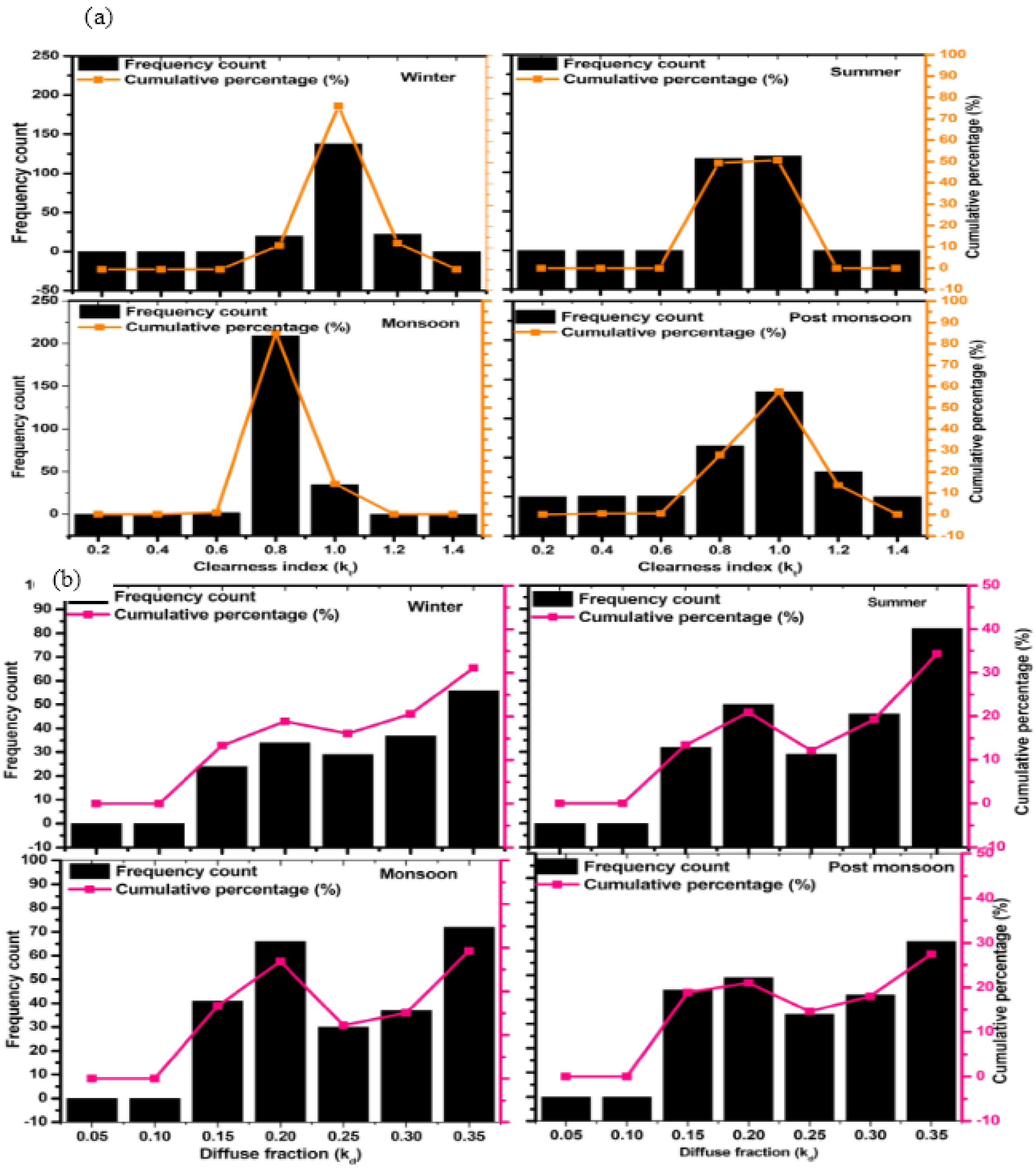

Fig. 5

Figure 5

The seasonal pattern of frequency and cumulative frequency of (a) clearness index (k_t) and (b) diffuse fraction (k_d) in Kadapa for the years 2016–2018.

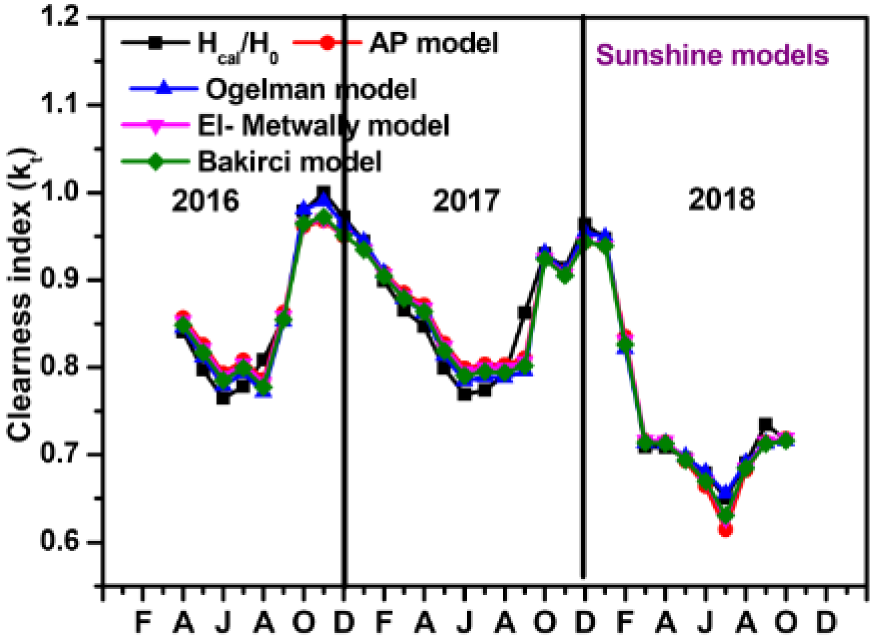

Fig. 6

Figure 6

Monthly variation of calculated and estimated global solar radiation using sunshine based models.

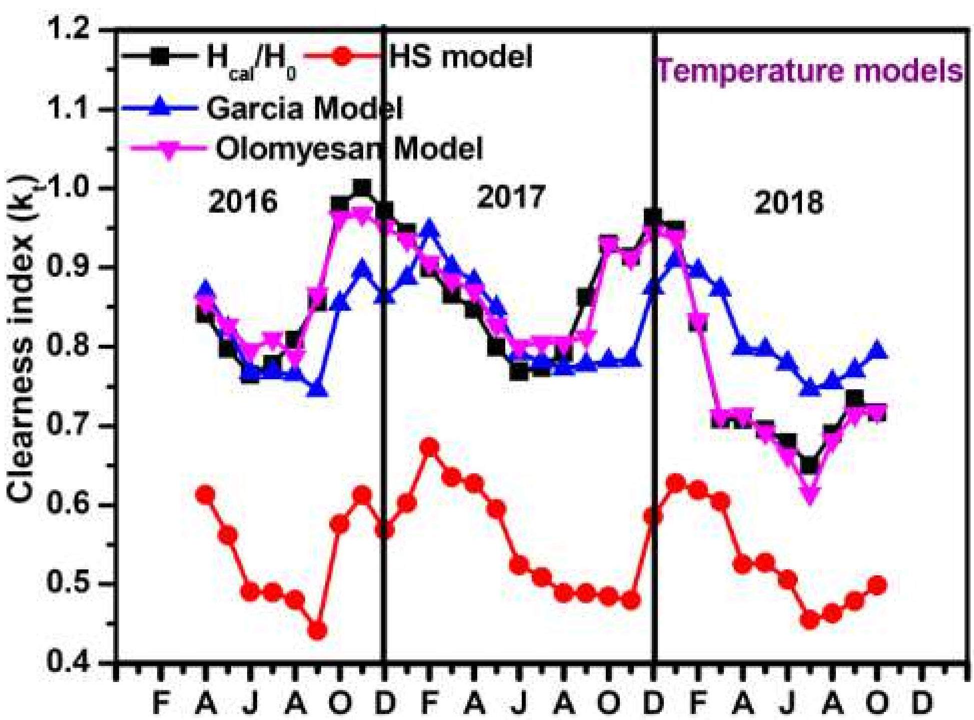

Fig. 7

Figure 7

Monthly variation of calculated and estimated global solar radiation using temperature based models.

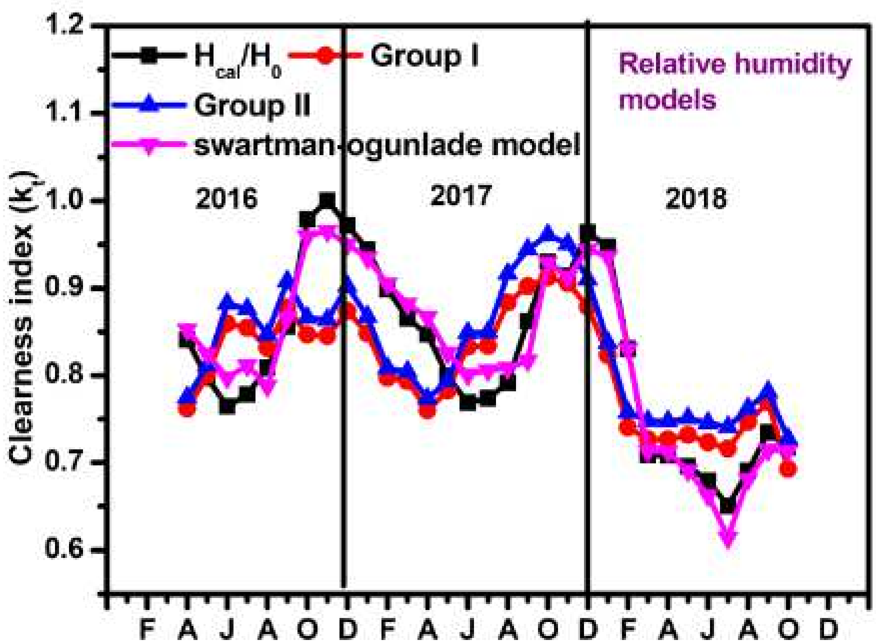

Fig. 8

Figure 8

Monthly variation of calculated and estimated global solar radiation using relative humidity based models.

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