Study of Models for Predicting the Mean Hourly Global Radiation from Daily Summations

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Abstract: It is mandatory to predict the hourly solar radiation received during the average day of each month for different solar energy applications, particularly in design methods, Scientists have developed methods to achieve this using different input parameters. The objective of this study is to compare statistically existing models for estimating the mean hourly global radiation incident on a horizontal surface from mean daily global radiation and to recommend one that best fits measured data from five Indian locations chosen namely, Bangalore, Jodhpur, Mumbai, New Delhi and Srinagar. From our results it is observed that *Collares-Pereira and Rabl model as modified by Gueymard* (CPRG) yields the best performance for estimating mean hourly global radiation incident on a horizontal surface for Indian regions. In addition to CPRG model, *Collares-Pereira and Rabl* (CPR) and *Whillier /Liu and Jordan* (WLJ) models yield better performance than Newell, Baig and Garg models. Moreover each model gives an average amount of under-estimation in the calculated value.

Keywords: Hourly global radiation, Indian region, statistical comparison.

INTRODUCTION

Accurate determination of the hourly solar radiation received during the average day of each month is a prerequisite in different solar energy applications, particularly in design methods. As soon as the early 1950s, Whillier [1,2] introduced the 'utilisability' method to predict analytically the performance of active solar collectors (see also [3]). This method used a simple formulation to estimate the mean hourly radiation during each hour of an average day of the month, based on the ratio of the hourly to daily irradiations received by a horizontal surface outside of the atmosphere. This methodology has been perfected.

The emphasis is placed here on the prediction of the monthly-average hourly global radiation over a 'long-term' period of around eleven years as opposed to individual hourly periods for a specific day and a specific year. In other words, the long-term calculations involved here provide the mean hourly distribution of global radiation over the average day of each average month. The *daily integration* approach introduced by Whillier involved the hourly/daily radiation ratio just mentioned and received much attention in the literature. Some early reports were of qualitative nature (e.g. [4-6]). Liu and Jordan generalized Whillier's finding by adding a few datapoints from a Canadian site. Another key contribution was the model introduced by Collares-Pereira and Rabl [7]; hereafter, CPR, who modified the original Whillier formulation. CPR realized that the atmospheric attenuation of direct and global radiation had a dependency upon hour angle. They used a dataset combining two years of individual hourly data from four U.S. stations and the original data of [4], and proposed a correction to the original equations by Whillier or Liu and Jordan which assumed no atmospheric effect. CPR also pointed out that the interest of such a method was that it could predict hourly radiation a (which is a rarely available quantity at any site) from straightforward information: hour angle and mean daily irradiation, *H*.

Gueymard [8] proposed a slight correction to the CPR model (hereafter, CPRG) to make it internally consistent. He also showed that morning/afternoon asymmetries could limit the accuracy of the predicted mean hourly radiation. This asymmetry problem received more attention later [9-13]. Following CPR, it is assessed here that only daily radiation values are available at any site; there is no way to predict asymmetric irradiations during the day from just daily global information.

It was demonstrated [14] that the hourly/daily ratio is significantly affected by latitude and solar elevation. This finding prompts a closer examination of the latitudinal, or more generally, *climatic in*fluences on the daily integration method. This constitutes the main objective of the present study.

In the *mathematical* approach, the diurnal variation of the hourly/daily radiation ratio is simulated with different types of mathematical formula of time. It is still not clear which mathematical representation is best to describe the physical processes involved. Cosine distributions have been proposed [15-17], as well as a quadratic [17], various forms of exponentials or Gaussian distributions [18-22]. Despite their merit, the accuracy of these methods is not established. In particular, it remains to be seen which, of the daily integration or the mathematical approach, is better when applied to a site where daily radiation can only be indirectly obtained, from mean monthly sunshine or cloudiness information for

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1876-3251/08

instance. Elements to answer this question will be proposed here.

In this paper, the various models to determine the hourly solar radiation for different Indian climatic conditions have been studied to predict the best model on the basis of RMSE and MBE. It is observed that CPRG model is most suitable for clear sky condition of Indian climatic conditions.

EXPERIMENTAL DATA

Long term monthly-mean hourly global radiation data for a measuring site are obtained from hourly global radiation by averaging individual hourly values for each month over a period of one to eleven years. The long term monthly-mean daily global irradiation is obtained as the sum of each individual hourly irradiation for that day. The solar radiation data have been collected for the period of 1991-2001 from India Meteorology Department (IMD) Pune, India. Using this source of data, a dataset of global radiation for a total of five sites has been assembled. This dataset encompasses a large diversity of climatic conditions, including desertic (hot and dry), coastal (warm and humid), moderate, cold with cloudy and composite. This diversity is associated with a very large altitude (elevation) span, which ranges from 11 m to 1586 m above mean sea level. The typical data for New Delhi climate has been given in Table **1**.

The present results are based on a large number of different instrument types, calibration methods, and climates, so that the overall error should remain small. Most other errors are random, and they tend to decrease rapidly as the averaging period increases. Therefore, they should be negligible here.

These data have been obtained using a thermoelectric pyranometer. The pyranometer used are supposed to be calibrated once a year with reference to the World Radiometric Reference (WRR). Critical information such as calibration history, instrument changes, data quality control process, and shading due to obstructions in the horizon, is simply not available for these stations. Therefore it is to be expected that some data sites have larger uncertainties, with possibly more incorrect or missing data than others. But this situation is also confronted by any investigator using this kind of radiation data directly to design solar energy systems.

METHODOLOGY

In what follows, all calculations are made on an average hourly basis. The solar geometry need be determined for only an average day of each month. The average days of the month are taken from [23].

The day length (in hours) is simply obtained as:

$$S_o = k\omega_o \quad (1)$$

where $k = 24/\pi$, ω_o is the sunrise hour angle (in radians) obtained from

$$\cos\omega_o = -\tan\phi\tan\delta \quad (2)$$

where ϕ is the site's latitude, δ is solar declination obtained from

$$\delta = 23.45\sin\left[\frac{360}{365}\left(284+n\right)\right] \quad (3)$$

where n is the day of the year i.e. 1 for Jan 1.

EXISTING MODELS

Whillier/Liu and Jordan model (*WLJ*): In this model, global radiation is considered to follow the same hourly distribution as if there were no atmosphere. For an hourly period evaluated at the middle of the hourly interval, according to the present procedure, the extraterrestrial hourly/daily ratio can be obtained (see derivation in [2, 4, 6]) simply as:

Table 1. Measured Average Hourly Global Solar Radiations for Clear Sky Weather Condition (W/m^2) for New Delhi

Time ► Month ▼	8 a.m.	9 a.m.	10 a.m.	11 a.m.	12 p.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.
January	132.99	355.56	554.69	680.73	726.74	733.85	656.08	500.00	311.46	106.42
February	180.29	403.58	594.44	729.39	786.02	792.03	728.58	584.23	391.22	178.23
March	266.77	488.94	671.21	804.33	866.93	869.28	803.15	665.33	483.01	264.10
April	368.14	588.48	767.81	888.32	941.01	944.12	878.68	746.90	568.30	348.61
May	406.31	608.84	776.26	897.98	956.82	950.51	886.62	761.37	580.81	372.48
June	436.67	637.22	802.22	915.00	951.67	946.11	882.78	765.56	611.67	420.00
July	367.36	587.04	737.27	831.71	881.48	896.53	820.60	753.24	569.68	373.15
August	333.59	528.54	674.49	820.20	868.18	807.83	766.67	658.08	477.78	305.81
September	277.96	501.30	682.04	809.07	869.07	855.19	779.81	656.48	483.89	270.19
October	168.75	364.58	565.28	694.45	761.80	756.25	686.11	543.75	362.50	152.08
November	121.46	316.04	485.35	609.97	664.01	657.45	587.37	454.17	274.62	84.09
December	93.12	275.27	443.25	565.87	621.83	618.39	553.31	426.19	253.97	68.78

$$r_0 = (\cos\omega - \cos\omega_o) / kA(\omega_o) \quad (4)$$

where $A(\omega_o) = \sin\omega_o - \omega_o \cos\omega_o$

Table 2. Recommended Average Days for Months and Values of n by Months

Months	n for *i*th Day of Month	For Average Day of Month		
		Date	n	δ
January	*i*	17	17	-20.9
February	31+ *i*	16	47	-13.0
March	59+ *i*	16	75	-2.4
April	90+ *i*	15	105	9.4
May	120+ *i*	15	135	18.8
June	151+ *i*	11	162	23.1
July	181+ *i*	17	198	21.2
August	212+ *i*	16	228	13.5
September	243+ *i*	15	258	2.2
October	273+ *i*	15	288	-9.6
November	304+ *i*	14	318	-18.9
December	334+ *i*	10	344	-23.0

Table 3. Latitude and Altitude of the Locations Used in this Study

Location	Latitude	Altitude (m)
Bangalore	12°58' N	921
Jodhpur	26°18' N	224
Mumbai	18°54' N	11
New Delhi	28°35' N	216
Srinagar	34°05' N	1586

Collares-Pereira and Rabl model (*CPR*). The CPR model corrects WLJ's r_o for the atmospheric effect as follows:

$$r_{CPR} = (a + b\cos\omega) r_o \quad (5)$$

where *a* and *b* are linear functions of

$\sin(\omega_o - \pi/3)$ [7].

and are given by

$$a = 0.4090 + 0.5016\sin(\omega_o - 1.047) \quad 5(a)$$

$$b = 0.6609 - 0.4767\sin(\omega_o - 1.047) \quad 5(b)$$

Collares-Pereira and Rabl model as modified by Gueymard (*CPRG*). The CPRG model [8] consists in a slight modification of to ensure consistency through renormalization

$$r_{CPRG} = (a + b\cos\omega) r_o / f \quad (6)$$

where $f = a + 0.5b(\omega_o - \sin w_o \cos\omega_o) / A(\omega_o)$ (7)

Newell model (*N*). There are, in fact, two slightly differing models from Newell [17]. For simplicity, only the parabolic function of time will be tested here as an example of Newell's 'simple modeling approach'

$$r_N = (1.5 / S_o)\left[1 - 4(t-12)^2 / S_o^2\right] \quad (8)$$

where S_o is evaluated from (1)

Jain model (*J*). Based on the normal distribution equation, Jain [9] proposed

$$r_J = \frac{1}{\sigma_J\sqrt{2\pi}} \exp\left[-\frac{(t-12)^2}{2\sigma_J^2}\right] \quad (9)$$

where $\sigma_J = 0.461 + 0.192 S_o$

Baig et al. model (*B*). Jain's exponential model is corrected in Baig model with a cosine function for better accuracy around sunrise and sunset [20]

$$r_B = \frac{1}{2\sigma_B\sqrt{2\pi}} \exp\left\{\left[-\frac{(t-12)^2}{2\sigma_B^2}\right] + \cos\left[\pi(t-12)/(S_o - 1)\right]\right\} \quad (10)$$

where $\sigma_B = 0.26 + 0.21 S_o$

Garg and Garg Model (G). Garg and Garg [25] checked the adequacy of WLJ model for various Indian stations and showed that the model is not suitable for predicting the hourly solar radiation received during the average day of each month. Therefore they proposed the following new model.

$$r_G = r_o - 0.008\sin 3(\omega - 0.65) \quad (11)$$

Measured values of radiation ratio are computed as

$$r_{meas} = \frac{\bar{I}}{\bar{H}} \quad (12)$$

where

r_{meas} is the measured radiation ratio,

$\bar{I}$ is the measured monthly mean hourly global radiation and

$\bar{H}$ is the measured monthly mean daily global radiation.

Methods of Comparison

In this study two statistical test, root mean square error (RMSE) and mean bias error (MBE), are used to evaluate the accuracy of the models described above.

Root Mean Square Error

The root mean square error is defined as

Table 4. Percentage Root Mean Square Error (RMSE) between Predicted Results and Measured Monthly-Mean Hourly Irradiation for Location Bangalore

		WLJ	CPR	CPRG	Newell	Jain	Baig	Garg
January	RMSE	16.8	15.8	15.7	18.4	16.7	16.3	17.1
	MBE	-2.4	-2.6	-1.77	-2.67	-6.08	-3.8	-3.4
February	RMSE	18.2	17.8	17.8	19.4	18.8	18.3	18.2
	MBE	-2.9	-3.1	-2.2	-3.3	-6.6	-3.9	-4
March	RMSE	18.2	17	16.9	19.8	17.8	17.2	18.2
	MBE	-3.7	-3.6	-2.8	-4.3	-7.2	-4.3	-4.8
April	RMSE	16.7	14.1	13.8	19.3	15.3	14.1	16.1
	MBE	-4.7	-4.4	-3.6	-5.4	-7.9	-4.7	-5.8
May	RMSE	13.9	11.9	11.6	16.6	14.1	12	13.8
	MBE	-5.6	-5	-4.3	-6.4	-8.5	-5.2	-6.6
June	RMSE	15.4	14.1	13.9	17.5	16.3	14.3	15.8
	MBE	-6	-5.3	-4.7	-6.9	-8.9	-5.5	-7.1
July	RMSE	13.7	11.4	11.1	16.4	13.5	11.5	13.3
	MBE	-5.8	-5.2	-4.5	-6.7	-8.7	-5.3	-6.9
August	RMSE	12.5	9.5	9.2	15.4	11.6	9.6	11.3
	MBE	-5.1	-4.6	-3.9	-5.8	-8.2	-4.9	-6.2
September	RMSE	15.1	11.7	11.5	17.9	12.6	11.7	13.2
	MBE	-4.1	-3.9	-3.1	-4.7	-7.5	-4.4	-5.2
October	RMSE	13.4	10.8	10.6	16	12.1	11.1	12.4
	MBE	-3.2	-3.3	-2.4	-3.6	-6.8	-4	-4.3
November	RMSE	14.2	13.1	13	16	14.6	13.8	14.4
	MBE	-2.5	-2.7	-1.8	-2.8	-6.2	-3.8	-3.5
December	RMSE	19	17.6	17.5	20.6	18.3	18	19
	MBE	-2.2	-2.5	-1.6	-2.5	-5.9	-3.8	-3.3

$$RMSE = \left\{ \left[\sum \left(r_{i,calc} - r_{i,meas} \right)^2 \right] / n \right\}^{1/2} \qquad (13)$$

where $r_{i,calc}$ is the ith calculated value, $r_{i,meas}$ is the ith measured value, and n is the total number of observations. The RMSE is always positive, a zero value is ideal. This test provides information on the short-term performance of the models by allowing a term by term comparison of the actual deviation between the calculated value and the measured value. However a few large errors in the sum can produce a significant increase in RMSE.

Mean Bias Error

The mean bias error is defined as

$$MBE = \left[\sum (r_{i,calc} - r_{i,meas}) \right] / n \qquad (14)$$

This test provides information on the long-term performance. A low MBE is desired. Ideally a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation.

RESULTS

For known values of latitude (Table **3**), the values of 'a', 'b' and 'f' have been computed from Equations 5(a), 5(b) and 7 respectively. After evaluating 'a', 'b' and 'f', the radiation ratio proposed by various models [Equations 4 to 11] can be evaluated. Further, the measured values of the average monthly mean hourly global radiation can be determined from Equation (12) for known values of monthly daily global radiation.

For typical data of New Delhi (Table **1**), the variation of average monthly mean hourly global radiation has been shown in Fig. (**1**) for the month of June. The observed average monthly mean hourly global radiation for the month of June has also been shown in Fig. (**1**). It is noted that there CPRG model predicts the best result in comparison to other models.

Equations 13 and 14 have been computed for all months of five stations and the results for clear sky conditions are given in Tables **4-8**.

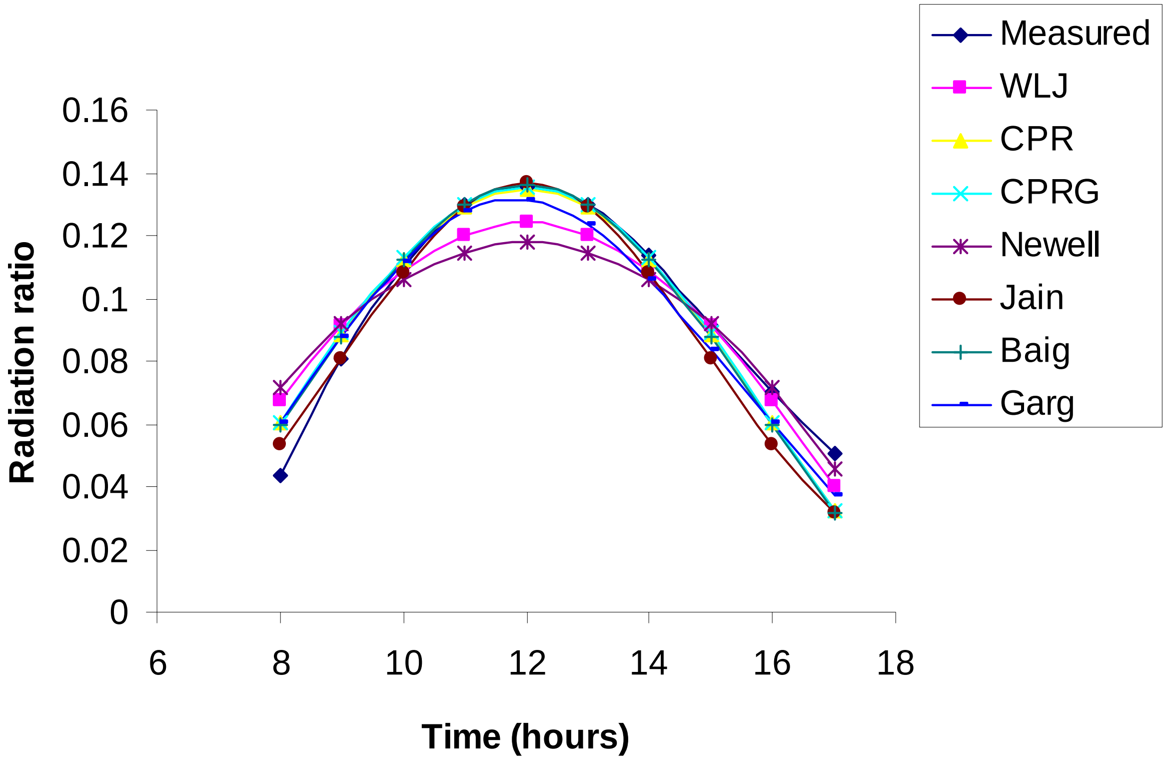

Fig. (1). Measured and estimated ratios of monthly mean hourly to daily global radiation for the month of June at Bangalore.

Table 5. Percentage Root Mean Square Error (RMSE) between Predicted Results and Measured Monthly-Mean Hourly Irradiation for Location Jodhpur

		WLJ	CPR	CPRG	Newell	Jain	Baig	Garg
January	RMSE	15.8	16.3	16.4	16.6	16.9	17.7	17.1
	MBE	-1.1	-1.6	-0.81	-1.24	-4.71	-3.9	-2.2
February	RMSE	13.7	14.8	14.9	14.5	16	16	15.2
	MBE	-2	-2.3	-1.5	-2.2	-5.7	-3.7	-3
March	RMSE	12	13.4	13.4	13	15.5	14.2	13.8
	MBE	-3.6	-3.5	-2.7	-4	-7.1	-4.2	-4.6
April	RMSE	11.97	12.6	12.5	13.5	15.4	13	13.6
	MBE	-5.7	-5.1	-4.4	-6.5	-8.6	-5.3	-6.7
May	RMSE	12.4	11.9	11.7	14.7	15	12	13.8
	MBE	-7.6	-6.5	-6	-8.9	-10	-6.5	-8.7
June	RMSE	13	12.5	12.3	15.3	15.7	12.5	14.7
	MBE	-8.6	-7.2	-6.9	-10	-10.7	-7.2	-9.7
July	RMSE	12.7	12.6	12.4	14.7	15.8	12.6	14.5
	MBE	-8.2	-6.9	-6.5	-9.5	-10.4	-6.9	-9.3
August	RMSE	12.4	12.3	12.1	14.4	15.2	12.5	13.8
	MBE	-6.5	-5.6	-5.1	-7.5	-9.2	-5.7	-7.6
September	RMSE	12.3	12.6	12.5	13.9	15	13.2	13.6
	MBE	-4.3	-4.1	-3.3	-4.9	-7.6	-4.5	-5.4
October	RMSE	13.3	14.1	14.2	14.4	15.6	15.1	14.7
	MBE	-2.4	-2.7	-1.8	-2.7	-6.1	-3.8	-3.5
November	RMSE	15.6	16.5	[8] 16.6	16.3	17.3	17.9	17.1
	MBE	-1.3	-1.8	-0.9	-1.4	-4.9	-3.8	-2.3
December	RMSE	15.9	16.7	16.9	16.6	17.2	18.4	17.5
	MBE	-0.97	-1.5	-0.7	-1	-4.4	-4	-2

Table 6. Percentage Root Mean Square Error (RMSE) between Predicted Results and Measured Monthly-Mean Hourly Irradiation for Location Mumbai

		WLJ	CPR	CPRG	Newell	Jain	Baig	Garg
January	RMSE	17.5	18.2	18.2	18.2	18.9	19.2	18.9
	MBE	-1.7	-2.2	-1.3	-1.9	-5.5	-3.7	-2.8
February	RMSE	16.2	16.8	16.9	17	17.9	17.7	17.5
	MBE	-2.5	-2.7	-1.8	-2.8	-6.2	-3.8	-3.6
March	RMSE	16.4	16.8	16.8	17.4	18.2	17.4	17.7
	MBE	-3.7	-3.6	-2.8	-4.2	-7.1	-4.2	-4.7
April	RMSE	15.9	15.9	15.8	17.3	17.6	16.2	17
	MBE	-5.1	-4.7	-3.9	-5.9	-8.2	-4.9	-6.2
May	RMSE	16	15.3	15.2	17.8	17.2	15.5	16.8
	MBE	-6.4	-5.6	-5	-7.4	-9.2	-5.7	-7.5
June	RMSE	14.6	14.3	14.1	16.5	16.7	14.4	15.7
	MBE	-7.1	-6.1	-5.6	-8.2	-9.6	-6.1	-8.2
July	RMSE	23	24.4	24.3	23.3	27	24.7	25.3
	MBE	-6.8	-5.8	-5.3	-7.8	-9.4	-5.9	-7.8
August	RMSE	16.3	16.9	16.8	17.4	19.5	17.3	18.1
	MBE	-5.7	-5.1	-4.4	-6.5	-8.6	-5.3	-6.7
September	RMSE	14.4	14.6	14.5	15.7	16.5	15.1	15.5
	MBE	-4.2	-4	-3.2	-4.8	-7.5	-4.5	-5.3
October	RMSE	12	11.6	11.5	13.8	13.4	12.4	12.6
	MBE	-2.8	-3	-2.1	-3.2	-6.5	-3.9	-3.9
November	RMSE	15.4	14.9	14.8	16.8	16.1	15.7	15.9
	MBE	-1.9	-2.3	-1.4	-2.2	-5.6	-3.7	-2.9
December	RMSE	16	15.7	15.7	17.2	16.7	16.7	16.6
	MBE	-1.5	-2	-1.1	-1.7	-5.3	-3.7	-2.6

The performances of the seven models to predict mean hourly global radiation from mean daily global radiation were evaluated using the root mean square and mean bias error tests. The results of the statistical comparison of the seven models are presented in Tables **3-7**.

For moderate climate of Bangalore, the evaluated values of percentage root mean square error (RMSE) and percentage mean bias error (MBE) for radiation ratio have been given in Table **4** for each month. The values of RMSE and MBE both are minimum for the model proposed by Newell (Equation 8) during the months from January to April. During the remaining eight months of the year, the values of RMSE and MBE both are minimum for the model proposed by CPRG (Equation 6). Hence this model gives closer results in comparison to others.

For desertic (hot and dry) climate of Jodhpur, the evaluated values of percentage root mean square error (RMSE) and percentage mean bias error (MBE) for radiation ratio have been given in Table **5** for each month. The values of RMSEs are minimum during months from January to April and September to December for the model proposed by WLJ (Equation 4). The values of RMSEs are minimum during months from May to August for the model proposed by CPRG (Equation 6). The values of MBEs are minimum during all months of the year for the model proposed by CPRG (Equation 6). Hence this model gives closer results in comparison to others.

For coastal (warm and humid) climate of Mumbai, the evaluated values of percentage root mean square error (RMSE) and percentage mean bias error (MBE) for radiation ratio have been given in Table **6** for each month. WLJ model (Equation 4) yields minimum RMSEs during months from January to March and July to September. CPRG model (Equation 6) yields minimum RMSEs during months from April to June and from October to December. CPRG model (Equation 6) gives minimum MBEs during all months of the year. Hence this model gives closer results in comparison to others.

For composite climate of New Delhi, the evaluated values of percentage root mean square error (RMSE) and percentage mean bias error (MBE) for radiation ratio have been given.

In Table **7** for each month. WLJ, CPR and CPRG models give minimum (almost equal) RMSEs during months from January to April. CPRG model gives minimum RMSEs during the months from May to August. CPR and CPRG models give minimum (almost equal) RMSEs during the months from September to December. Again CPRG model gives minimum MBEs during all months of the year. Hence this model gives closer results in comparison to others.

For cold and cloudy climate of Srinagar, the evaluated values of percentage root mean square error (RMSE) and percentage mean bias error (MBE) for radiation ratio have been given in Table **8** for each month. CPRG model gives the best results in terms of RMSEs and MBEs during all months of the year. Hence this model gives closer results in comparison to others. CPR model is next best with the smallest range of MBEs.

CPRG model generally gives the best results for clear sky conditions of Indian regions. The low MBEs are particularly remark-able. Therefore, its use is recommended for Indian regions.

ACKNOWLEDGEMENTS

The authors are grateful to the Indian Meteorological Department, Pune, India for providing the hourly global and diffuse radiation data for the period of 11 years from 1991 to 2001.

Table 7. Percentage Root Mean Square Error (RMSE) between Predicted Results and measured Monthly-Mean Hourly Irradiation for Location New Delhi

		WLJ	CPR	CPRG	Newell	Jain	Baig	Garg
January	RMSE	13.7	13.4	13.5	15	14.6	14.9	14.4
	MBE	-0.9	-1.5	-0.7	-1.1	-4.5	-4	-2
February	RMSE	14.5	14.6	14.6	15.7	15.7	15.6	15.4
	MBE	-1.8	-2.2	-1.3	-2	-5.6	-3.7	-2.9
March	RMSE	14.6	16.1	16.1	15.3	17.9	16.8	16.4
	MBE	-3.5	-3.5	-2.6	-4	-7	-4	-4.5
April	RMSE	11.5	11.5	11.4	13.4	14.4	11.9	12.8
	MBE	-5.9	-5.2	-4.5	-6.7	-8.7	-5.4	-6.9
May	RMSE	12.5	11	10.7	15.2	14.1	11	13.3
	MBE	-8.1	-6.8	-6.4	-9.3	-10.3	-6.8	-9.1
June	RMSE	12.3	11	10.9	15.1	14.5	11	13.4
	MBE	-9.2	-7.6	-7.3	-10.7	-11.1	-7.6	-10.2
July	RMSE	13.5	12.4	12.3	15.9	15.6	12.5	14.7
	MBE	-8.6	-7.2	-6.8	-10.1	-10.7	-7.2	-9.7
August	RMSE	11.9	10.2	9.9	14.7	13	10.3	12.1
	MBE	-6.8	-5.8	-5.3	-7.8	-9.4	-5.9	-7.8
September	RMSE	12.3	11.7	11.6	14.2	13.9	12.2	12.8
	MBE	-4.4	-4.1	-3.4	-5	-7.7	-4.6	-5.5
October	RMSE	15.5	13.7	13.6	17.4	15	14.2	15.2
	MBE	-2.3	-2.6	-1.7	-2.6	-6	-3.8	-3.3
November	RMSE	14.3	12.9	12.9	15.9	14.5	14	14.3
	MBE	-1.1	-1.6	-0.83	-1.3	-4.7	-3.9	-2.2
December	RMSE	15.9	15.2	15.3	17.2	16.3	16.6	16.5
	MBE	-0.88	-1.4	-0.62	-0.99	-4.2	-4.3	-1.9

Table 8. Percentage Root Mean Square Error (RMSE) between Predicted Results and Measured Monthly-Mean Hourly Irradiation for Location Srinagar

		WLJ	CPR	CPRG	Newell	Jain	Baig	Garg
January	RMSE	15.6	15.4	15.5	16.7	17.4	17.2	16.4
	MBE	-0.87	-1.3	-0.6	-0.99	-3.8	-4.6	-1.9
February	RMSE	23.8	22.5	22.5	25	23	22.9	24
	MBE	-1.4	-1.9	-1.1	-1.6	-5.2	-3.8	-2.5
March	RMSE	16.6	16.1	16	18.1	17.6	16.6	17.3
	MBE	-3.4	-3.4	-2.6	-3.9	-6.9	-4.1	-4.5
April	RMSE	11.5	9.7	9.4	14.4	13.1	10	12.1
	MBE	-6.4	-5.6	-4.9	-7.3	-9.1	-5.7	-7.4
May	RMSE	14.1	11.1	10.8	17.6	13.9	11.1	14.2
	MBE	-9.1	-7.5	-7.3	-10.6	-11	-7.5	-10.2
June	RMSE	14.4	12.4	12.3	17.5	15.6	12.4	15.4
	MBE	-10.5	-8.6	-8.5	-12.3	-12.1	-8.6	-11.6
July	RMSE	14.4	10.6	10.4	18.3	13.4	10.6	14
	MBE	-9.9	-8.1	-7.9	-11.5	-11.6	-8.1	-10.9
August	RMSE	16.1	13.9	13.7	18.8	16.2	14	16.4
	MBE	-7.5	-6.4	-5.9	-8.7	-9.9	-6.4	-8.6
September	RMSE	11.7	8.6	8.3	14.7	11.5	8.9	11
	MBE	-4.5	-4.2	-3.4	-5.1	-7.7	-4.6	-5.5
October	RMSE	12	8.8	8.6	14.6	11.5	9.4	10.8
	MBE	-1.9	-2.3	-1.4	-2.2	-5.7	-3.7	-3
November	RMSE	17.6	14.1	14	19.6	16.5	14.4	16.2
	MBE	-0.9	-1.4	-0.6	-1	-4.2	-4.3	-1.9
December	RMSE	20	18.9	19	21.1	19.3	20.4	20.6
	MBE	-1	-1.3	-0.7	-1.2	-3.5	-5.1	-2.1

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Received: January 22, 2008 Revised: January 31, 2008 Accepted: February 1, 2008