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## Solar radiation estimation using sunshine hours for hot and humid climate of Konkan region

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**Abstract**

The accurate knowledge of the solar radiation intensity at a given location is of importance to the development solar system design, crop modeling and input to other modeling purpose. In the present study an attempt was made to estimate the different components of solar radiation such Ra, Rs, Rnl, Rns, Rn using methodology suggested by FAO- 56 method based on the sunshine hours and temperatures for Alibag station using 24 years weekly climatic data with 1240 observations. The correlation analysis showed that net solar radiations (Rn) showed maximum positive correlation coefficient was observed for sunshine hours followed by maximum and minimum temperature. These results indicated that the different components of solar radiation are highly influenced by sunshine hours followed by maximum temperature. This correlation analysis is helpful for development of empirical equations under limited or lack of climatic parameters. The study also found that the different component of solar radiation such as extraterrestrial radiation (Ra), clear sky solar radiation (Rso), Net shortwave solar radiation (Rns), Net long wave solar radiation (Rnl), Net solar radiation (Rn) estimated by FAO-56 method can be used for crop modeling and input to other models. The derived weekly values had revealed the more error during monsoon season which might be due to cloudy conditions and heavy rainfall. The study also developed linear regression equation  $R_n = 0.652 * T_{mean} + 0.635 * SSH - 10.874$  which can be used for prediction of solar radiation with considerable accuracy during the summer and winter season when compared with FAO-56 method.

**Keywords:** Extraterrestrial radiation (Ra), Clear sky solar radiation (Rso), Net shortwave solar radiation (Rns), Net long wave solar radiation (Rnl), Net solar radiation (Rn), FAO-56 method, linear regression

**Introduction**

The accurate knowledge of the solar radiation intensity at a given location is of importance to the development of solar energy system design. This information is used in the design, cost and effectiveness estimation of a project. Further, monthly mean daily data are needed for the estimation of long-term solar systems performances such as the simulation of solar energy systems require, at the least, knowledge of daily values of global solar radiation on a horizontal surface. Thus, accurate estimation of daily values of global radiation data is essential for the design and long-term evaluation of solar energy conversion systems performances, such as in the design of a solar project, meteorological forecasting, solar heating, drying and architectural design.

The values of the daily global irradiation measurements are not available at every location due to the cost of measuring equipment, maintenance, and calibration. In places where no measured values are available, a common application has been to determine this parameter by appropriate correlations, which are empirically, established using the measured data. Several empirical models have been used to calculate solar radiation, utilizing available meteorological, climatological, and geographical parameters such as sunshine hours, air temperature, latitude, precipitation, relative humidity, and cloudiness.

The most commonly used parameter for estimating global solar radiation is sunshine duration. Sunshine duration can be easily and reliably measured, and data are widely available. Most of the models for estimating solar radiation that appear in the literature use the sunshine ratio. The most widely used method is that of Angstrom, who proposed a linear relationship between the ratio of average daily global radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration.

In above application, the most important parameters that are often needed are the average solar irradiation and its components; measurements of which are not available at every location especially in developing countries due to cost, maintenance and calibration requirements of the measuring equipment. Due to lack of instructions and availability of climatic data Allen *et al.* (1998) [11] described the method for prediction of solar radiation based on the sunshine hours in irrigation and drainage paper no. 56 Allen *et al.* (1998) [11]

Jakhrani, *et al.* (2010) [2] evaluated the various models for the estimation of monthly average global solar radiation from bright sunshine hours and other meteorological parameters the required data for the suggested model is usually available in the most meteorological sites. The proposed model demonstrated acceptable results, and statistically displayed lower RMSE and MBE as compared to the examined models. It could be a good estimator for predicting the global solar radiation in coastal and humid areas. Katiyar and Pandey (2010) [3] used measured data of the global solar radiation along with the bright sunshine hours of four prominent cities *viz.* Jodhpur, Calcutta, Bombay, and Pune. It is observed that in comparison to first order, second and the third order Angstrom type correlations do not improve the accuracy of the estimated global radiation for all four cities and developed first order Angstrom type correlations and constants, applicable to all Indian locations. Srivastava and Pandey, (2013) [9] developed the solar radiation model for places where measurements are not carried out and for places where measurement records are not available. The study found that Angstrom-PreScott model parameters are estimated for seven different sites in India was found to be a good fit. They also developed correlation for predicting the solar radiation using only sunshine hour data. Gana and Akpootu (2013) [1] developed regression constants for the first order Angstrom-type correlations for Kebbi based monthly calculated clearness index and monthly sunshine. It was observed that the quadratic equation model performed better in terms of coefficient of determination ( $R^2$ ) and correlation coefficient. Onyango and Ongoma (2015) estimated the total solar radiation potential over Nairobi City using several theoretical models based on bright sunshine hours the study revealed that most models tested in the current studies were able to adequately estimate daily mean monthly global radiation from sunshine duration with Akinoglu and Ecevit model giving the best estimation

Razika *et al.* (2015) [8] developed the correlations in order to estimate solar radiation using sunshine hours, maximum temperature and relative humidity. The study observed that the quadratic equation model performed better in terms of coefficient of determination than the  $R^2$  and RMSE than other models. The agreement between the measured and monthly model was remarkable and this model is recommended for use in M'sila region. Meenal and Selvakumar, (2016) [4] estimate the global solar radiation on horizontal surface using sunshine duration, maximum temperature and minimum temperature using linear Angstrom and non-linear polynomial relations for 10 years period data at Chennai. The result of the correlations shows that sunshine duration based model gives the best result with a coefficient of determination of  $R^2 = 0.9784$ . The results revealed that models using sunshine hours had the smallest values of MBE, MAPE, MABE and RMSE of 0.0516, 0.6449, 0.5855 0.6953 respectively. Hence the regression equations using sunshine duration can be used to predict the GSR of the representative regions in the absence of experimental data. Namrata, *et al.* (2016) [5] developed a

linear regression model for estimating radiation for some selected cities of Jharkhand region. The proposed model was preferred for estimation of solar radiation in Ranchi, with smallest statistical errors among all models and close agreement with measured data. Qingwen Zhang (2018) [7] evaluated the capability of 12 solar radiation models based on meteorological data obtained from 21 meteorological stations in China. The results showed that, the sunshine-based models were more accurate than the temperature-based models and the BC model is recommended to estimate both daily and monthly average daily when only temperature data are available. Tihomir *et al.* (2020) [10] assessed the performance of seventeen sunshine-duration-based models at Croatia. The study found that the Rietveld model was found to perform the best overall, followed by Soler and Dogniaux-Lemoine monthly dependent models. For three best-performing models, new adjusted coefficients are calculated, and they are validated using separate dataset. Only the Dogniaux-Lemoine model performed better with adjusted coefficients, but across all analyzed locations, the adjusted models showed improvement in reduced maximum percentage error.

Based on the above reviews, it was revealed that the bright sunshine hours and ambient temperature found best for predicting of solar radiation under limited data conditions or lack of measured data. In the present study an attempt was made to estimate the solar radiation using the sunshine hours as suggested of Allen *et al.* (1998) [11] and to develop simple linear regression equation based on sunshine hour or temperature for prediction of solar radiation for Alibag station

## Materials and Methodology

### Study area and climatic data

The study was carried out at for Alibag station which is located in coastal belt of Maharashtra State. The region is characterized as humid zone. The climatic conditions are typical coastal i.e. hot and humid. The region comes under heavy rainfall with average annual rainfall more than 3500 mm. Three meteorological data of Alibag station was used for estimation of solar radiation namely  $T_{max}$ ,  $T_{min}$ ,  $RH_{max}$ ,  $RH_{min}$ ,  $SSH$ ,  $WS$  at 2 m height. Daily data from year 1991 to 2014 i.e. 24 years was used for analysis. The data was analyzed on daily basis and clumped into standard meteorological weeks (MW) for further analysis.

### Estimation of solar radiation using sunshine hours

The solar radiation can be estimated using daily sunshine hours ( $n$ ). The detailed stepwise calculation procedures as suggested by Allen *et al.* (1998) [11] and Lincoln Zotarelli *et al.* (2010) [12] for solar radiation is given as

#### 1) The inverse relative distance Earth-Sun ( $d_r$ ) and solar declination ( $\delta$ )

$$d_r = 1 + 0.033 \cos \left[ \frac{2\pi}{365} J \right]$$

$$\delta = 0.409 \sin \left[ \frac{2\pi}{365} J - 1.39 \right]$$

Where,  $J$  = number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

#### 2) Conversion of latitude ( $\lambda$ ) in degrees to radians

The latitude,  $\lambda$ , expressed in radians is positive for the northern hemisphere and negative for the southern

hemisphere (see example below). The conversion from decimal degrees to radians is given by

$$\varphi[\text{Radians}] = \frac{\pi}{180} \varphi[\text{decimal degrees}]$$

### 3) Sunset hour angle (...s)

The sunset hour angle (...s) is given by:

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

Where,  $\varphi$  = latitude expressed in radians,  $\delta$  = solar declination,

### 4) Extraterrestrial radiation (Ra)

The extraterrestrial radiation, Ra, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [(\omega_s \sin \varphi \sin \delta) + (\cos \varphi \cos \delta \sin \omega_s)]$$

Where, Ra = extraterrestrial radiation, MJ m<sup>-2</sup> day<sup>-1</sup>; G<sub>sc</sub> = solar constant = 0.0820 MJ m<sup>-2</sup> min<sup>-1</sup>; d<sub>r</sub> = inverse relative distance Earth-Sun. s = sunset hour angle, rad,  $\varphi$  = latitude, rad,  $\delta$  = solar declination, rad,

### 5) Clear sky solar radiation (Rso)

The calculation of the clear-sky radiation is given by:

$$R_{so} = (0.75 + 2E10^{-5}z)R_a$$

Where, z = elevation above sea level, m; Ra = extraterrestrial radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,

### 6) Net solar or net shortwave radiation (Rns)

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1 - a)R_s$$

Where, R<sub>ns</sub> = net solar or shortwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>; a = albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop, dimensionless; R<sub>s</sub> = the incoming solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup>

### 7) Net outgoing long wave solar radiation (Rnl)

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law.

$$R_{nl} = \sigma \left[ \frac{T_{\max,K}^4 + T_{\min,K}^4}{2} \right] \left( 0.34 - 0.14 \sqrt{\epsilon_a} \right) \left( 1.35 \frac{R_s}{R_{so}} - 0.35 \right)$$

Where, R<sub>nl</sub> = net outgoing longwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,  $\sigma$  = Stefan-Boltzmann constant [4.903 10<sup>-9</sup> MJ K<sup>-4</sup> m<sup>-2</sup> day<sup>-1</sup>], T<sub>max</sub> = K maximum absolute temperature during the 24-hour period [K = °C + 273.16], T<sub>min</sub> = K minimum absolute temperature during the 24hour period [K = °C + 273.16],  $\epsilon_a$  =

actual vapor pressure, kPa, R<sub>s</sub> = the incoming solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup> R<sub>so</sub> = clear sky solar radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,

### 8) Actual vapor pressure (ea) derived from relative humidity

The actual vapor pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations should be used.

$$e_a = \frac{e_{(T_{\min})} \left[ \frac{RH_{\max}}{100} \right] + e_{(T_{\max})} \left[ \frac{RH_{\min}}{100} \right]}{2}$$

Where, ea = actual vapour pressure, kPa; e(T<sub>min</sub>) = saturation vapour pressure at daily minimum temperature, kPa, e(T<sub>max</sub>) = saturation vapour pressure at daily maximum temperature, kPa, RH<sub>max</sub> = maximum relative humidity, %; RH<sub>min</sub> = minimum relative humidity, %.

### 9) Net radiation (Rn)

The net radiation (Rn) is the difference between the incoming net shortwave radiation (R<sub>ns</sub>) and the outgoing net longwave radiation (R<sub>nl</sub>):

$$R_n = R_{ns} - R_{nl}$$

Where, R<sub>ns</sub> = net solar or shortwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>, R<sub>nl</sub> = net outgoing longwave radiation, MJ m<sup>-2</sup> day<sup>-1</sup>,

## Results and Discussion

### Correlation between the solar radiation, temperature and sunshine hours

The correlation analysis between the climatic parameters and solar radiation components such as net shortwave (R<sub>ns</sub>), net longwave (R<sub>nl</sub>) and net solar radiation (R<sub>n</sub>) is shown in Table 1. The analysis revealed that net shortwave radiation shown the positive correlation with maximum temperature and sunshine hours while it also shown the negative correlation with minimum temperature. The highest correlation coefficient of 0.87 was observed with sunshine hours which clearly indicated that net shortwave radiation significantly depends upon the sunshine hours. Net longwave (R<sub>nl</sub>) radiation indicated the negative correlation with maximum and minimum temperature and significantly higher positive correlation with sunshine hours. The net solar radiations (R<sub>n</sub>) show the positive correlation with temperature and sunshine hours. The maximum correlation coefficient was observed for sunshine hours followed by maximum temperature and minimum temperature. These results indicated that the different components of solar radiation are highly influenced by sunshine hours followed by the temperature. This relationship will helpful for development of empirical equations under limited or lack of climatic parameters.

### Estimation of different component of solar radiation

The component of solar radiation such as extraterrestrial radiation (Ra), clear sky solar radiation (R<sub>so</sub>), Net shortwave solar radiation (R<sub>ns</sub>), Net long wave solar radiation (R<sub>nl</sub>), Net solar radiation (R<sub>n</sub>) were estimated and described as below.

### Extraterrestrial radiation (Ra)

The descriptive statistic for different components of solar radiation was determined using 24 years weekly data (1248 observations) and presented in Table 2. The extraterrestrial

radiation (Ra) was ranged from 39.27 MJ/m<sup>2</sup>/day to 26.38 MJ/m<sup>2</sup>/day with average of 34.22 MJ/m<sup>2</sup>/day. The standard error and standard deviation was 0.13 and 4.68 respectively. The sample variance was 21.92. Negative skewness (Cs = -0.43) indicated a distribution with an asymmetric tail extending toward more negative values and the negative kurtosis (Ck = -1.38) indicated a relatively flat distribution

#### Net shortwave solar radiation (Rns)

The net shortwave radiation was estimated based on the solar radiation (Rs) and clear sky radiation (Rso). The maximum net shortwave radiation was 23.86 MJ/m<sup>2</sup>/day and minimum of 7.35 MJ/m<sup>2</sup>/day with the mean value of 13.90 MJ/m<sup>2</sup>/day. The standard deviation was less than 3 per cent with variance of 8.65. The negative value of kurtosis shown that the distribution is relatively flat distribution and skewness indicates the symmetry of distribution around its mean. The range between the maximum and minimum net shortwave solar radiation was 16.51 MJ/m<sup>2</sup>/day.

#### Net long wave solar radiation (Rnl)

The net longwave radiation was ranged from 7.99 MJ/m<sup>2</sup>/day to 0.36 MJ/m<sup>2</sup>/day with the average of 2.87 MJ/m<sup>2</sup>/day. The standard error was very less about 0.04 %. The percent deviation in the analyzed data period was about 1.32 %. The skewness shows the asymmetric data and extended towards the negative values while kurtosis shown the flat distribution.

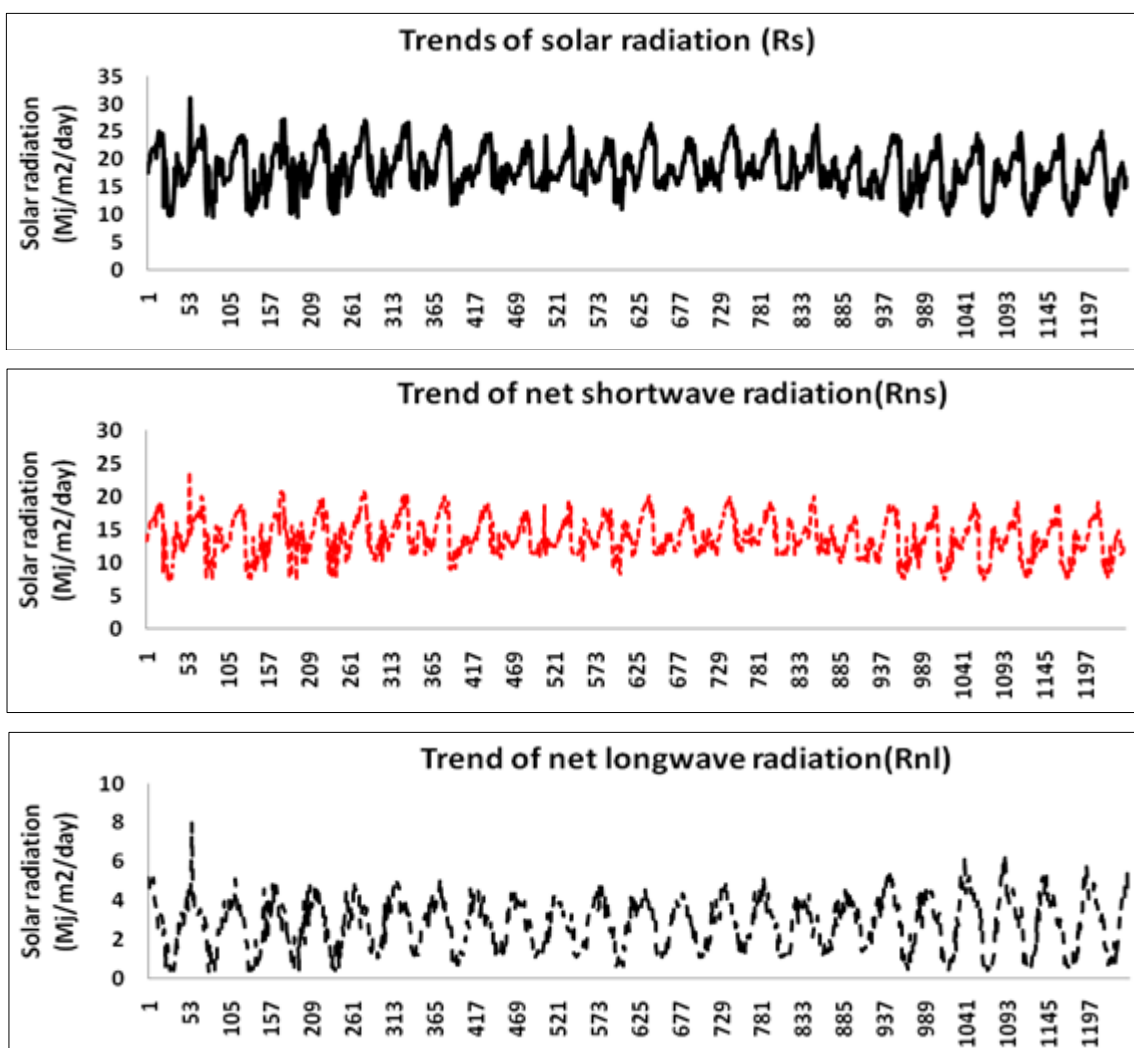
#### Net solar radiation (Rn)

The negative value of kurtosis shown that the distribution is

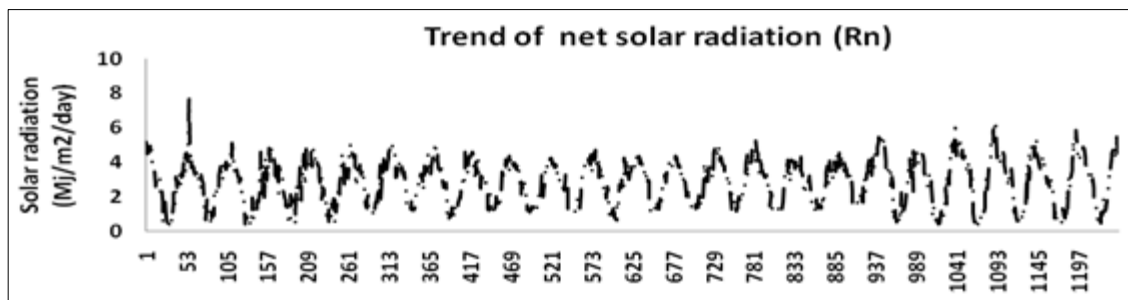
relatively flat distribution and positive value of skewness indicates the symmetry of distribution around its mean. The range between the maximum and minimum net radiation was 11.66 MJ/m<sup>2</sup>/day. The net radiation is the difference between the short and long wave solar radiation. The maximum net radiation was 17.44 MJ/m<sup>2</sup>/day and minimum of 5.78 MJ/m<sup>2</sup>/day with the mean value of 11.03 MJ/m<sup>2</sup>/day. The standard deviation was less than 7 per cent with variance of 6.13. The range between the maximum and minimum net solar radiation was 11.66 MJ/m<sup>2</sup>/day.

#### Development of linear regression equation

For estimation of net solar radiation based on the mean temperature and solar radiation the linear regression equation method was used. The estimated net solar radiation derived by FAO-56 method was considered as dependent parameters and climatic parameters like mean temperature and sunshine hours as independent. The regression coefficients were derived and equation was developed. The developed equation was used for prediction of net radiation (Rn) i.e.  $R_n = 0.652 * T_{mean} + 0.635 * SSH - 10.874$ . The coefficient of correlation between the predicted value by FAO-56 method and developed regression equation shown the correlation coefficient of  $r = 0.81$  and average standard error of 1.40 MJ/m<sup>2</sup>/day. The average per cent error was 1.77 %. The seasonal data analysis also indicated that there was large variation in predicted values and that of estimated by FAO-56 method during the monsoon season, which might be due to dense cloud cover, less temperature and heavy rainfall.







**Fig 1:** Trends of solar radiation (Ra), Net shortwave (Rns), Net longwave (Rnl), net solar radiation (Rn).

**Table 1:** Correlation between the climatic parameters and radiation components

	Tmax(oC)	Tmin(oC)	Tmean	SSH	Rns	Rnl	Rn
Tmax(oC)	1						
Tmin(oC)	0.45	1.00					
Tmean	0.76	0.92	1.00				
SSH	0.25	-0.44	-0.21	1.00			
Rns	0.33	-0.03	0.12	0.87	1.00		
Rnl	-0.03	-0.76	-0.57	0.85	0.55	1.00	
Rn	0.41	0.37	0.45	0.58	0.90	0.12	1

**Table 2:** Descriptive statistics of different estimated radiation components

	Ra	Rso	Rs	Rns	Rnl	Rn
Minimum	26.38	19.79	9.55	7.35	0.36	5.78
Maximum	39.27	29.46	30.98	23.86	7.99	17.44
Mean	34.22	25.67	18.05	13.90	2.87	11.03
Standard Error	0.13	0.10	0.11	0.08	0.04	0.07
Deviation	4.68	3.51	3.82	2.94	1.32	2.48
Variance	21.92	12.34	14.59	8.65	1.74	6.13
Kurtosis	-1.38	-1.38	-0.47	-0.47	-0.85	-0.58
Skewness	-0.43	-0.43	0.07	0.07	-0.11	0.49
Range	12.89	9.67	21.44	16.51	7.63	11.66

## Conclusions

The analysis of different components of solar radiation such Ra, Rn, Rnl, Rns estimated by FAO-56 method can be used under limited or lack of climatic data or radiation data. The study also observed that under lack of radiation data the developed regression equation  $Rn = 0.652 * Tmean + 0.635 * SSH - 10.874$  can be used for prediction of solar radiation with considerable accuracy during the summer and winter season.

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