ESTIMATION OF DIFFUSE FRACTION OF GLOBAL SOLAR RADIATION OVER A SEMI-ARID REGION, ANANTAPUR, A.P.

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Abstract: In the present study, the estimation of diffuse fraction based on clearness index (k_t) and relative sunshine (S/S_0) over Anantapur region (14.62ºN, 77.65º E and 331m asl) during January 2016 to September 2017 was calculated. The clearness index and relative sunshine was high in the month of February 2017 (0.84±0.01 and 0.64±0.01) and low in the month of June 2016 (0.65±0.09 and 0.51±0.07). The regression analysis was employed to correlate the diffuse fraction with clearness index and relative sunshine. Four models are proposed to estimate the diffuse fraction; Page model, Liu and Jordan model, Iqbal model and Gopinathan model. These proposed models are compared with the well-established models from literature. The statistical analysis were observed between proposed and literature model values of diffuse fraction such as such as mean bias error (MBE), mean percentage error (MPE), root mean square error (RMS), coefficient of correlation (R), coefficient of determination (R^2), in this Liu and Jordan model has minimum values of MBE, MPE and RMSE. This indicates that this model is good model for all proposed models having coefficient of determination R^2=0.98.

Index terms: **Diffuse fraction, clearness index, relative sunshine.**

I. INTRODUCTION

Solar radiation plays an important role as a renewable energy source as solar radiation measurements. These can be used to estimate potential power levels that can be generated from photovoltaic cells and also necessary for determining cooling loads for buildings [1]. The recording of the solar radiant energy on the earth's surface is a requirement not only in the studies of climate change, environmental pollution but also in agriculture, hydrology, food industry and non-conventional energy development programs. 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 (µ-rays) to10^{8} µm (radio waves) [2]. The terrestrial solar spectrum deviates from extra-terrestrial spectrum because of various absorptions in the earth's atmosphere [3]. The utilization of solar energy, like any other natural resources, requires detailed information on availability of the amount of total solar radiation striking the earth surface. This total amount of solar radiation incidents on the earth surface is called global solar radiation. The global solar radiation reaching the earth's surface is made up of two components, direct and diffuse. As the solar radiation passes through the atmosphere, it undergoes absorption and scattering by various constituents of the atmosphere. The amount of solar radiation finally reaching the surface of earth depends quite significantly on the concentration of airborne particulate matter, gaseous pollutants and water (vapour, liquid or solid) in the sky, which can further attenuate the solar energy and change the diffuse and direct radiation ratio. Solar radiation varies from one geographical location to another. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the day length. The ratio is known as fraction of sunshine hours (S/S_0). It is found to vary daily and seasonality. 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/m^2). This value is equivalent to the level of solar irradiance shortly after sunrise or shortly before sunset in cloud-free conditions.

A number of diffuse fraction models are available in the literature [4-9]. These models are usually expressed in terms of polynomial functions relating the diffuse fraction k_d to the clearness index k_t as well as to other variables such as solar altitude, air temperature and relative humidity. Such models require complex calculation methods. Diffuse radiation has been correlated with usually measured or more easily computable quantities. Generally two types of correlation are used: Diffuse radiation as a function of clearness index. Diffuse radiation as a function of fractional sunshine duration. By using this regression analysis, diffuse fraction can be estimated as a function of clearness index and relative sunshine values for Anantapur region during January 2016 to September 2017.

The monthly average clearness index (k_t) is measure of transparency of the atmosphere to the solar radiation. It is also called clearness index or coefficient of transmission. Clearness index is used in a number of energy industry equipment design procedures. Diffuse fraction is the how much amount of radiation can be diffused from the global solar radiation. Diffuse fraction models have been explored by various authors [10-15]. These all are established various models to correlate diffuse fraction with clearness index and relative sunshine duration.

This paper presented a comprehensive study of the prediction of the diffuse fraction of solar radiation from other ground variables, including clearness index, relative sunshine duration over the Anantapur region. The reliability and usability of these models mainly depends on the correlation between the predicted 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) and coefficient of determination (R^2).

II. 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 were carried out at Sri Krishnadevaraya University (SKU, 14.62°N, 77.65°E, 331m asl), from January 2016 to September 2017. 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 used to estimating the global solar radiation on a horizontal surface based on sunshine model is described by the equation as [16-18].

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

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 [19] and a, b are regression coefficients. Their values have been obtained from the relationship given by **R. C. Srivastava and Harsha Pandey** [20] as

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

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

The importance of this correlation lies in the fact 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, by using the sunshine duration method it allow 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) [21]** as follows,

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

where H_o extraterrestrial radiation [MJm^{-2}day^{-1}], G_{sc} solar constant = 0.0820 MJm^{-2} min^{-1}, d_r inverse relative 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:

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

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:

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

In this research, the diffuse fraction of models are classified according to the basis of their input parameters employed in correlating with the clearness index (k_t) and relative sunsine (S/S_0). It point outs the depletion of the incoming global solar radiation by the atmosphere and there for gives both the level of availability of solar irradiance at the surface of the earth and the changes in atmospheric conditions [22].

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

K_d is the diffuse fraction for the day, 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:

$$k_d = \frac{H_d}{H} \quad (11)$$

which is the transmission characteristics of diffuse solar radiation and hence mirror the effectiveness of the sky in transmitting diffuse solar radiation.

III. ESTIMATION OF DIFFUSE SOLAR FRACTION USING DIFFERENT MODELS

The following correlation models were used for the monthly mean daily diffuse solar fraction estimating on a horizontal surface. The comparison was based on the predicted irradiance data from Anantapur. The models involve the mathematical formulations with multiple coefficients whose values are generally valid for a specific location. Multiple regression analysis was carried out to develop the models. The proposed regression models are Liu and Jordan model, Page model, Iqbal model and Gopinathan model. In order to determine the regression coefficients for estimating the diffuse fraction to show the validation of relative sunshine duration and clearness index for Anantapur for the period of January 2016 to September 2017. The regression constants and the coefficient of determination R^2 values for different models were shown in Table 1. The results for the four models were summarized below;

$$\frac{H_d}{H} = -11.0399 + 60.39439k_t - 106.646k_t^2 + 62.08272k_t^3 \quad (12)$$

$$\frac{H_d}{H} = 0.5313 - 0.5215k_t \quad (13)$$

$$\frac{H_d}{H} = 0.4922 - 0.3511\left(\frac{S}{S_0}\right) \quad (14)$$

$$\frac{H_d}{H} = 0.528415 - 0.45866k_t + 0.04477\left(\frac{S}{S_0}\right) \quad (15)$$

Empirical models are also selected from literature for comparison with the proposed models. These are described as below:

Liu and Jordan model

$$\frac{H_d}{H} = 1.3900 - 4.0270k_t + 5.5310k_t^2 - 3.1080k_t^3 \quad (16)$$

Page model [23]

$$\frac{H_d}{H} = 1.00 - 1.13k_t \quad (17)$$

Iqbal model [24]

$$\frac{H_d}{H} = 1.2547 - 1.2055\left(\frac{S}{S_0}\right) \quad (18)$$

Gopinathan model

$$\frac{H_d}{H} = 1.1940 - 0.838k_t - 0.0446\left(\frac{S}{S_0}\right) \quad (19)$$

Table 1: Regression equations for proposed models

Models	Regression equations	R^2value
Liu and Jordan model	$\frac{H_d}{H} = -11.0399 + 60.39439k_t - 106.646k_t^2 + 62.08272k_t^3$	0.806
Page model	$\frac{H_d}{H} = 0.5313 - 0.5215k_t$	0.809
Iqbal model	$\frac{H_d}{H} = 0.4922 - 0.3511\left(\frac{S}{S_0}\right)$	0.771
Gopinathan model	$\frac{H_d}{H} = 0.528415 - 0.45866k_t + 0.04477\left(\frac{S}{S_0}\right)$	0.810

IV. STATISTICAL ANALYSIS

The comparison of observed values to the model values is very important to evaluate the models use of some statistical indicators, which gives the accuracy and applicability of the models. Evaluation of the performance of the proposed models in terms of standard errors was employed. Statistical error test of the results obtained from the proposed model Equations (12 to 15) and those nominated from the literature Equations (16 to 19) was performed using Mean Bias Error (MBE), Mean Percentage Error (MPE), Root Mean Square Error (RMSE), coefficient of correlation (R) and coefficient of determination (R^2).

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{est} - H_{pre}\right) \tag{20}$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{est} - H_{pre}}{H_{pre}}\right)*100 \tag{21}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{est} - H_{pre}\right)^2\right]^{\frac{1}{2}} \tag{22}$$

$$R = \frac{\sum\left[\left(H_{est} - \overline{H}_{est}\right)\times\left(H_{pre} - \overline{H}_{pre}\right)\right]}{\sqrt{\sum\left(H_{est} - \overline{H}_{est}\right)^2 \times \sum\left(H_{pre} - \overline{H}_{pre}\right)^2}} \tag{23}$$

The test of MBE provides information on the long-term performance of models studied. A positive MBE value gives the average amount of over-estimation in the calculated values and vice versa. In general, a small MBE is desirable. It should be noted; however, that over-estimation of an individual observation will cancel under-estimation in a separate observation. MPE gives long term performance of the examined regression equations, a positive MPE values provides the averages amount of overestimation in the calculated values, while the negatives value gives underestimation. A low value of MPE is desirable [25]. The RMSE test gives the information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the predicted and estimated values. The lower the RMSE, the more accurate is the estimate. The values of the MBE represent the systematic error, while the RMSE is a non-systematic error. For better data modelling, the coefficient of correlation (R) and coefficient of determination (R^2) should be closely one as possible. $\overline{H_{pre}}$ and $\overline{H_{est}}$ are the average values of predicted and estimated diffuse solar radiation.

V. RESULTS AND DISCUSSION

5.1. Monthly variation of solar radiation

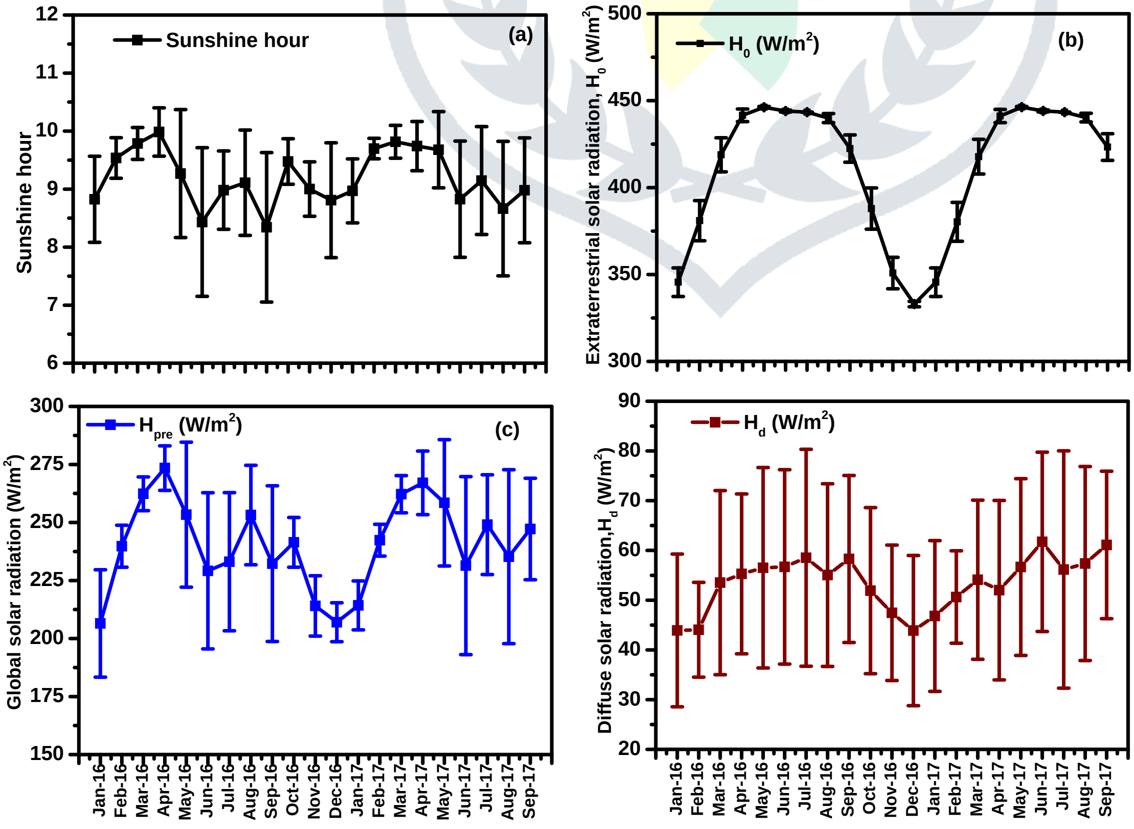

Fig.1. Monthly variation of (a) sunshine hour (b) extra-terrestrial solar radiation (c) global solar radiation and (d) diffuse solar radiation for Anantapur region during Jan 2016 to Sep 2017.

The monthly variation of sunshine hour (S), extraterrestrial solar radiation (H_0), global solar radiation (H) and diffuse solar radiation (H_d) is shown in Fig.1. The sunshine was 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 [26]. 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) [27]. The sunshine hour is directly affects the result of global solar radiation. From the above figure, the sunshine duration was gradually increases with increase in global solar radiation up to from December to April after that both the sunshine and global solar radiation were decreases due to rainfall and cloudy conditions in the months of June, July August and September. The highest values of monthly mean sunshine hour and monthly mean daily global solar radiation was observed in the month of April 2016 (9.98 hour and 273.42±9.60 W/m^2) due to sky that clear off cloud and some aerosol particles that attenuate the incident of solar radiation to the earth's surface. The lowest values of monthly mean sunshine hour and monthly mean daily global solar radiation was observed in September 2016 (8.34 hour) and January 2016 (206.50±23.13 W/m^2) respectively, due to presence of cloud, rainfall, suspension of water particles that lead to scattering, absorption and reflection of incoming solar radiation to the earth's surface [28]. The annual variation of extra-terrestrial, global and diffuse solar radiation values over the January 2016 to September 2017 was observed 411.28±5.31, 240.62±19.82 and 53.41±16.85 W/m^2 respectively. The monthly mean values of sunshine hour, extra-terrestrial solar radiation, global solar radiation and diffuse solar radiation was shown in Table 2. The Extra-terrestrial solar radiation is the radiation at the top of the atmosphere with an average of irradiance is 1367 W/m^2. The starting point in developing these expressions has been the instantaneous extra-terrestrial solar radiation on a surface normal to sun's rays. It also represents in terms of the solar constant and an expression in relationship of the day in the year, to take into account the varying distance between the sun and the earth from day to day. These values were depending on the finite time interval considered and also measured the other parameters are the latitude, declination and the hour angles. H_0 was high in the month of May 2016 (446.22±0.44 w/m^2) and low in the month of December 2016 (332.99±1.56 W/m^2) respectively. The maximum diffuse solar radiation was observed in the month of June 2017 (61.73±18.03 W/m^2) due the solar radiation received at the surface during the periods consists mainly of the diffuse components. This is consistent with the dependence of the diffuse solar radiation reaching the surface on solar elevation and atmospheric turbidity, air mass, atmospheric water vapour content and layer, and distribution of cloud cover in the regions during the period [29] and minimum was observed in December 2016 (43.88±15.10 w/m^2) due to the clouds and dust particles.

Table 2: The monthly mean values of sunshine hour, extra-terrestrial solar radiation, global solar radiation and diffuse solar radiation for Anantapur during January 2016 to September 2017.

Month	sunshine hour	H_0(W/m^2)	H_{pre}(W/m^2)	H_d(W/m^2)
Jan-16	8.824	345.587	206.509	43.915
Feb-16	9.537	380.981	239.777	44.051
Mar-16	9.786	418.860	262.360	53.530
Apr-16	9.984	441.605	273.420	55.283
May-16	9.268	446.225	253.372	56.510
Jun-16	8.433	444.021	229.170	56.683
Jul-16	8.982	443.392	233.107	58.525
Aug-16	9.110	439.974	253.186	55.043
Sep-16	8.342	422.453	232.281	58.282
Oct-16	9.476	387.928	241.444	51.924
Nov-16	9.001	350.835	214.047	47.460
Dec-16	8.809	332.993	207.026	43.889
Jan-17	8.969	345.587	214.281	46.816
Feb-17	9.699	380.299	242.353	50.636
Mar-17	9.816	417.781	262.199	54.102
Apr-17	9.741	441.186	267.084	52.009
May-17	9.678	446.253	258.467	56.660
Jun-17	8.827	444.084	231.420	61.734
Jul-17	9.147	443.399	249.076	56.164
Aug-17	8.664	440.254	235.270	57.368
Sep-17	8.979	423.329	247.196	61.103

5.2. Monthly variation of relative sunshine and clearness index

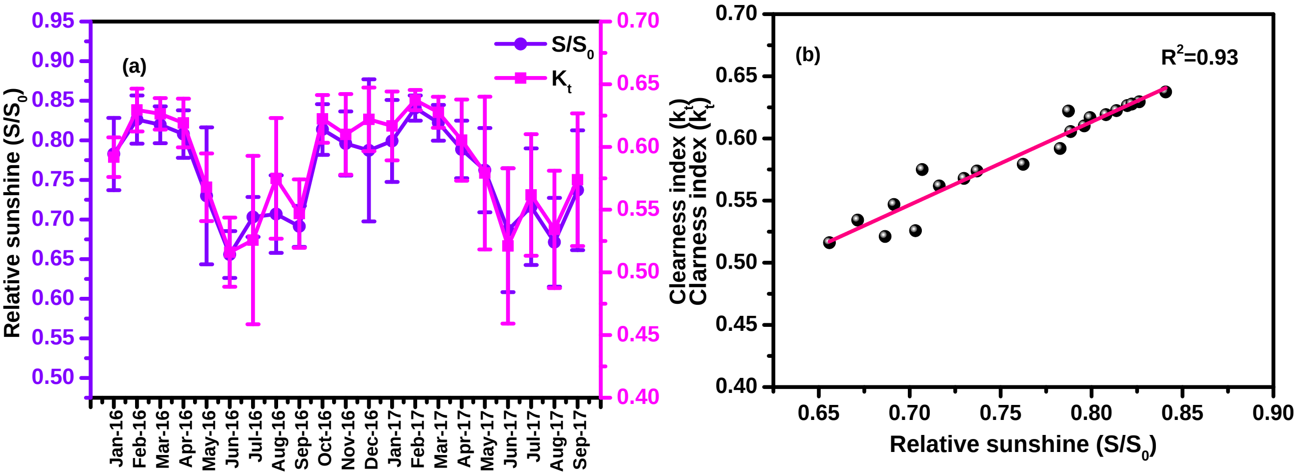

Fig.2. Monthly variation of clearness index (k_t) and relative sunshine (S/S_0) and their correlation for Anantapur region during Jan 2016 to Sep 2017.

The monthly variation and correlation of clearness index, relative sunshine for Anantapur for the period of January 2016 to September 2017 was shown in Fig. 2. Clearness index k_t (=H/H_0) is the percentage deflection by the sky of the incoming global radiation and therefore indicates both the level of availability of solar radiation and changes in atmospheric conditions in a given locality and time of the year considered [30]. If K_t<0.3 indicates very overcast sky, 0.3<k_t< 0.7 shows partly cloudy skies and k_t> 0.7 suggests the clear sky conditions [28]. According to WMO (2006) classification based on sunshine hour the sky condition is; 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 [31,32]. Relative sunshine duration is a key variable involved in the calculation procedures of several agricultural and environmental indices. Table 2. shows the average of predicted global solar radiation (H_{pre}), extra-terrestrial solar radiation (H_0), bright sunshine hour (S), monthly averaged day length (S_0) and clearness index (H_{pre}/H_0) respectively. The relative sunshine and clearness index are high in the month of February 2017 (0.84±0.01 and 0.64±0.01) and low in the month of June 2016 (0.65±0.09 and 0.51±0.07) with an annual average of 0.76±0.06 and 0.59±0.04. High values of clearness index indicate great availability of solar irradiation during dry season as the cloud is free from sky condition like cloud, aerosol and water vapour. From the above observations Anantapur location is clear sky in summer and winter seasons and partially cloud in monsoon and post monsoon seasons. The clearness index and relative sunshine are positively correlated with a correlation coefficient of 0.93.

Table 2: The monthly average values of relative sunshine and clearness indedx for Anantapur during January 2016 to September 2017.

Month	S	S_0	H_{pre}	H_0	S/S_0	$K_t=H_{pre}/H_0$
Jan-16	8.824	11.248	206.509	345.587	0.785	0.598
Feb-16	9.537	11.542	239.777	380.981	0.826	0.629
Mar-16	9.786	11.940	262.360	418.860	0.820	0.626
Apr-16	9.984	12.356	273.420	441.605	0.808	0.619
May-16	9.268	12.697	253.372	446.225	0.730	0.568
Jun-16	8.433	12.858	229.170	444.021	0.656	0.516
Jul-16	8.982	12.769	233.107	443.392	0.703	0.526
Aug-16	9.110	12.465	253.186	439.974	0.731	0.575
Sep-16	8.342	12.060	232.281	422.453	0.692	0.550
Oct-16	9.476	11.645	241.444	387.928	0.814	0.622
Nov-16	9.001	11.307	214.047	350.835	0.796	0.610
Dec-16	8.809	11.154	207.026	332.993	0.790	0.622
Jan-17	8.969	11.248	214.281	345.587	0.797	0.620
Feb-17	9.699	11.536	242.353	380.299	0.841	0.637
Mar-17	9.816	11.926	262.199	417.781	0.823	0.628
Apr-17	9.741	12.343	267.084	441.186	0.789	0.605
May-17	9.678	12.688	258.467	446.253	0.763	0.579
Jun-17	8.827	12.857	231.420	444.084	0.687	0.521
Jul-17	9.147	12.775	249.076	443.399	0.716	0.562
Aug-17	8.664	12.477	235.270	440.254	0.694	0.534
Sep-17	8.979	12.074	247.196	423.329	0.744	0.584

5.3. Monthly variation of relative sunshine and diffuse fraction

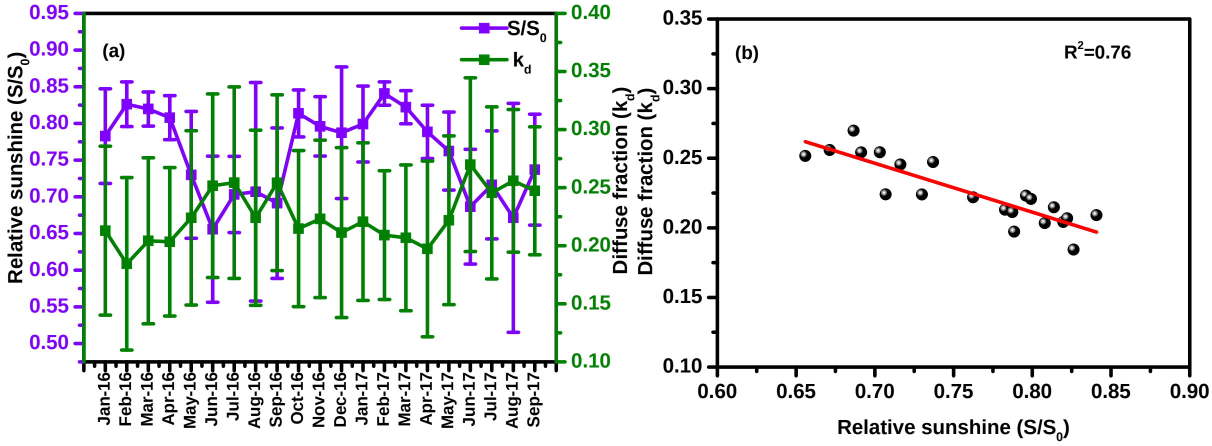

Fig.3. Monthly variation of diffuse fraction (k_d) and relative sunshine (S/S_0) and their correlation for Anantapur region during Jan 2016 to Sep 2017.

The relative sunshine could be used as an estimator of the diffuse fraction of daily global solar radiation because most of the variability in the daily values of clearness index can be explained by changes in the relative sunshine [33,34]. The monthly variation and correlation between the relative sunshine and diffuse fraction of solar radiation is shown in Fig.3. The monthly mean relative sunshine was high in the month of February 2017 (0.84±0.01) and low in the month of June 2016 (0.65±0.09) and the monthly mean diffuse fraction was high in the month of June 2017 (0.27±0.07) and low in the month of February 2016 (0.18±0.03) respectively with an annual variation of 0.76±0.06 and 0.23±0.07 for relative sunshine and diffuse fraction during the period January 2016 to September 2017 was observed. These monthly mean values are denoted in Table 3. From the above Figure the relative sunshine and diffuse fraction were negatively correlated with correlation coefficient of 0.76.

Table 3: The monthly average values of relative sunshine and diffuse fraction for Anantapur during January 2016 to September 2017.

Month	S	S_0	H_{pre}	H_d	S/S_0	$K_d=H_d/H_{pre}$
Jan-16	8.824	11.248	206.509	43.985	0.785	0.213
Feb-16	9.537	11.542	239.777	55.726	0.826	0.184
Mar-16	9.786	11.940	262.360	53.584	0.820	0.204
Apr-16	9.984	12.356	273.420	55.610	0.808	0.203
May-16	9.268	12.697	253.372	56.753	0.730	0.224
Jun-16	8.433	12.858	229.170	56.632	0.656	0.252
Jul-16	8.982	12.769	233.107	59.993	0.703	0.254
Aug-16	9.110	12.465	253.186	56.938	0.731	0.224
Sep-16	8.342	12.060	232.281	59.053	0.692	0.254
Oct-16	9.476	11.645	241.444	51.849	0.814	0.215
Nov-16	9.001	11.307	214.047	47.756	0.796	0.223
Dec-16	8.809	11.154	207.026	44.544	0.790	0.211
Jan-17	8.969	11.248	214.281	47.300	0.797	0.221
Feb-17	9.699	11.536	242.353	62.389	0.841	0.209
Mar-17	9.816	11.926	262.199	54.227	0.823	0.207
Apr-17	9.741	12.343	267.084	52.679	0.789	0.197
May-17	9.678	12.688	258.467	57.364	0.763	0.222
Jun-17	8.827	12.857	231.420	62.433	0.687	0.270
Jul-17	9.147	12.775	249.076	61.147	0.716	0.245
Aug-17	8.664	12.477	235.270	60.198	0.694	0.256
Sep-17	8.979	12.074	247.196	61.118	0.744	0.247

5.4. Monthly variation of clearness index and diffuse fraction

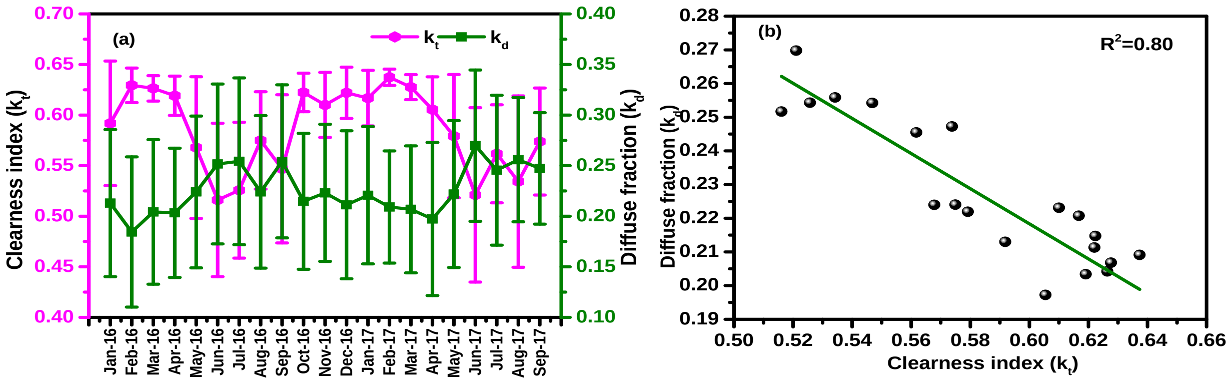

Fig.4. Monthly variation of clearness index (k_t) and diffuse fraction (k_d) and their correlation for Anantapur region during Jan 2016 to Sep 2017.

Figure 4. shows that the monthly variation of clearness index and diffuse fraction and its correlation for Anantapur region during January 2016 to September 2017. K_t and k_d gives the sky conditions in the process of transmitting and scattering of incoming solar radiation. The clearness index low means global solar radiation was low which gives the cloudy sky with highest percentage of diffuse components. High clearness index means higher the global solar radiation which dominated by the direct component. From the above figure, the two parameters are inversely proportional to each other; higher the clearness index lowers the diffuse fraction for all the months and these two are correlated with correlation coefficient of 0.54. For Anantapur region the k_t value range between 0.52-0.64 and the k_d value range between 0.19-0.27 respectively. The highest clearness index was observed in the month of February 2017 (0.64±0.01) and lowest in the month of June 2016 (0.52±0.07). The variation in clearness index is due to the level of humidity and the position of the sun relative to the observation site. The diffuse fraction was high in the month of June 2017 (0.27±0.07) and low in the month of February 2016 (0.18±0.03). The average values of clearness index and diffuse fraction were 0.59±0.04 and 0.23±0.07 respectively for the entire study period.

5.5. Monthly variation of Predicted and estimated diffuse fraction using different models

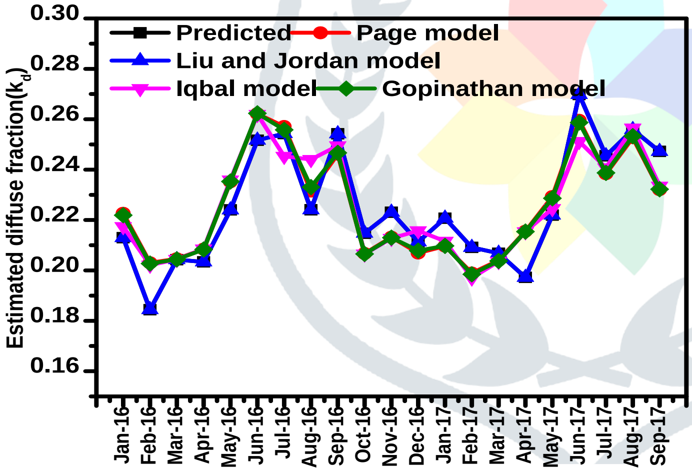

Fig.5. Monthly variation of predicted and estimated diffuse fraction (k_d) by using different models for Anantapur region during Jan 2016 to Sep 2017.

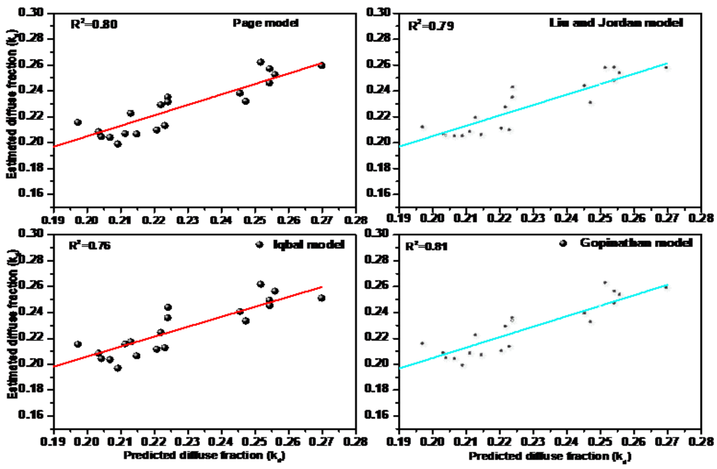

Fig.6. Scatter plots between predicted and estimated diffuse fraction for different developed models.

The comparison between predicted and estimated diffuse solar fraction using different models shown in equations (12 to 15) to estimating the diffuse fraction during the study period January 2016 to September 2017 is shown in Fig.(5) &(6). The result of the four models were summarised in below Table 4. The predicted and estimated diffuse fraction values are good correlated with correlation coefficients of 0.80, 0.79, 0.76 and 0.81 for Page model, Liu and Jordan model, Iqbal model and Gopinathan model is shown in Fig. (6) respectively. From the above results Gopinathan model was best correlated with our predicted results with correlation coefficient of 0.81. From the Fig.(5) the monsoon months are overestimated to the predicted values over the study period was observed.

Table 4: shows the predicted and estimated diffuse fraction using different models that are Page, Liu and Jordan, Iqbal and Gopinathan models.

Month	k_t	S/S_0	k_d	Page model	Liu and Jordan model	Iqbal model	Gopinathan model
Jan-16	0.592	0.783	0.213	0.223	0.219	0.217	0.222
Feb-16	0.629	0.826	0.184	0.203	0.204	0.202	0.203
Mar-16	0.626	0.820	0.204	0.205	0.205	0.204	0.204
Apr-16	0.619	0.808	0.20	0.208	0.206	0.209	0.208
May-16	0.568	0.730	0.224	0.235	0.234	0.236	0.235
Jun-16	0.516	0.656	0.251	0.262	0.257	0.262	0.262
Jul-16	0.526	0.703	0.254	0.257	0.258	0.245	0.256
Aug-16	0.575	0.707	0.224	0.231	0.242	0.244	0.233
Sep-16	0.547	0.691	0.254	0.246	0.247	0.249	0.247
Oct-16	0.622	0.814	0.214	0.207	0.205	0.207	0.207
Nov-16	0.610	0.796	0.223	0.213	0.209	0.213	0.213
Dec-16	0.622	0.787	0.211	0.207	0.208	0.216	0.208
Jan-17	0.617	0.799	0.220	0.210	0.210	0.212	0.210
Feb-17	0.637	0.841	0.209	0.199	0.205	0.197	0.198
Mar-17	0.628	0.822	0.206	0.204	0.205	0.204	0.204
Apr-17	0.605	0.789	0.197	0.216	0.211	0.215	0.215
May-17	0.579	0.762	0.221	0.229	0.227	0.225	0.229
Jun-17	0.521	0.687	0.269	0.260	0.257	0.251	0.259
Jul-17	0.562	0.716	0.245	0.238	0.243	0.241	0.239
Aug-17	0.534	0.671	0.255	0.253	0.253	0.256	0.253
Sep-17	0.574	0.737	0.247	0.232	0.230	0.233	0.232

5.6. Correlation of diffuse fraction with clearness index for different models

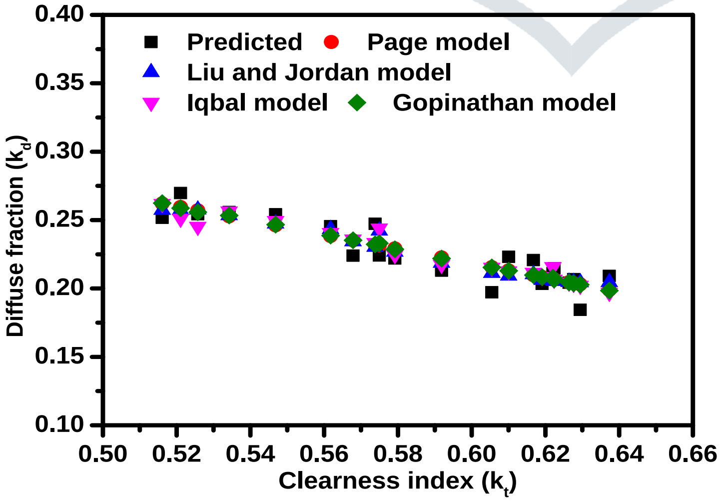

Fig.7. Correlation of diffuse fraction with clearness index for different models

The diffuse fraction of daily global solar radiation was highly correlated with K_t. The parameter K_t usually serves as an indicator of the relative clearness index of the atmosphere; it is affected primarily by the dust content of the atmosphere and by the amount of perceptible water as well; therefore it varies from one season to another season [35]. The correlation between predicted and estimated diffuse fraction by using different models for Anantapur region is shown in Fig.7. Clearness index was increases the diffuse fraction was decrease; at the higher clearness index value lower the diffuse fraction and vice versa was shown in Fig.7. Within each model, the developed simple linear regression models for the diffuse fraction of daily global radiation, using K_t as the independent variable. Regressions and equations obtained are given Table 1.

VI. EVALUATION OF MODELS

The results of the statistical error analysis of the different models were shown in Table 5. The coefficient of determination were varied from 0.63 to 0.98, this shows the good results between proposed models due to regression and models taken from literature values of diffuse solar radiation. The MBE values are ranges from 18.16 to 106.06 (W/m^2), the positive values of MBE indicates the over estimation. The RMSE values for the proposed models are varying from 19.39 (W/m^2) for Liu and Jordan model which is also a minimum value among all the RMSE. In all model representations the statistical errors of Liu and Jordan model have minimum values of MBE, MPE and RMSE. This indicates that this model is good model for all proposed models having coefficient of determination R^2=0.98.

Table 5: shows the summary of the model evaluations using the values from proposed models and literature values of diffuse solar radiation.

Model	MBE (W/m^2)	MPE (%)	RMSE (W/m^2)	R	R^2
Page model	27.66	50.55	28.33	0.96	0.93
Liu and Jordan model	19.39	35.71	19.58	0.99	0.98
Iqbal model	27.24	48.96	29.52	0.92	0.84
Gopinathan model	107.21	198.59	107.56	0.95	0.91

Month	Proposed model	Literature model	Proposed model	Literature model	Proposed model	Literature model	Proposed model	Literature model
	Page model	Page model	Liu and Jordan model	Liu and Jordan model	Iqbal model	Iqbal model	Gopinathan model	Gopinathan model
Jan-16	46.945	68.398	43.853	61.893	46.402	64.249	47.233	136.940
Feb-16	51.380	69.231	54.198	65.105	51.388	62.011	51.490	150.982
Mar-16	56.495	76.647	58.160	71.837	56.640	69.935	56.536	165.943
Apr-16	59.571	82.142	58.486	76.376	59.792	76.751	59.556	174.761
May-16	59.708	90.789	58.776	80.487	60.122	94.961	59.443	173.708
Jun-16	58.121	98.408	57.042	84.032	58.426	106.353	59.095	169.954
Jul-16	58.340	96.338	60.555	82.788	56.797	94.868	59.746	169.592
Aug-16	59.041	94.182	61.688	82.741	61.468	101.920	60.261	176.406
Sep-16	56.432	88.747	58.372	77.488	57.254	97.861	55.909	163.738
Oct-16	52.330	71.642	52.373	66.848	52.468	66.099	52.355	153.598
Nov-16	47.308	66.494	44.770	61.245	47.417	63.161	47.307	138.549
Dec-16	44.894	63.477	43.567	58.681	46.290	63.257	45.157	133.464
Jan-17	46.860	67.145	44.719	61.694	47.308	62.417	47.703	139.099
Feb-17	51.268	67.811	58.389	64.346	51.101	58.435	51.489	150.842
Mar-17	56.348	76.236	58.567	71.549	56.451	69.111	56.414	165.542
Apr-17	59.453	84.348	55.696	77.332	59.645	81.234	59.410	173.990
May-17	59.893	89.307	57.235	79.911	59.329	86.746	60.159	174.373
Jun-17	58.292	95.157	60.230	81.849	57.308	98.844	58.624	168.178
Jul-17	59.224	93.172	61.106	81.746	59.914	97.454	59.802	173.823
Aug-17	58.185	93.233	60.898	80.770	59.111	104.783	57.575	168.535
Sep-17	57.740	86.906	55.926	77.415	58.238	90.530	57.450	168.156

VII. CONCLUSIONS:

The regression equations for diffuse fraction in terms of clearness index and relative sunshine for Anantapur region was estimated by using the Liu and Jordan model, page model, Iqbal model and Gopinathan models. The clearness index was high in summer months and low in monsoon months whereas diffuse fraction was high in monsoon months and low in winter months. The diffuse fraction estimated from the different models are good correlated with the predicted values were also studied. The statistical error analysis was calculated between proposed models due to regression and models taken from literature values of diffuse solar radiation. In all models, the statistical errors of Liu and Jordan model have minimum values of MBE, MPE and RMSE having R^2=0.98.

VIII. ACKNOWLEDGMENT

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