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Research Article

Study and Analysis of Solar Radiation Models

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Abstract

In this paper, we have reviewed various models from 2001-2014 to find out the most suitable models for the estimation of daily diffuse solar radiation data on horizontal surface. Since, these models were developed using different parameters such as clearness index, sunshine fraction, ambient temperature, humidity, atmospheric water vapor content, etc. Therefore, we have grouped models on the basis of clearness index, sunshine fraction, clearness index and sunshine fraction based models, models from other parameters, and models from extraterrestrial radiation. Further, groups are classified into linear and non-linear correlations to select the appropriate models. The performance of models have been graphically as well as statistically analyzed by four prominent locations viz. Jodhpur (26.28⁰ N, 73.02⁰ E), Ahmedabad (23.03⁰ N, 72.58⁰ E), Kolkata (22.56⁰ N, 88.36⁰ E) and Mumbai (18.97⁰ N, 72.82⁰ E) which represent the varying weather conditions of India. Finally, selected models from various groups compared with the measured data for Mumbai to find the most suitable models for the estimation of diffuse solar radiation data on horizontal surface for Indian locations.

Keywords: *Parameters; atmospheric water vapor content; ambient temperature; extraterrestrial radiation.*

1. Introduction

The demand of energy is increased due to speedy rise in population and advancement in the technology day-to-day. In the entire process of development, growth and continued existence of all living beings, solar energy can play an important role in the socio-economic development of a country. Therefore, countries should have high awareness to utilize alternative sources of energy for the most part the renewable ones. Solar radiation data is an essential component of the global energy balance which drives various systems. Unfortunately, only global radiation measurements are available on meteorological sites however; direct and diffuse solar radiation are also needed separately for many applications. For this purpose, a number of models and methods have been build up to estimate the diffuse solar radiation at poles apart places in the world. These models were typically expressed in terms of linear or polynomial fitting relating with the clearness index, sunshine fraction, some weather elements such as relative cloud cover, relative humidity, solar declination and sometimes have latitude dependency. These radiation models for one location may not successfully apply to other places.

Therefore, the aim of this paper is to broadly collect and present the diffuse solar radiation models available in the literature from 2001 up to 2014. This review in sequential manner will be useful for the selection of models to estimate the diffuse solar radiation for a place of interest. Further, study has been carried out to find out the most suitable correlations for estimating the daily diffuse solar radiation over India.

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Nomenclature

$\bar{H}$ Monthly average daily global radiation incident on a horizontal surface (W/m²)
$\bar{H}_d$ Monthly average daily diffuse radiation incident on a horizontal surface (W/m²)
H Daily global radiation incident on a horizontal surface (W/m²)
H_d Daily diffuse radiation incident on a horizontal surface (W/m²)
H_o Daily extraterrestrial radiation incident on a horizontal surface (W/m²)
$\bar{K}_t$ Monthly average daily clearness index, $\frac{\bar{H}}{\bar{H}_o}$
K_t Daily clearness index, $\frac{H}{H_o}$
S or $\bar{n}$ Monthly average daily number of bright sunshine hours (h)
S_o or $\bar{N}$ Monthly average daily maximum possible sunshine duration (h) or day length
h_n Solar elevation at solar noon
$\bar{T}_a$ Monthly average daily ambient temperature
$\bar{R}_h$ Monthly average daily relative humidity
N_d Day length in hours
$\frac{Ne}{8}$ Fraction, in eights, of the sky covered by clouds
W Atmospheric water vapor content (in cm)
S_{max} Monthly mean of maximum possible sunshine hours per day

2. Models used

A variety of models or correlations have been developed by various authors to estimate the diffuse solar radiation on horizontal surface over the years. In this review paper, we have analyzed 26 models from 2001 up to 2014 which are as follows:

Model 1: Miguel *et al*. model (2001)

Miguel *et al*. developed third order polynomial correlation between diffuse fraction and clearness index using an assembled data set from several countries in the North Mediterranean belt area.

$$\frac{H_d}{H} = \begin{cases} 0.952 & K_t \le 0.13 \\ 0.868 + 1.335K_t - 5.782K_t^2 + 3.721K_t^3 & 0.13 < K_t \le 0.80 \\ 0.141 & K_t > 0.80 \end{cases} \quad (1)$$

Model 2: Becker model (2001)

Becker model follows valko's approach is based on the calculation of the Linke turbidity factors for the stations Bet-Dagan, Jerusalem, Beer Sheva, Sedom and Eilat.

$$D = C_j * (D_R + D_B) * (KN_{LM} + KN_H - 1) \quad (2)$$

with

D diffuse radiation in W/m^2

C_j seasonal correction (continual representation according to Jendritzky, 1990)
=1+0.11∗cos((J−15)∗2π/365), with J=number of days in the year (Julian date)

D_R diffuse radiation by Raleigh dispersion in W/m^2
=39.78∗sin(h)$^{0.35}$ (according to Jendritzky, 1990),with h=solar angle;

D_B diffuse radiation by vapour dispersion in W/m^2
=2.6∗sin(h)$^{0.66}$∗(10^3∗B−12)$^{0.81}$, with B=turbidity coefficient according to Schu¨epp;

KN_{LM} factor of cloud influence at low and medium level
=0.89+0.11∗10$^{(0.17*N_{LM})}$, with N_{LM}=number of clouds at low and medium level in tenths;

KN_H factor of cirrus influence
=1+0.035∗N_H, with N_H=number of cirrus in tenths.

Model 3: Oliveira *et al*. model (2002)

Oliveira *et al*. using data from a tropical Sao paulo site, Brazil, proposed a fourth order polynomial correlation for the estimation of daily values of diffuse solar radiation.

$$\frac{H_d}{H} = \begin{cases} 1.0 + 0.27K_t - 2.5K_t^2 - 2.6K_t^3 + 4.3K_t^4 & (for\ Jan - dec)\ 0.17 < K_t < 0.70 \\ 1.0 + 0.07K_t - 1.9K_t^2 - 2.9K_t^3 + 4.1K_t^4 & (for\ april - Aug) 0.10 < K_t < 0.70 \\ 1.1 + 0.23K_t - 2.6K_t^2 - 2.2K_t^3 + 4.3K_t^4 & (for\ sept - march) 0.20 < K_t < 0.70 \end{cases} \quad (3a)$$

Again, daily values of diffuse radiation for Sao Paulo city, during all months of the year can be estimated by following equation.

$$\frac{H_d}{H} = 1.0 + 0.27K_t - 2.5K_t^2 - 2.6K_t^3 + 4.3K_t^4 \quad (3b)$$

Model 4: El-Sebaii *et al*. (2003)

El-Sebaii *et al* using data for four Egyptian locations (Matruh, Al-Arish, Rafah and Aswan) developed three empirical correlations for estimating the monthly average daily diffuse radiation at these locations and claimed that given three models can be used for present locations as well as any Egyptian location.

$$\frac{\bar{H}_d}{\bar{H}} = 1.242 - 1.337K_t \quad (4a)$$

$$\frac{\bar{H}_d}{\bar{H}} = -0.209 + 2.183\left(\frac{\bar{n}}{\bar{N}}\right) - 1.785\left(\frac{\bar{n}}{\bar{N}}\right)^2 \quad (4b)$$

$$\frac{\bar{H}_d}{\bar{H}_o} = -0.113 + 1.217\left(\frac{\bar{n}}{\bar{N}}\right) - 0.954\left(\frac{\bar{n}}{\bar{N}}\right)^2 \quad (4c)$$

Model 5: Karatasou *et al*. model (2003)

Karatasou *et al*. modified Liu and Jordan correlation for Athens, Greece location and proposed following correlation.

$$\frac{H_d}{H} = \begin{cases} 0.99 & < 0.1 \\ 1.00 + 0.3884K_t - 5.0108K_t^2 + 6.2682K_t^3 - 2.8273K_t^4 & 0.1 \le K_t < 0.75 \end{cases} \quad (5)$$

Model 6: Bashahu model (2003)

Bashahu used 16 year set of data on the global and diffuse radiation on a horizontal surface at Dakar, together with data on climatologically quantities; nine following correlations have been developed to estimate the monthly average diffuse radiation for Dakar as:

$$\frac{H_d}{H} = 1.13 - 1.29\,K_t \qquad 0.51 \le K_t \le 0.68 \quad (6a)$$

$$\frac{H_d}{H} = 37.4368 - 61.3179\,K_t + 0.2856K_t^2 - 0.8451K_t^3 \qquad 0.51 \le K_t \le 0.68 \quad (6b)$$

$$H_d = 1.281(K_t)^{-1.173}\left|\overline{\sin h_n}\right|^{1.801} \qquad 0.51 \le K_t \le 0.68$$

$$0.798 \le \left|\overline{\sin h_n}\right| \le 0.9996 \quad (6c)$$

$$\frac{H_d}{H} = 1.059 - 0.984\,\frac{N}{N_d} \qquad 0.60 \le \frac{N}{N_d} \le 0.80 \quad (6d)$$

$$\frac{H_d}{H_o} = -7.0744 + 31.4386\,\frac{N}{N_d} - 15.5906\left(\frac{N}{N_d}\right)^2 \qquad 0.60 \le \frac{N}{N_d} \le 0.80 \quad (6e)$$

$$H_d = 1.539\left(\frac{N}{N_d}\right)^{-1.242}\left|\overline{\sin h_n}\right|^{1.975} \qquad 0.60 \le \frac{N}{N_d} \le 0.80$$

$$0.798 \le \left|\overline{\sin h_n}\right| \le 0.9996 \quad (6f)$$

$$\frac{H_d}{H} = 0.12 + 0.52\,\frac{Ne}{8} \qquad 0.28 \le \frac{Ne}{8} \le 0.65 \quad (6g)$$

$$\frac{H_d}{H} = 0.67 - 0.59\,\frac{Ne}{8} \qquad 0.35 \le 1 - \frac{Ne}{8} \le 0.72 \quad (6h)$$

$$\frac{H_d}{H_o} = 0.2271 - 0.1302\,\frac{N}{N_d} + 0.0198W \qquad 0.60 \le \frac{N}{N_d} \le 0.80$$

$$2.91 \le W \le 4.96 \quad (6i)$$

The most suitable equations recommended for Dakar are (6a), (6d) and (6h).

Model 7: Jin *et al*. model (2004)

Jin *et al*. have used the data of 78 meteorological stations in China and proposed a countrywide general correlation model on the basis of Liu and Jordan method.

$$\frac{H_d}{H} = \begin{cases} 0.987 & K_t < 0.20 \\ 1.292 - 1.447K_t & 0.20 \le K_t < 0.75 \\ 0.209 & K_t > 0.75 \end{cases} \quad (7)$$

Model 8: Ali Al-Mohamad model (2004)

Ali al-mohamad presented an analytical method for the calculation of the diffuse radiation for eastern Mediterranean countries.

$$\frac{H_d}{H} = 1.0278 - 1.9039\, K_t + 2.362K_t^2 - 1.7527K_t^3 \quad (8)$$

Model 9: Tarhan and Sari model (2005)

Sefa Tarhan and Ahmet Sari developed two hybrid models over the Central Black Sea Region of Turkey, covering five provinces- Amasya, Corum, Ordu, Samsun and Tokat.

Cubic polynomial model

$$\frac{H_d}{H} = 1.0207 - 1.6582K_t + 1.1018K_t^2 - 0.4019K_t^3 \quad (9a)$$

Quadratic polynomial model

$$\frac{H_d}{H} = 0.9885 - 1.4276\, K_t + 0.5679K_t^2 \quad (9b)$$

Model 10: Aras *et al*. model (2006)

Haydar Aras,Ozgur Balli and Arif Hepbasli developed twelve hybrid models to predict the monthly average daily diffuse solar radiation on a horizontal surface over Turkey's Central Anatolia Region (CAR),which covers the 12 provinces (Afyon, Ankara, Cankiri, Corum, Eskisehir, Kayseri, Kirsehir, Konya, Nevsehir, Nigde, Sivas, and Yozgat).

$$\frac{H_d}{H} = 0.663 - 0.4883\frac{S}{S_o} \quad (10a)$$

$$\frac{H_d}{H} = 0.6492 - 0.4323\,\frac{S}{S_o} - 0.0512\left(\frac{S}{S_o}\right)^2 \quad (10b)$$

$$\frac{H_d}{H} = 0.5562 + 0.1536\,\frac{S}{S_o} - 1.2027\left(\frac{S}{S_o}\right)^2 + 0.7122\left(\frac{S}{S_o}\right)^3 \quad (10c)$$

$$\frac{H_d}{H} = 0.2595 - 0.0978\,\frac{S}{S_o} \quad (10d)$$

$$\frac{H_d}{H} = 0.2142 + 0.0863\frac{S}{S_o} - 0.1684\left(\frac{S}{S_o}\right)^2 \quad (10e)$$

$$\frac{H_d}{H} = 0.2427 - 0.0933\frac{S}{S_o} + 0.1846\left(\frac{S}{S_o}\right)^2 - 0.2184\,\left(\frac{S}{S_o}\right)^3 \quad (10f)$$

$$\frac{H_d}{H} = 1.0212 - 1.1672K_t \quad (10g)$$

$$\frac{H_d}{H} = 1.1244 - 1.5582K_t + 0.3635K_t^2 \quad (10h)$$

$$\frac{H_d}{H} = 1.7111 - 4.9062K_t + 6.6711K_t^2 - 3.9235K_t^3 \quad (10i)$$

$$\frac{H_d}{H} = 0.331 - 0.2333K_t \quad (10j)$$

$$\frac{H_d}{H} = 0.0511 + 0.8267K_t - 0.9854K_t^2 \quad (10k)$$

$$\frac{H_d}{H} = 0.3276 - 0.7515K_t + 1.9883K_t^2 - 1.8497K_t^3 \quad (10l)$$

Then most accurate correlation model over any selected city in the CAR of Turkey was in the cubic polynomial form given by Eq. (10i)

Model 11: Benghanem *et al*. model (2007)

Benghanem *et al*. developed a correlation for medina site (Kingdom of Saudi Arabia).This correlation connecting diffuse irradiation with both clearness index and sunshine duration.

$$\frac{H_d}{H} = 1.23 - 0.62\left(\frac{S}{S_o}\right) - 0.735K_t \quad (11)$$

Model 12: Elminir *et al*. model (2007)

In this task an artificial neural network (ANN) model was proposed to predict diffuse fraction for the Egyptian environment.

$$\frac{H_d}{H} = 0.7980 - 0.7475\,K_t - 0.0702\,\frac{S}{S_o} \qquad (12)$$

Model 13: Ulgen and Hepbasli model (2009)

Koray Ulgen and Arif Hepbasli used the meteorological data for the province of Ankara, Istanbul and Izmir and developed eight hybrid models for estimating the monthly average daily diffuse solar radiation on a horizontal surface for Turkey. Models are classified into four groups as follows

Group I: From the diffuse fraction or cloudness index, function of the clearness index

$$\frac{H_d}{H} = 0.6772 - 0.4841K_t \qquad (13a)$$

$$\frac{H_d}{H} = 0.981 - 1.9028\,K_t + 1.9319K_t^2 - 0.6809K_t^3 \qquad (13b)$$

Group II: From the diffuse fraction or cloudness index, function of the relative sunshine duration

$$\frac{H_d}{H} = 0.5456 - 0.2242\,\frac{S}{S_o} \qquad (13c)$$

$$\frac{H_d}{H} = 0.6595 - 0.7841\,\frac{S}{S_o} + 0.7461\left(\frac{S}{S_o}\right)^2 - 0.2579\left(\frac{S}{S_o}\right)^3 \qquad (13d)$$

Group III: From the diffuse coefficient, function of the clearness index

$$\frac{H_d}{H_o} = 0.1155 + 0.1958K_t \qquad (13e)$$

$$\frac{H_d}{H_o} = 0.0273 + 0.727K_t - 1.0411{K_t}^2 + 0.6659K_t^3 \qquad (13f)$$

Group IV: From the diffuse coefficient, function of the relative sunshine duration

$$\frac{H_d}{H_o} = 0.1677 + 0.0926\,\frac{S}{S_o} \qquad (13g)$$

$$\frac{H_d}{H_o} = 0.1437 + 0.2151\,\frac{S}{S_o} - 0.1748\left(\frac{S}{S_o}\right)^2 + 0.0697\left(\frac{S}{S_o}\right)^3 \qquad (13h)$$

Model 14: Jiang model (2009)

In this study [16], nine equations were validating to estimate the monthly mean daily diffuse solar radiation for eight typical meteorological stations (Haerbin, Lanzhou, Beijing, Wuhan, Kunming, Guangzhou, Wulumuqi and Lasa) in China, and found that the quadratic model performed better than the other models. Later on selected model were analyzed for Kashi, Geermu, Shenyang, Chengdu and Zhengzhou locations for generalization of selected model.

$$\frac{\bar{H}_d}{\bar{H}} = 0.945 - 0.675\bar{K}_t - 0.166\bar{K}_t^2 - 0.173\left(\frac{S}{S_o}\right) - 0.079\left(\frac{S}{S_o}\right)^2 \qquad (14)$$

Model 15: Jiang model (2009)

In this work measured available 10 years data (1995-2004) at Beijing station were used to develop empirical relationship for estimating the daily diffuse radiation. For this purpose, nine correlations were used to express dependency of diffuse radiation on various parameters. Finally given model is recommended in the whole semi wet region of north of China:

$$\frac{H_d}{H} = 0.945 + 0.734K_t - 2.876K_t^2 + 1.421K_t^3 - 0.392\left(\frac{S}{S_o}\right) + 0.378\left(\frac{S}{S_o}\right)^2 - 0.404\left(\frac{S}{S_o}\right)^3 \quad (15)$$

Model 16: Pandey *et al*. model (2009)

In this study [18] data of four prominent locations (Jodhpur, Kolkata, Mumbai and Pune) have been taken to develop correlations between the diffuse fraction and sunshine fraction for each selected locations and they also developed an All India Correlation (AIC).

Pandey *et al*. models for Jodhpur, Kolkata, Mumbai, Pune in India respectively

$$\frac{H_d}{H} = -2.887 + 17.95\left(\frac{S}{S_o}\right) - 29.4\left(\frac{S}{S_o}\right)^2 + 14.92\left(\frac{S}{S_o}\right)^3 \quad (16a)$$

$$\frac{H_d}{H} = 3.419 - 15.03\left(\frac{S}{S_o}\right) + 25.18\left(\frac{S}{S_o}\right)^2 - 13.86\left(\frac{S}{S_o}\right)^3 \quad (16b)$$

$$\frac{H_d}{H} = 0.8384 - 0.2841\left(\frac{S}{S_o}\right) - 0.8208\left(\frac{S}{S_o}\right)^2 + 0.4315\left(\frac{S}{S_o}\right)^3 \quad (16c)$$

$$\frac{H_d}{H} = 1.033 - 0.9107\left(\frac{S}{S_o}\right) - 0.1288\left(\frac{S}{S_o}\right)^2 + 0.0972\left(\frac{S}{S_o}\right)^3 \quad (16d)$$

AIC (I) is given as:

$$\frac{H_d}{H} = 0.09781 + 4.763\left(\frac{S}{S_o}\right) - 11.32\left(\frac{S}{S_o}\right)^2 + 7.167\left(\frac{S}{S_o}\right)^3 \quad (16e)$$

Model 17: El-Sebaii *et al*. model (2010)

El-Sebaii *et al*. [19] analyzed the data for Jeddah, Saudi Arabia, during the period (1996-2007) and obtained following correlations.

$$\frac{H_d}{H} = 4.618 - 6.269K_t \quad (17a)$$

$$\frac{H_d}{H} = 5.488 - 5.672\left(\frac{S}{S_o}\right) \quad (17b)$$

$$\frac{H_d}{H_o} = 3.542 - 3.664\left(\frac{S}{S_o}\right) \quad (17c)$$

$$\frac{H_d}{H_o} = 2.973 - 4.037K_t \quad (17d)$$

Furthermore, H_d/H and H_d/H_o were correlated for the combination of K_t and $\left(\frac{S}{S_o}\right)$

$$\frac{H_d}{H} = 4.609 - 6.318K_t + 0.047\left(\frac{S}{S_o}\right) \quad (17e)$$

$$\frac{H_d}{H_o} = 3.002 - 3.882K_t - 0.150\left(\frac{S}{S_o}\right) \quad (17f)$$

Model 18: Li *et al*. model (2011)

In this study two models have been proposed to estimate the monthly average daily diffuse solar radiation based on multiple predictors including the clearness index, relative sunshine duration, ambient temperature and relative humidity. One of them was to increase the estimation accuracy.

$$\frac{H_d}{H} = 0.4461 + 0.4187K_t - 0.8972\left(\frac{S}{S_o}\right) + 0.0049T_a + 0.3231R_h \quad (18a)$$

and the other was to estimate diffuse solar radiation direct from other meteorological elements in the absence of the global solar radiation.

$$\frac{H_d}{H_o} = 0.5686 - 0.3724\left(\frac{S}{S_o}\right) + 0.2991\log\left(\frac{S}{S_o}\right) + 0.0031T_a - 0.2035R_h \quad (18b)$$

Model 19: Karakoti *et al*. model (2011)

In this paper the experimental data on global, diffuse radiation and sunshine hours reported by Mani and Rangarajan have been analyzed for 12 locations (Bhavnagar, Kolkata, Goa, Jodhpur, Chennai, Nagpur, New Delhi, Pune, Tiruvanantpuram, Vishakhapatanam, Ahmadabad and Mumbai) of India. For this purpose they have taken a group of relation, on performing the statistical analysis. They found given square and third order equation between diffuse coefficient and percent possible sunshine is the most accurate model for all these locations.

$$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2 \quad (19a)$$

$$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2 + d\left(\frac{S}{S_{max}}\right)^3 \quad (19b)$$

Where regression coefficients for the chosen locations:

Stations	For third order equation				For second order equation	
	a	b	c	d	a	b
Ahmedabad	0.5456	-1.1613	1.744	-0.9945	-	-
Bhavnagar	0.308	0.068	-0.078	-0.155	0.28	-0.37
Mumbai	0.3509	-0.4695	1.0988	-0.9116	-	-
Kolkata	0.3401	-0.3815	0.8308	-0.6857	0.2378	-0.3323
Goa	0.2537	0.1737	-0.0495	-0.2947	1.0654	-0.6604
Jodhpur	- 0.0684	1.8254	-2.7068	1.085	0.35	-0.02672
Chennai	0.2753	0.3472	-0.9128	0.4683	0.4195	0.0597
Nagpur	0.3181	-0.0986	0.0422	-0.1253	0.2957	-0.1895
New Delhi	0.7863	-2.0503	2.7041	-1.3029	0.3887	-0.0174
Pune	0.1982	0.8814	-1.7625	0.8095	0.4113	-0.0575
Tiruvanantpuram	0.3751	-0.2126	0.0570	-0.0980	0.3350	0.1838
Vishahapatanam	0.3503	-0.1720	-0.0068	-0.0119	0.3426	-0.0435

Model 20: Karakoti *et al*. model (2012)

To investigate the diffuse solar radiation for 23 stations of India, Karakoti *et al*. developed seven empirical models which correlates diffuse solar radiation with sunshine duration, temperature and relive humidity. They used the data of 18 sites (Bhavnagar, Bhopal, Chennai, Ahmadabad, Goa, Hyderabad, Jaipur, Jodhpur, Minicoy, Mumbai, Patna, Port Blair, Ranchi, Shillong, Srinagar, Thiruvananthapuram, Varanasi and Visakhapatnam) out of 23 for developing seven empirical models. Moreover, the measured values of monthly mean daily diffuse radiation of other five locations (Bangalore, Kolkata, Nagpur, New Delhi and Pune) were analyzed to evaluate the proposed empirical correlations. In this study found that although all seven developed correlation performs with good accuracy but the following correlation of diffuse transmittance with percent sunshine, temperature and relative humidity is the most suitable fit for Indian locations.

$$\frac{H_d}{H_o} = 0.2008 - 0.1223\left(\frac{S}{S_o}\right) + 0.0014T_a + 0.0011R_h \quad (20)$$

Model 21: Li *et al*. model (2012)

Li *et al*. reported following two models for general application estimating the monthly average daily diffuse radiation in China. This study is the further investigation of Li *et al*. model for improved accuracy.

$$\frac{H_d}{H} = 1.1937 - 0.682K_t - 0.4658\left(\frac{S}{S_o}\right) - 0.0008T_a - 0.1987R_h \quad (21a)$$

$$\frac{H_d}{H_o} = 0.7537 - 0.5832\left(\frac{S}{S_o}\right) + 0.4954\log\left(\frac{S}{S_o}\right) - 0.0005T_a - 0.1123R_h \quad (21b)$$

Model 22: Khatib *et al*. model (2012)

This study presents a linear and a non linear model for diffuse solar radiation on horizontal surface for five sites in Malaysia as: Alor Setar, Ipoh, Johor Bharu, Kuala Lumpur and kuching.

Linear correlation: $\frac{H_d}{H} = 1.2623 - 1.3307K_t$ (22a)

Non linear correlation: $\frac{H_d}{H} = 0.9497 + 0.9270K_t - 4.8821K_t^2 + 3.2542K_t^3$ (22b)

Model 23: Bortolini *et al*. model (2013)

Bortolini *et al*. proposed a multi-location model to estimate the horizontal daily diffuse component of solar radiation, on considering measured data between 2004 and 2007 by 44 European weather stations. In this study both annual and seasonal scenarios are developed. Consequently, general expressions given as:

Annual correlation $\frac{\widehat{H_d}}{H} = 0.9888 + 0.3950K_t - 3.7003K_t^2 + 2.2905K_t^3$ (23a)

For Summer $\frac{\widehat{H_d}}{H} = 1.0172 + 0.0158K_t - 2.7036K_t^2 + 1.5729K_t^3$ (23b)

For Winter $\frac{\widehat{H_d}}{H} = 0.9403 + 0.9887K_t - 5.2499K_t^2 + 3.4586K_t^3$ (23c)

Model 24: Khalil *et al*. model (2013)

In this work Khalil *et al*. used measured hourly daily data of diffuse solar irradiation incident on a horizontal surface for Cairo, Egypt (Lat. 30°05' N and Long. 31°15'E), during the period (1990–2010) and proposed following equations.

$\frac{H_d}{H} = 5.817 - 6.517K_t$ (24a)

$\frac{H_d}{H} = 8.342 - 6.455\left(\frac{S}{S_o}\right)$ (24b)

$\frac{H_d}{H_o} = 3.815 - 5.319\left(\frac{S}{S_o}\right)$ (24c)

$\frac{H_d}{H_o} = 4.912 - 6.894K_t$ (24d)

Furthermore, for improvement H_d/H and H_d/H_o were correlated for the combination of K_t and $\left(\frac{S}{S_o}\right)$

$\frac{H_d}{H} = 6.314 - 5.131K_t + 0.136\left(\frac{S}{S_o}\right)$ (24e)

$\frac{H_d}{H_o} = 5.292 - 4.226K_t - 0.321\left(\frac{S}{S_o}\right)$ (24f)

Model 25: Ahwide *et al*. model (2013)

In this paper, Ahwide *et al*. used global solar radiation data from three Libyan locations: Sabha-desert region, Ghdames-middle region and Tripoli- Mediterranean region and established a relationship between daily diffuse fraction and daily clearness index.

The seasonal is indicated by sunset hour angleω_s.

For ω_s <81.4°

$$\frac{H_d}{H} = \begin{cases} 1.0 - 0.2727K_t + 2.4495K_t^2 - 11.9514K_t^3 + 9.3879K_t^4 & K_t < 0.715 \\ 0.143 & K_t \geq 0.715 \end{cases} \quad (25a)$$

For ω_s ≥81.4°

$$\frac{H_d}{H} = \begin{cases} 1 + 0.2832K_t - 2.5557K_t^2 + 0.8448K_t^3 & K_t < 0.722 \\ 0.175 & K_t \geq 0.722 \end{cases} \quad (25b)$$

Ahwide *et al*. also compared this correlation with Liu and Jordan, Choudhury, Erbs *et al*.[29] and Stanhill correlations and found that the developed correlation for three Libya's towns are quite similar to Erbs correlation.

Model 26: Khorasanizadeh *et al*. model (2014)

In this study Khorasanizadeh *et al*. established nine different diffuse solar radiation models from three categories for Tabass. For this purpose long-term daily global solar radiation on a horizontal surface and sunshine hours for period of 1988–2000 were utilized.

$$\frac{\bar{H}_d}{\bar{H}} = 1.07884 - 1.22683\bar{K}_t \quad (26a)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.54953 + 0.40150\bar{K}_t - 1.24800\bar{K}_t^2 \quad (26b)$$

$$\frac{\bar{H}_d}{\bar{H}} = -15.23783 + 73.28934\bar{K}_t - 113.23003\bar{K}_t^2 + 57.25228\bar{K}_t^3 \quad (26c)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.69374 - 0.54737\left(\frac{\bar{n}}{\bar{N}}\right) \quad (26d)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.66712 - 0.47647\left(\frac{\bar{n}}{\bar{N}}\right) - 0.04661\left(\frac{\bar{n}}{\bar{N}}\right)^2 \quad (26e)$$

$$\frac{\bar{H}_d}{\bar{H}} = -1.64727 + 8.78160\left(\frac{\bar{n}}{\bar{N}}\right) - 12.31385\left(\frac{\bar{n}}{\bar{N}}\right)^2 + 5.38465\left(\frac{\bar{n}}{\bar{N}}\right)^3 \quad (26f)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.89355 - 0.61839\bar{K}_t - 0.27894\left(\frac{\bar{n}}{\bar{N}}\right) \quad (26g)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.92336 - 0.74695\bar{K}_t + 0.10078\bar{K}_t^2 - 0.24825\left(\frac{\bar{n}}{\bar{N}}\right) - 0.02106\left(\frac{\bar{n}}{\bar{N}}\right)^2 \quad (26h)$$

$$\frac{\bar{H}_d}{\bar{H}} = 0.95930 - 0.87130\bar{K}_t + 0.29191\bar{K}_t^2 - 0.09790\bar{K}_t^3 - 0.28419\left(\frac{\bar{n}}{\bar{N}}\right) + 0.02653\left(\frac{\bar{n}}{\bar{N}}\right)^2 - 0.02083\left(\frac{\bar{n}}{\bar{N}}\right)^3 \quad (26i)$$

Finally, based on statistical indicators they recommended model (26i) is the best diffuse model for Tabass

Table 1: Classification of models used for estimating the daily diffuse solar radiation

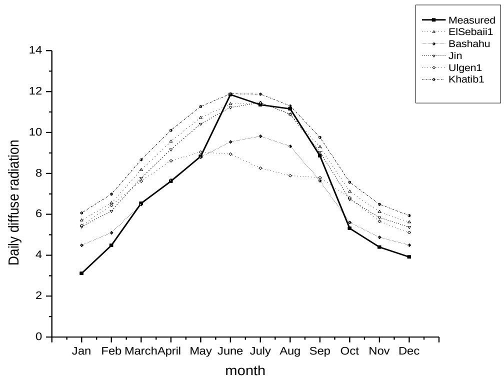
Group I: Clearness index based models							
Sn.	Linear co-relations			Sn.	Non linear co-relations		
1.	Model [4]:	$\frac{H_d}{H} = 1.242 - 1.337K_t$		1.	Model [1]:	$\frac{H_d}{H} = 0.868 + 1.335K_t - 5.782K_t^2 + 3.721K_t^3$	$0.13 < K_t \leq 0.8$
2.	Model [6]:	$\frac{H_d}{H} = 1.13 - 1.29\,K_t$	$0.51 \leq K_t \leq 0.68$	2.	Model [3]:	$\frac{H_d}{H} = 1.0 + 0.27K_t - 2.5K_t^2 - 2.6K_t^3 + 4.3K_t^4$	
3.	Model [7]:	$\frac{H_d}{H} = 1.292 - 1.447K_t$	$0.20 \leq K_t < 0.75$	3.	Model [5]:	$\frac{H_d}{H} = 1.00 + 0.3884K_t - 5.0108K_t^2 + 6.2682K_t^3 - 2.8273K_t^4$	$0.1 \leq K_t < 0.75$
4.	Model [13]:	$\frac{H_d}{H} = 0.6772 - 0.4841K_t$		4.	Model [8]:	$\frac{H_d}{H} = 1.0278 - 1.9039K_t + 2.362K_t^2 - 1.7527K_t^3$	
5.	Model [22]:	$\frac{H_d}{H} = 1.2623 - 1.3307K_t$		5.	Model [9]:	$\frac{H_d}{H} = 0.9885 - 1.4276K_t + 0.5679K_t^2$	
				6.	Model [9]:	$\frac{H_d}{H} = 1.0207 - 1.6582K_t + 1.1018K_t^2 - 0.4019K_t^3$	
				7.	Model [10]:	$\frac{H_d}{H} = 1.7111 - 4.9062K_t + 6.6711K_t^2 - 3.9235K_t^3$	
				8.	Model [13]:	$\frac{H_d}{H} = 0.981 - 1.9028K_t + 1.9319K_t^2 - 0.6809K_t^3$	
				9.	Model [22]:	$\frac{H_d}{H} = 0.9497 + 0.9270K_t - 4.88219K_t^2 + 3.2542K_t^3$	
				10.	Model [23]:	$\frac{\hat{H}_d}{H} = 0.9888 + 0.3950K_t - 3.7003K_t^2 + 2.2905K_t^3$	
Group II: Sunshine fraction based models							
1.	Model [6]:	$\frac{H_d}{H} = 1.059 - 0.984\frac{\bar{N}}{N_d}$	$0.60 \leq \frac{N}{N_d} \leq 0.80$	1.	Model [4]:	$\frac{H_d}{H} = -0.209 + 2.183\left(\frac{n}{N}\right) - 1.785\left(\frac{n}{N}\right)^2$	
2.	Model [13]:	$\frac{H_d}{H} = 0.5456 - 0.2242\frac{S}{S_o}$		2.	Model [13]:	$\frac{H_d}{H} = 0.6595 - 0.7841\frac{S}{S_o} + 0.7461\left(\frac{S}{S_o}\right)^2 - 0.2579\left(\frac{S}{S_o}\right)^3$	
				3.	Model [16]:	$\frac{H_d}{H} = 0.09781 + 4.763\left(\frac{S}{S_o}\right) - 11.32\left(\frac{S}{S_o}\right)^2 + 7.167\left(\frac{S}{S_o}\right)^3$	
Group III: Clearness index and relative sunshine duration based models							
1.	Model [11]:	$\frac{H_d}{H} = 1.23 - 0.62\left(\frac{S}{S_o}\right) - 0.735K_t$		1.	Model [14]:	$\frac{\bar{H}_d}{\bar{H}} = 0.945 - 0.675\bar{K}_t - 0.166\bar{K}_t^2 - 0.173\left(\frac{S}{S_o}\right) - 0.079\left(\frac{S}{S_o}\right)^2$	
2.	Model [12]:	$\frac{H_d}{H} = 0.7980 - 0.7475K_t - 0.0702\frac{S}{S_o}$		2.	Model [15]:	$\frac{H_d}{H} = 0.945 + 0.734K_t - 2.876K_t^2 + 1.421K_t^3 - 0.392\left(\frac{S}{S_o}\right) + 0.378\left(\frac{S}{S_o}\right)^2 - 0.404\left(\frac{S}{S_o}\right)^3$	
3.	Model [17]:	$\frac{H_d}{H} = 4.609 - 6.318K_t + 0.047\left(\frac{S}{S_o}\right)$		3.	Model [26]:	$\frac{H_d}{H} = 0.95930 - 0.87130K_t + 0.29191K_t^2 - 0.09790K_t^3 - 0.28419\left(\frac{S}{S_o}\right) + 0.02653\left(\frac{S}{S_o}\right)^2 - 0.02083\left(\frac{S}{S_o}\right)^3$	
4.	Model [24]:	$\frac{H_d}{H} = 6.314 - 5.131K_t + 0.136\left(\frac{S}{S_o}\right)$					

Group IV: Models from other parameters

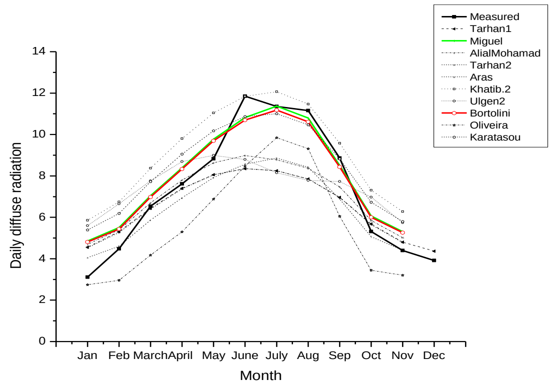
1.	Model [6]:	$\frac{H_d}{H} = 0.67 - 0.59\frac{Ne}{8}$ $\quad 0.35 \le 1 - \frac{Ne}{8} \le 0.72$
2.	Model [18]:	$\frac{H_d}{H} = 0.4461 + 0.4187K_t - 0.8972\left(\frac{S}{S_o}\right) + 0.0049T_a + 0.3231R_h$
3.	Model [21]:	$\frac{H_d}{H} = 1.1937 - 0.6821K_t - 0.4658\left(\frac{S}{S_o}\right) + 0.0008T_a - 0.1987R_h$

Group V: Models from extraterrestrial radiation

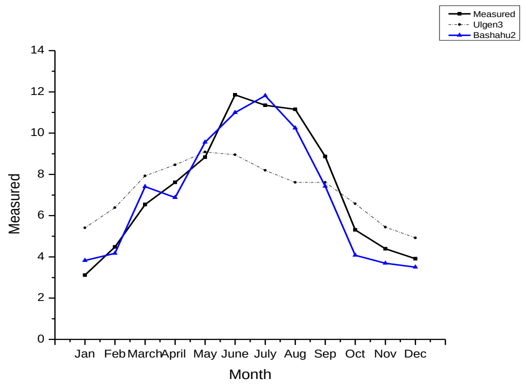
1.	Model [4]:	$\frac{H_d}{H_o} = -0.113 + 1.217\left(\frac{\bar{n}}{\bar{N}}\right) - 0.954\left(\frac{\bar{n}}{\bar{N}}\right)^2$
2.	Model [13]:	$\frac{H_d}{H_o} = 0.1155 + 0.1958K_t$
3.	Model [13]:	$\frac{H_d}{H_o} = 0.0273 + 0.727K_t - 1.0411{K_t}^2 + 0.6659K_t^3$
4.	Model [13]:	$\frac{H_d}{H_o} = 0.1677 + 0.0926\frac{S}{S_o}$
5.	Model [13]:	$\frac{H_d}{H_o} = 0.1437 + 0.2151\frac{S}{S_o} - 0.1748\left(\frac{S}{S_o}\right)^2 + 0.0697\left(\frac{S}{S_o}\right)^3$
6.	Model [17]:	$\frac{H_d}{H_o} = 3.002 - 3.882K_t - 0.150\left(\frac{S}{S_o}\right)$
7.	Model [18]:	$\frac{H_d}{H_o} = 0.5686 - 0.3724\left(\frac{S}{S_o}\right) + 0.2991\log\left(\frac{S}{S_o}\right) + 0.0031T_a - 0.2035R_h$
8	Model [19]:	$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2$
9.	Model [19]:	$\frac{H_d}{H_o} = a + b\left(\frac{S}{S_{max}}\right) + c\left(\frac{S}{S_{max}}\right)^2 + d\left(\frac{S}{S_{max}}\right)^3$
10.	Model [20]:	$\frac{H_d}{H_o} = 0.2008 - 0.1223\left(\frac{S}{S_o}\right) + 0.0014T_a + 0.0011R_h$
11.	Model [21]:	$\frac{H_d}{H_o} = 0.7537 - 0.5832\left(\frac{S}{S_o}\right) + 0.4954\log\left(\frac{S}{S_o}\right) - 0.0005T_a - 0.1123R_h$
12.	Model [24]:	$\frac{H_d}{H_o} = 5.292 - 4.226K_t - 0.321\left(\frac{S}{S_o}\right)$



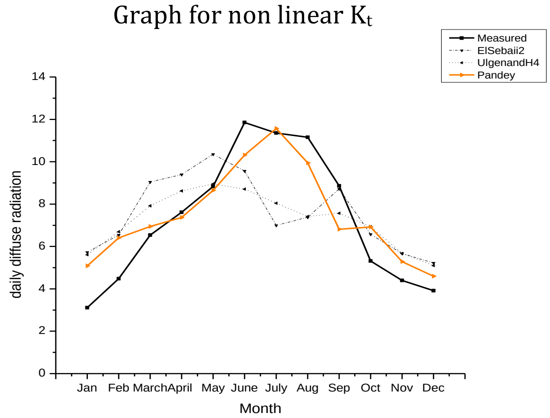
Graph for linear K_t



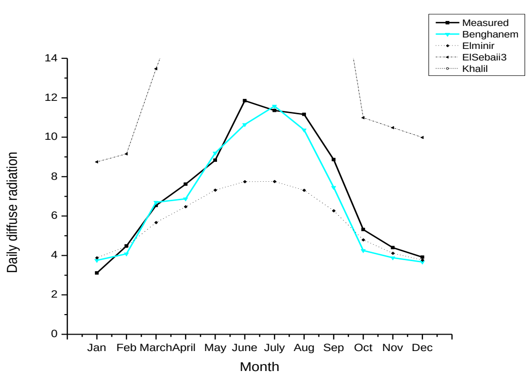
Graph for non linear K_t



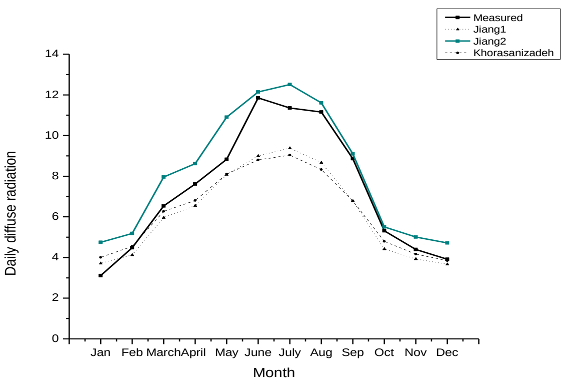
Graph for linear S/S_o



Graph for non linear S/S_o

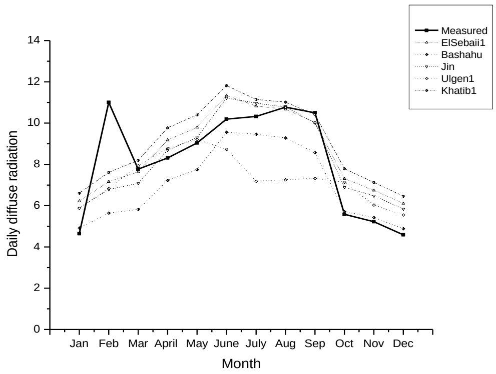


Graph for linear K_t and S/S_o

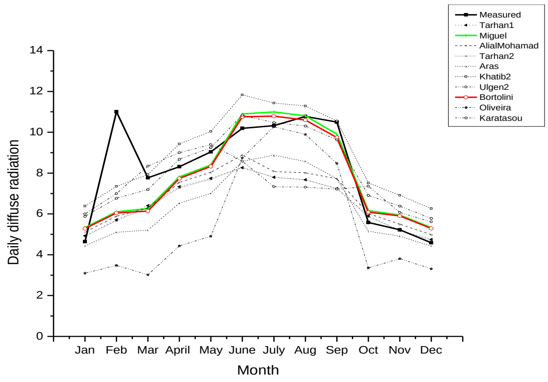


Graph for non linear Kt and S/S_o

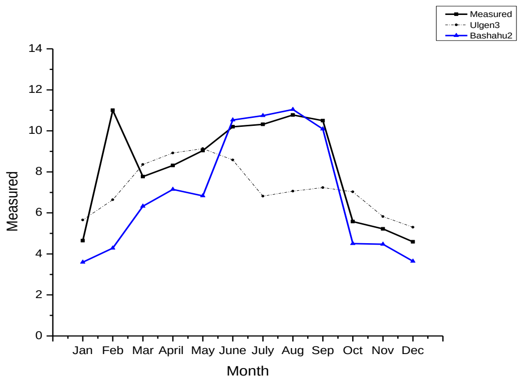
Fig.1 Measured and estimated results for Jodhpur, India



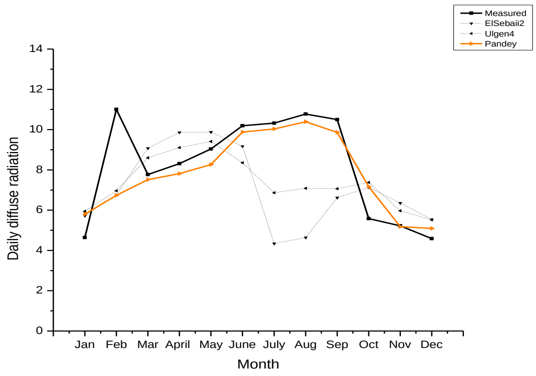
Graph for linear K_t



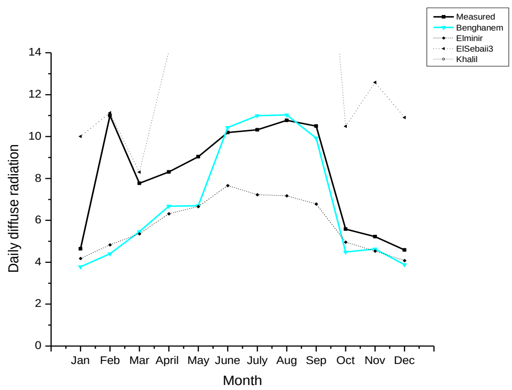
Graph for non linear K_t



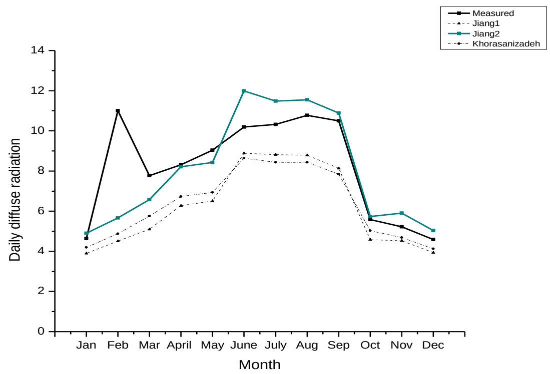
Graph for linear S/S_o



Graph for non linear S/S_o

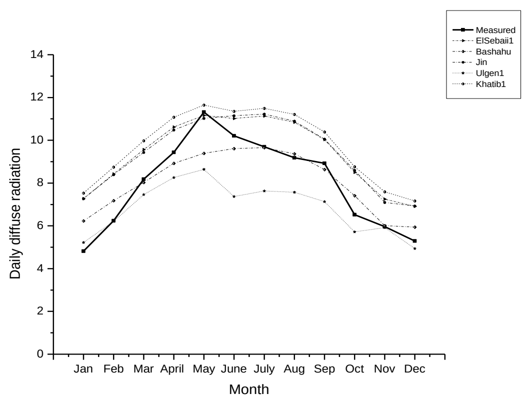


Graph for linear K_t and S/S_o

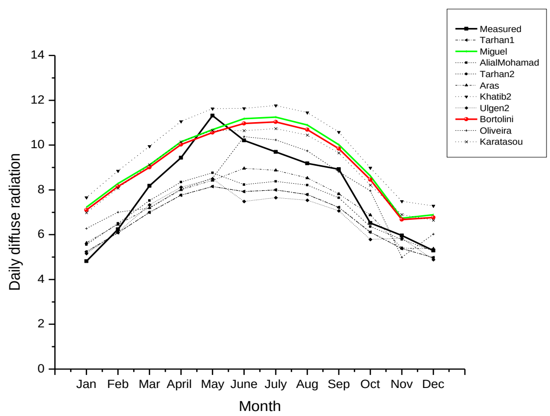


Graph for non linear K_t and S/S_o

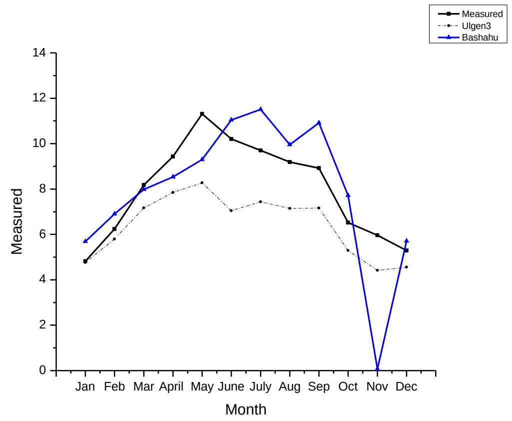
Fig.2 Measured and estimated results for Ahmedabad, India



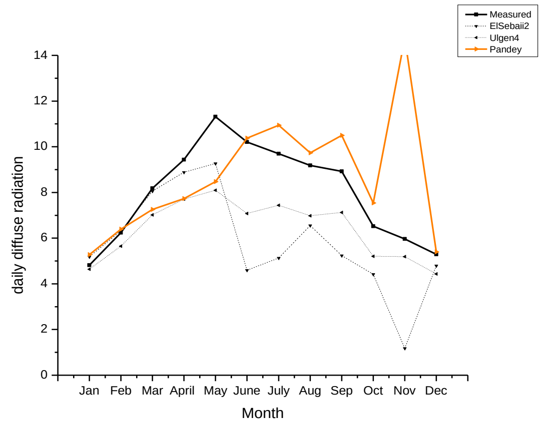
Graph for linear K_t



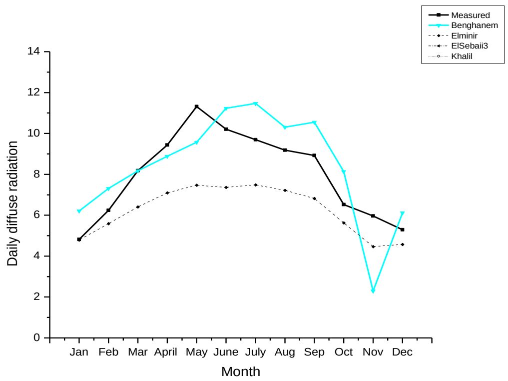
Graph for non linear K_t



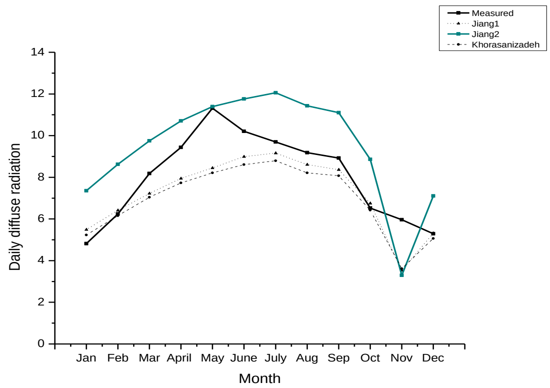
Graph for linear S/S_o



Graph for non linear S/S_o

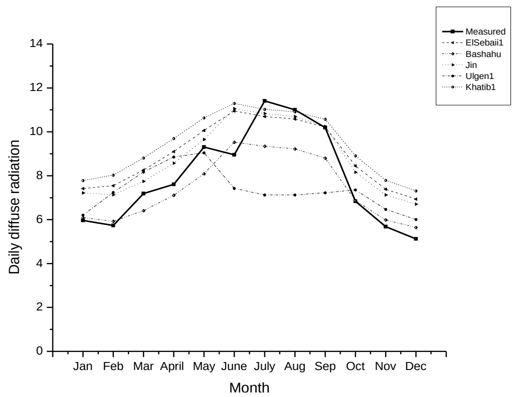


Graph for linear K_t and S/S_o

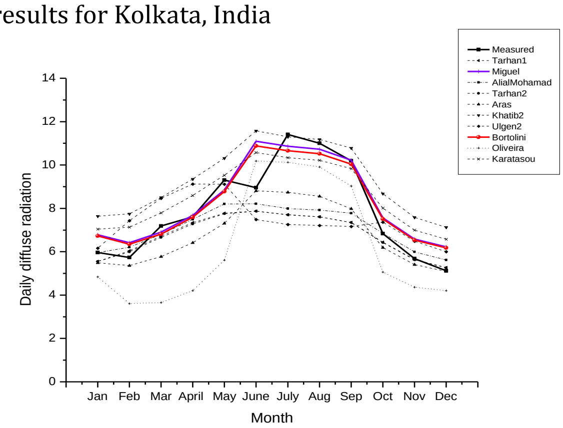


Graph for non linear K_t and S/S_o

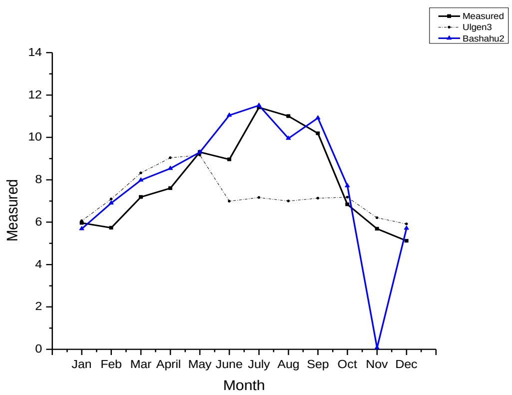
Fig.3 Measured and estimated results for Kolkata, India



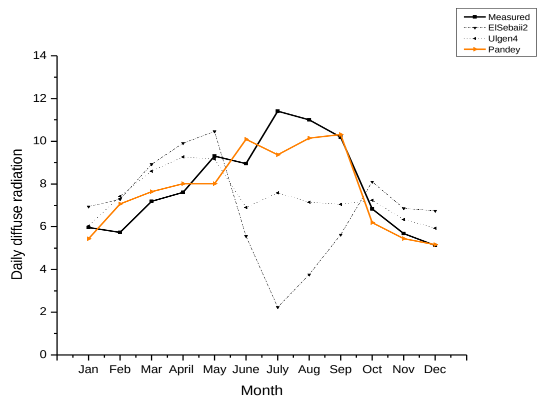
Graph for linear K_t



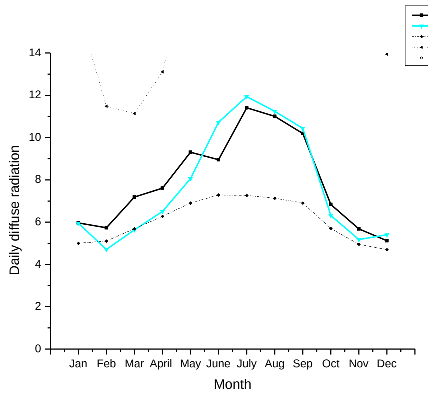
Graph for non linear K_t



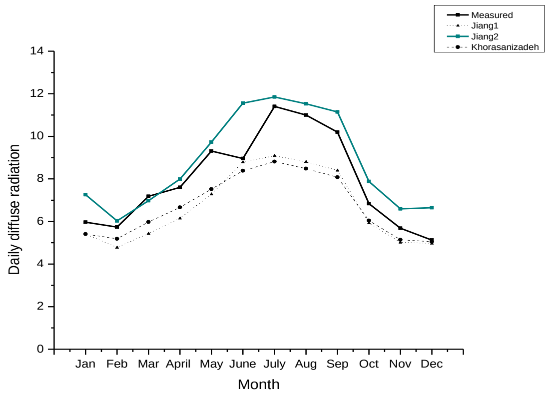
Graph for linear S/S_o



Graph for non linear S/S_o



Graph for linear K_t and S/S_o



Graph for non linear K_t and S/S_o

Fig.4 Measured and estimated results for Mumbai, India

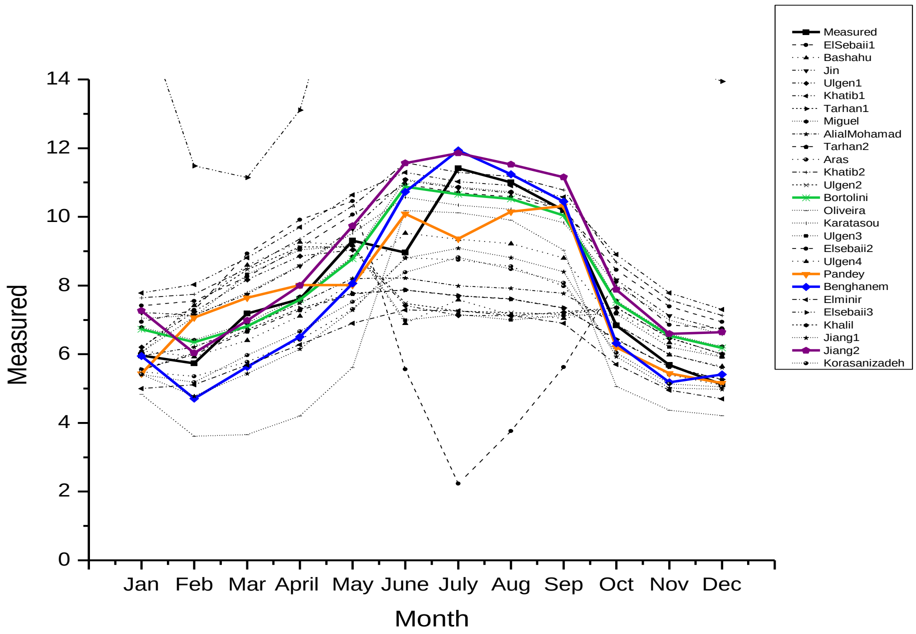


Fig.5 Estimated and measured results from all correlations (2001-2014) for Mumbai

3. Statistical evaluation

The accuracy and performance of each selected correlation for predicting daily diffuse radiation is tested by calculating the root mean square error (RMSE), mean bias error (MBE), mean percentage error (MPE) and t-test statistic. These error indices are defined as:

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n} {d_i}^2}$$

$$\text{MBE}=\frac{1}{n}\sum_{i=1}^{n} d_i$$

$$\text{MPE}=\frac{1}{n}\sum_{i=1}^{n}\left(\frac{d_i}{m_i}\right)*100$$

$$t=\sqrt{\frac{(n-1)MBE^2}{RMSE^2-MBE^2}}$$

where n is the number of data pairs, d_i is the difference between i^{th} measured and calculated values and m_i is the i^{th} measured value. Generally, low values of RMSE and MPE are desirable. Positive MBE shows overestimation while negative MBE indicates under estimation. Smaller value of t shows better performance of model.

Table 1: Statistical results for the validation of selected correlations

	Jodhpur				Ahmedabad				Kolkata				Mumbai			
Model	MBE	RMSE	MPE	t	MBE	RMSE	MPE	t	MBE	RMSE	MPE	t	MBE	RMSE	MPE	t
Clearness index based Linear models																
El-Sebaii *et al* i (eq.4a)	1.2671	1.6001	-26.51	4.3	0.4259	1.5285	-10.05	0.96	1.4131	1.5552	-20.82	7.22	1.0503	1.3787	-16.67	3.9
Bashahu (eq.6a)	-0.298	1.1345	-2.138	0.9	-1.141	1.887	10.765	2.52	0.0499	0.8445	-3.266	0.2	-0.499	1.0193	4.2128	1.86
Jin *et al* (eq.7)	1.0056	1.3315	-21.7	3.82	0.1665	1.4908	-6.163	0.37	1.3973	1.5564	-20.6	6.76	0.8458	1.1578	-13.46	3.55
Ulgen and H i (eq.13a)	0.0189	1.9721	-12.14	0.03	-0.841	2.1907	3.7489	1.38	-1.141	1.5298	11.944	3.71	-0.562	2.065	1.8779	0.94
Khatib *et al.* (eq.22a)	1.7104	1.9683	-33.54	5.82	0.8695	1.7067	-16.01	1.96	1.7641	1.8637	-25.35	9.73	1.4803	1.7474	-22.55	5.29
Clearness index based Non Linear models																
Miguel *et al* (eq.1)	0.4909	0.8895	-12.61	2.19	-0.332	1.5847	1.1268	0.71	1.2722	1.4931	-18.99	5.4	0.4085	0.8619	-6.876	1.79
Oliveira*et al*(eq.3b)	7.8327	1.9974	25.754	7.65	-2.595	3.2818	32.663	4.28	-0.051	1.2121	-1.879	0.14	-1.683	2.1383	22.944	4.23
Karatasou *et al* (eq.5)	0.8418	1.3193	-19.97	2.75	0.0115	1.4698	-4.553	0.03	1.0359	1.2525	-15.97	4.88	0.6357	1.0884	-11.07	2.39
Ali Al-Mohamad(eq.8)	-0.43	1.5592	-2.297	0.95	-1.322	2.0948	11.71	2.7	-0.764	1.1894	7.1437	2.78	-0.832	1.5695	7.1125	2.07
Tarhan i (eq.9b)	-0.782	1.833	2.3555	1.56	-1.582	2.2914	14.981	3.16	-1.178	1.5254	12.498	4.03	-1.141	1.7697	11.257	2.8
Tarhan ii (eq.9a)	-0.801	1.8285	2.7569	1.62	-1.611	2.3075	15.396	3.23	-1.179	1.5262	12.514	4.03	-1.162	1.7761	11.554	2.87
Aras *et al* (eq.10i)	-0.982	1.611	7.8087	2.55	-1.787	2.3527	19.088	3.87	-0.684	1.1681	6.227	2.4	-1.156	1.4786	12.921	4.16
Ulgen and H ii (eq.13b)	0.052	2.0811	-13.34	0.08	-0.728	2.2	2.1268	1.16	-1.192	1.5557	12.64	3.96	-0.48	2.0734	0.8046	0.79
Khatib *et al.*(eq.22b)	1.558	1.7734	-30.42	6.1	0.7418	1.639	-13.87	1.7	1.8817	1.9867	-26.86	9.79	1.398	1.605	-20.87	5.88
Bortolini *et al*(eq.23a)	0.4062	0.8754	-11.46	1.74	-0.436	1.6036	2.3541	0.94	1.1245	1.3651	-17.09	4.82	0.2987	0.826	-5.583	1.29
Sunshine fraction based Linear models																
Ulgen and Hiii(eq.13c	-0.07	1.9977	-10.57	0.12	-0.949	2.2928	5.3495	1.51	-1.572	1.8209	18.257	5.67	-0.645	2.1138	3.1209	1.06
Bashahu (eq.6d)	-0.318	0.8401	4.1102	1.36	-1.228	2.1934	15.732	2.24	-0.039	2.0601	1.3615	0.06	-0.119	0.7854	2.8486	0.51
Sunshine fraction based Non Linear models																
El-Sebaii *et al* ii(eq4b)	0.3144	2.3513	-16.84	0.45	-1.067	3.1357	5.1312	1.2	-2.179	2.9589	25.862	3.61	-1.049	3.9554	3.9712	0.91
Ulgen and H iv(eq.13d)	-0.013	2.1656	-12.66	0.02	-0.805	2.3235	2.9762	1.23	-1.6	1.85	18.444	5.71	-0.526	2.0915	1.538	0.86
Pandey *et al*(eq.16e)	0.2063	1.2833	-10.84	0.54	-0.351	1.4146	0.7102	0.85	0.7168	2.8105	-13.4	0.87	-0.177	0.9473	1.0525	0.63
Clearness index and sunshine fraction based Linear models																
Benghanem *et al*(eq.11)	-0.414	0.7548	5.03	2.17	-1.293	2.2503	16.167	2.33	0.3733	1.614	-5.194	0.79	-0.242	0.9289	4.128	0.89
Elminir *et al.*(eq.12)	-1.488	2.1716	14.247	3.12	-2.346	2.8511	25.504	4.8	-1.738	2.0124	19.946	5.68	-1.84	2.2154	20.945	4.95
El-Sebaii *et al* iii(eq.17e)	10.427	11.711	-140.6	6.49	9.6996	12.309	-116.1	4.25	17.751	18.126	-230.7	16.06	12.244	13.95	-149.6	6.08
Khalil *et al.*(eq.24e)	55.902	56.669	-866.1	19.96	55.189	55.827	-730.7	21.75	52.578	53.192	-680	21.62	56.007	56.413	-750.4	27.51
Clearness index and sunshine fraction based Non Linear models																
Jiang i (eq.14)	-1.094	1.4754	11.717	3.67	-1.996	2.5123	22.944	4.34	-0.794	1.2973	8.5673	2.57	-1.244	1.4502	14.894	5.54
Jiang ii (eq.15)	0.8827	1.051	-15.36	5.13	-0.132	1.7416	0.077	0.25	1.4711	2.0376	-19.82	3.46	0.8502	1.1007	-11.81	4.03
Khorasanizadeh(eq.26i)	-0.995	1.5645	8.7204	2.73	-1.853	2.3803	20.338	4.12	-1.052	1.4324	11.879	3.59	-1.188	1.4422	13.559	4.82

4. Results and Discussions

The present study was carried out to find the most appropriate model for the prediction of daily diffuse solar radiation data on horizontal surface. For this purpose, all the developed models from 2001-2014 have been used, then estimated results have been compared with measured data of four prominent locations of India viz. Jodhpur, Ahmedabad, Kolkata and Mumbai. To overcome this complexity, these models were categorized into five groups through Table 1 on the basis of clearness index, sunshine fraction, clearness index and sunshine fraction, models from other parameters, and models from extraterrestrial radiation.

On the basis of clearness index, five linear models have been selected from literature and also shown through figs. 1-4 for Jodhpur, Ahemdabad, Kolkata and Mumbai respectively. From the results of Figs. 1-4, it has been found that, for the locations under consideration Jin *et al*. (Eq.7), El-sebaii *et al*.(Eq.4a) and Khatib *et al*.(Eq.22a) models predicts values higher than measured values. Ulgen and Hepsbasli (Eq.13a) did not found good match with the measured data of all considered locations. Bashahu who used 16 year data on global and diffuse radiation along with data of bright sunshine hours, fraction of sky cloud cover, ambient temp and water vapour pressure in air and three correlations have been recommended for Dakar for their simplicity and higher accuracy. Due to insufficiency of data for model (Eq.6h), we have analyzed only Eq. (6a, 6d) and found that clearness index dependent linear model (Eq.6a) gave less accurate results for Jodhpur, Kolkata and Mumbai and for Ahmedabad result was in underestimation, Eq.(6d) which depends on the relative sunshine duration has excellent fitting with measured data of all considered locations.

From the analysis of non linear clearness index models it was found that Tarhan and sari (Eq.9a, 9b), Ali al Mohamad (Eq.8) and Ulgen and Hepsbasli (Eq. 13b) gives under estimated values while Khatib *et al*. (Eq.22b) model gives over estimated result .Oliveira *et al*. (3b) and Aras *et al*. (10i) predicts worst results with the measured data for all considered locations. Miguel *et al*.(Eq.1) used combined data of Portugal, France and Spain countries to develop correlation. They also compared estimated results with experimental values and Jacovides *et al*., Frutos *et al*., and Macagnan *et al*. developed correlations, and found a small difference between the Miguel *et al*. (Eq.1) and Macagnan and Frutos correlations. While Bortolini *et al* (Eq.23a) used measured data of 44 European weather stations for developing a multi location model. From the Figs. 1-4, it was observed that both correlations gave approximate equal results and slightly closes to measured values of considered locations. Karatasou *et al*. (Eq.5) correlation estimated results were near about with the measured data for Ahemdabad and Mumbai, which were close to Miguel and Bortolini estimation but for Jodhpur and Kolkata values were over estimated. Hence on the basis of clearness index, Miguel *et al*. and Bortolini *et al*. models are recommended for the estimation of daily diffuse radiation on horizontal surface for all considered locations of India. All statistical results have also been confirmed for all considered locations and presented through Table 2.

Two linear and three non linear correlations have also been taken on the basis of bright sunshine hour and compared with our measured data through Figs. 1-4. From the results of Figs. 1-4 we found that Ulgen and Hepsbasli (Eq.13c, 13d) and El Sebaii (Eq.4b) predicts very poor results with measured data for all considered locations. However, Pandey *et al* (Eq.16e) All India Correlation (AIC) on the basis of non-linear sunshine fraction based models gave best results than any other selected models. The low values of MBE, RMSE, MPE, and t-test presented in Table 2 also confirmed the accuracy of Bashahu model (Eq.6d) in linear and Pandey *et al*(Eq.16e) in non-linear.

Furthermore, Four linear and three non linear models have been selected from literature on the basis of clearness index and sunshine fraction dependent models and also shown through Figs. 1-4. From the Figs. it was observed that El Sebaii (Eq.17e) model for Jeddah (lat. 21° 42' 37 N, long. 39° 11' 12 E), Saudi Arabia and Khalil *et al*.(Eq.24e) model for Cairo, Egypt (Lat. 30°05' N and Long. 31°15'E) predicts too much higher value than the measured data for all considered locations so we can say that these relations cant be used for the estimation of daily diffuse radiation on horizontal surface for any locations of India. On the other hand, observed result from Elminir (Eq.12) model was below than measured data. However, from all linear sunshine fraction based models Benghanem *et al*.(Eq.11) has good finding with measured data. Jiang (Eq.15) model from non linear correlations give best results than Jiang (Eq.14) and Khorasanizadeh (Eq.26i). Table2 confirms these results statistically.

Models from other parameters (Eqs. 6h, 18a, 21a) and extraterrestrial radiation dependent models (Eqs. 4c,13e, 13f, 13g, 13h, 17f, 18b, 19a, 19b, 20, 21b, 24f) for estimating daily diffuse solar radiation on horizontal surface were also categorized in this group. These correlations are tabulated in Table 1. Due to insufficient of data, we have made comparison on the basis of clearness index, sunshine fraction, clearness index and sunshine fraction.

Conclusion

The measured data for four prominent locations of India are used to select the models for estimating horizontal diffuse solar radiation at these locations. Miguel *et al*. and Bortolini *et al*. models on the basis of clearness index and Bashahu (6d) model from linear sunshine fraction based models have been proposed with resonable accuracy. A close agreement has been observed between measured and estimated data using Pandey *et al* (Eq.16e) model on the basis of sunshine fraction whereas Jiang (Eq.15) model give more accurate result on the basis of clearness index and sunshine fraction. Over all comparison of all Figs. and Tables we rercommended Pandey *et al* model for estimating diffuse solar radiation all over India and the other locations having similar climatic conditions.

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