Analysis and Modeling of Global Solar Radiation for Kodaikanal TamilNadu, India

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Abstract - Solar Energy utilization is very important for designing the photo-voltaic cell, solar energy equipments and thermal storage system. This paper has presented the effective utilization of solar energy potential available in the location of kodaikanal, Tamil Nadu, India. The solar radiation data has been collected from the Indian metrological department, Pune and were analyzed to find the first order and second order angstrom type regression equation. The estimated equation is compared with the statistical errors such as Mean Bias Error (MBE), Absolute Mean Bias Error (AMBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE) with the measured values of global radiations and bright sunshine hours. The global radiation model presented in this paper can be applied to the nearby similar geographical locations.

Key words: Solar Global radiation, sunshine hours, statistical errors, regression equations.

I. INTRODUCTION

Solar Energy is a part of sun's energy that falls on the earth surface which is in the form of electromagnetic wave. The solar energy is in two forms one is global radiation which is directly reached and other one is diffuse radiation which is scattered to the surface. In any solar energy conversion system, the knowledge of global solar radiation is extremely important for solar energy applications such as solar water heating, solar pumping, soar distillation, photo-voltaic cell and solar thermal storage system. But the measurement of solar radiation using pyarnometer is equipped only in selected sites which is very expensive. Therefore alternative method is to develop the global radiation models. This data is readily available in the metrological department. Many researchers had developed mathematical models. Angstrom (1) was the first one to propose such a model in 1924 for estimating the monthly average daily global irradiation (Hg) by using the bright sunshine data and J.A.Prescott (2) in 1940 modified this equation in a more convenient form (Angstrom-Prescott equation) by replacing the monthly average globaradiation on a clear day (Hg) by monthly average extraterrestrial radiation ($\bar{H}o$) as: $\frac{H_g}{H_0} = a + b\left(\frac{S_g}{S_0}\right)$ over the years the many researchers Anna Mani and S. Rangarajan, K. K. Gopinathan , M. Lqbal (3-5) have been developed various models considering the climatic conditions such as air temperature ,relative humidity ,cloudless. Clear sky and sunshine hours these factors depends on latitude and altitude. Al-Sadah et al, (6) had developed global radiation on a horizontal surface in the plane area of Uttar Pradesh using regression constants and the regression equation is derived. The global radiation models were statistically tested by M.R.Rictveld, Veeran PK and Kuma and Akinoglu (1990) (7-9). A model of Chennai location has been developed by the researchers' S.Ravichandran et al (10). In the present work, a correlation model has been developed for kodaikanal location of Tamil Nadu, India. The measured global radiation and bright sunshine hours has been collected from Indian metrological department, Pune India and used for this work.

II. DATA USED

The three years (2006-2008) data of the monthly average daily global solar radiation and the bright sunshine hours for kodaikanal Tamil Nadu, India has been collected from the Indian Meteorological Department Pune, India . The information regarding the geographical coordinates are Latitude: $10^0 14'$ N / Longitude:$77^0 28'$ E Site elevation: 2343 amsl. The Meteorological Department provided data for 4 a.m. to 8 p.m. The data recorded from 4 a.m. to 6 a.m. and from 6 p.m. to 8 p.m. for all days in this 3-year period were not used since the radiation recorded during this period was very low and in some cases had missin values since the exclusion would be minimum but does not affect the overall result.

III. METHODOLOGY

The three year data of daily average global and the bright sunshine hours for the Kodaikanal locations has been averaged to find the daily average global and sunshine hours for all the days of the year separately. The daily extra-terrestrial radiation and (Ho) the sunshine duration (So) on the locations has been calculated by using the expression

$$H_0 = \frac{24 \times 3600}{\pi} I_{sc}\left[1 + 0.033\, Cos\left(\frac{360\, n}{365}\right)\right] \times \left(Cos\, \phi\, Cos\, \delta\, Sin\, \omega_s + \frac{2\pi\omega_s}{360}\, Sin\, \phi\, Sin\, \delta\right)$$

$$So = \frac{2}{15} \cos^{-1} \left(\tan\Phi \tan\alpha\right)$$

Table 1 Represents the monthly average daily measurements of global radiation and bright sunshine hours for the kodaikanal location expressed as ratios of Hg/Ho and Sg/So In order to develop a global radiation model, by using Ms office Excel software and method of correlations two regression equations were obtained to estimate the monthly average daily global radiation, is namely,

I. Sunshine duration in linear form

$$\frac{Hg}{Ho} = 0.322 \frac{Sg}{So} + 0.365$$

II. Sunshine duration in quadratic form

$$\frac{Hg}{Ho} = 0.1424 \left[\frac{Sg}{So}\right]^2 + 0.4172 \frac{Sg}{So} + 0.3127$$

Table 1. Monthly average measured Global radiation compared with calculated global radiation in Linear fit Hg and Quadratic fit Hg, C Q (MJ/m2 day)

Month	Hg	Sg	Ho	So	Hg/Ho	Sg/so	HgL	HgQ
JAN	21.11516	14.92903	31.57	11.68	Sg/so	1.278171	24.27779	34.05123
FEB	27.37286	7.037931	31.36	11.94	0.872859	0.589441	17.20476	19.06972
MAR	47.26727	18.88452	36.46	11.77	1.296414	1.604462	31.84518	49.1722
APR	44.39477	18.80667	36.48	12.46	1.216962	1.509363	30.7525	46.21355
MAY	29.43878	7.467742	30.94	12.58	0.95148	0.59362	17.01571	18.89004
JUN	12.98443	6.52	36.63	12.53	0.354475	0.520351	19.28615	20.81857
JUL	14.97516	1.751613	36.72	11.94	0.40782	0.146701	14.943	13.84228
AUG	15.78065	3.016129	37.12	12.07	0.425125	0.249886	16.33145	15.80735
SEP	14.27413	2.806667	36.73	11.88	0.388623	0.236251	15.9996	15.39766
OCT	15.32901	3.532258	34.95	11.55	0.438598	0.305823	16.00233	15.85359
NOV	19.01832	6.153333	32.35	11.42	0.587892	0.538821	17.22387	18.72543
DEC	14.80686	5.222581	28.04	11.47	0.528062	0.455325	14.17994	14.92245

The fig1 shows the measured and calculated value of global radiation, sunshine hours and the linear model and the second order equations which shows the maximum global radiations was found 49017 MJ/m^2 /day in second order and 31.84MJ/m^2 /day in the linear model.

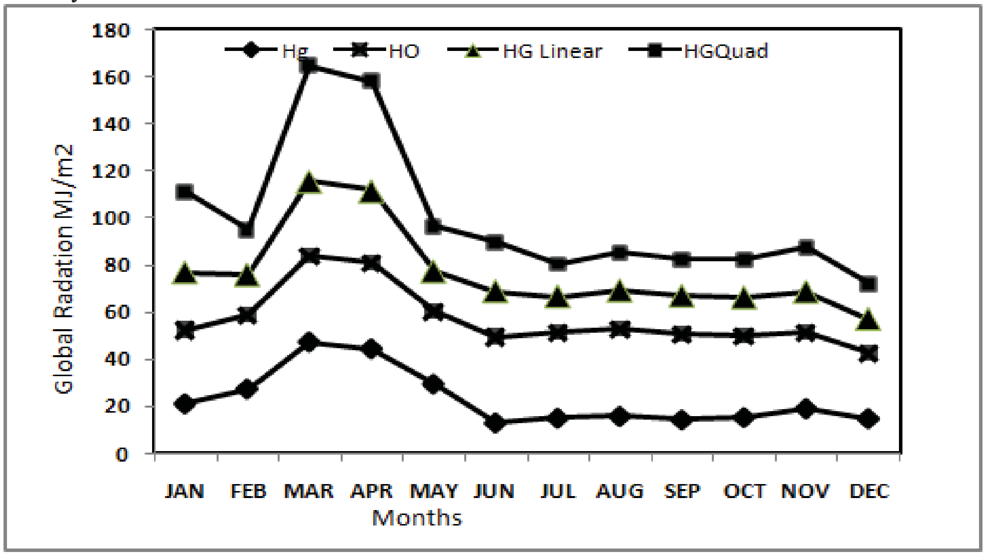

Figure1. Monthly average measured Global radiation compared with calculated global radiation in Linear fit Hg and Quadratic fit Hg, C Q (MJ/m2 day)

IV. STATISTICAL COMPARISON OF MODELS

The accuracy of the proposed global radiation model was tested by calculating the mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE) and absolute mean bias error (AMBE). These are defined below

$$: MBE = \left[\frac{1}{n}\sum_{j=1}^{n} d_j\right], \quad MPE = \frac{1}{n}\left[\sum_{j=1}^{n}\frac{|d_j|}{\overline{\overline{H}}_m} x100\right] \quad RMSE = \left[\frac{1}{n}\sum_{j=1}^{n} d_j^{\,2}\right] \quad AMBE = \left[\frac{1}{n}\sum_{j=1}^{n}|d_j|\right]$$

where, d_j is the difference between the jth calculated and jth measured value of global radiation on a horizontal surface and n is the number of data pairs.

The performance was calculated for each month of the year. The results of these computations for the various models in terms of the performance statistics are shown in Tables 2-3

Table 2. The comparison of Monthly average Global radiation in Linear fit and Measured values of Errors.

Month	Hg	Hgl	MBE	AMBE	RMSE	MPE
JAN	21.11516	24.27779	3.162629	3.162629	10.00222	14.978
FEB	27.37286	17.20476	-10.1681	10.1681	103.3903	-37.1466
MAR	47.26727	31.84518	-15.4221	15.42209	237.8409	-32.6274
APR	44.39477	30.7525	-13.6423	3.642271	186.1116	-30.7295
MAY	29.43878	17.01571	-12.4231	12.42307	154.3326	-42.1997
JUN	12.98443	19.28615	6.301718	6.301718	39.71165	48.53288
JUL	14.97516	14.943	-0.03216	0.032163	0.001034	-0.21478
AUG	15.78065	16.33145	0.550806	0.550806	0.303387	3.490387
SEP	14.27413	15.9996	1.725475	1.725475	2.977266	12.08813

OCT	15.32901	16.00233	0.673312	0.673312	0.45335	4.392405
NOV	19.01832	17.22387	-1.79445	1.794446	3.220037	-9.43536
DEC	14.80686	14.17994	-0.62692	0.626921	0.39303	-4.23399
Average			**-3.47459**	**4.71025**	**12.0728**	**-6.09213**

Table 3: The comparison of Monthly average Global radiation and Measured values of Errors

Month	Hg	HgQ	MBE	AMBE	RMSE	MPE
JAN	21.11516	34.05123	12.93607	12.93607	167.3418	61.26435
FEB	27.37286	19.06972	-8.30314	8.303143	68.94219	-30.3335
MAR	47.26727	49.1722	1.904929	1.904929	3.628754	4.030123
APR	44.39477	46.21355	1.818778	1.818778	3.307952	4.096828
MAY	29.43878	18.89004	-10.5487	10.54874	111.2759	-35.8328
JUN	12.98443	20.81857	7.834138	7.834138	61.37372	60.33486
JUL	14.97516	13.84228	-1.13288	1.132882	1.283422	-7.56507
AUG	15.78065	15.80735	0.026704	0.026704	0.000713	0.169218
SEP	14.27413	15.39766	1.123531	1.123531	1.262323	7.871104
OCT	15.32901	15.85359	0.524579	0.524579	0.275183	3.422128
NOV	19.01832	18.72543	-0.29289	0.292887	0.085783	-1.54002
DEC	14.80686	14.92245	0.115582	0.115582	0.013359	0.780595
Average			**0.500555**	**3.880163**	**34.89926**	**5.558153**

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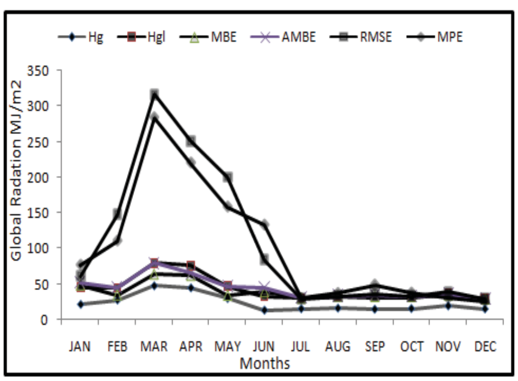

Fig.2 (a)

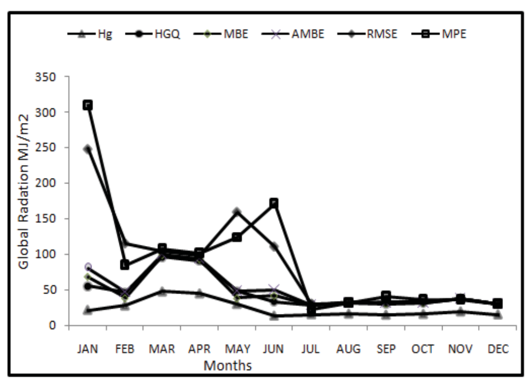

Fig2. (b)

Fig 2.The comparison of Monthly average Global radiation in (a) Linear fit and (b) quadratic fit and Measured values of Errors

The fig2 (a) and (b) shows the measured value of global radiation, The Angstrom type linear model and The Angstrom type quadratic model is statistically verified which shows least value of monthly mean bias error (MPE) of Linear fit is -6.09213 (MJ/m^2 day), and Quadratic fit is - (MJ/m^2 day) for kodaikanal

V. RESULTS AND DISCUSSION

The monthly average daily global radiation obtained by the present quadratic model has been compared with the measured data for kodaikanal and the local correlation in terms of MPE, RMSE, MBE and AMPE. The results of this comparison for different errors are listed in Table 4.

Table4. Monthly average Global radiation calculated from different models

Different Models	MPE	MBE	RMSE	AMBE
Mani and Rangarajan (1982)	10.1104	-1.9845	2.1523	1.9245
Gopinathan (1988)	6.8991	-0.8129	1.5107	1.3360
Akinoglu (1990)	3.6496	-0.1654	0.7658	0.7002
Rietveld (1978)	3.8626	0.0868	0.8079	0.7304
VeeranPKandKumar (1993)	4.7479	-0.0734	1.1492	0.9704
Present Study :Linear Fit	-6.09213	-3.47459	12.0728	4.71025
Present Study :Quadratic Fit	5.55815	0.50055	34.8992	3.8801

The present study indicates that Angstrom type Linear equation developed from the Kodaikanal data has predicted low error level MPE -6.09213, RMSE 12.071025, MBE -3.47459 and AMBE 4.71025 compared to all the Quadratic correlations MPE 5.558153, RMSE 34.89926, MBE -0.50055 and AMBE 3.888 and the other local model. Besides, the local models Akinoglu (1990) MPE 3.6496, RMSE 0.7658, MBE -0.1654 and AMBE 0.7002, Rietveld (1978) MPE 3.8626, RMSE 0.8079, MBE 0.0868 and AMBE 0.7304, yields the best estimates for Kodaikanal. The large error produced by the other local models is Gopinathan (1988) level MPE 6.8991, RMSE 1.5107, MBE -0.8129 and AMBE 1.3360, Mani and Rangarajan (1982) level MPE 10.1104, RMSE 2.1523, MBE -1.9845 and AMBE 1.9845, which models not suitable for kodaikanal location. Thus it is concluded that in particular area or particular location, correlation will be the most suitable to estimate the monthly average daily global radiation.

VI. CONCLUSION

An Angstrom type linear correlation was developed for Kodaikanal location. The estimate value of global solar radiation data has been analyzed and compared with the measured data and local correlation. Linear Angstrom type correlation model in the tables 2 and 3 show the performance of the proposed correlation was statistically compared with measured data and local correlation MPE -6.09123, RMSE 12.0728, MBE-3.47459 and AMBE 4.71025 gives a better prediction of global radiation for Kodaikanal compared to Quadratic model correlation MPE, 5.55815, RMSE, 34.8992 MBE 0.50055 and AMBE 3.8801 .So it is concluded that the following Linear model for kodaikanal location is suitable.

Sunshine duration in linear form

$$\frac{Hg}{Ho} = 0.322 \frac{Sg}{So} + 0.365$$

The result and correlation may then be used for any location with similar meteorological parameter and geographical characteristics at which solar data are not available.

NOMENCLATURE

H_g	-	Monthly average daily global radiation (MJ $m^{-2}d^{-1}$)
H_o	-	Monthly average daily extraterrestrial radiation (MJ $m^{-2}d^{-1}$)
S_g	-	Monthly average daily hours of bright sunshine hours (h)
So	-	Monthly average day length (h)
I_{sc}	-	Solar constant
n	-	Day of the year
ϕ	-	Latitude of the location
δ	-	Solar declination

ω_s - Hour angle
a, b and c - Regression coefficients

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