Prediction of clock time hourly global radiation from daily values over Bangladesh

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Abstract

A need for predicting hourly global radiation exists for many locations particularly in Bangladesh for which measured values are not available and daily values have to be estimated from sunshine data. The CPRG model has been used to predict values of hourly G_h for Dhaka (23.77^0N, 90.38^0E), Chittagong (22.27^0N, 91.82^0E) and Bogra (24.85^0N, 89.37^0E) for $\omega = \pm 7.5^0, \pm 22.5^0, \pm 37.5^0, \pm 52.5^0, \pm 67.5^0, \pm 82.5^0$ and $\pm 97.5^0$ i.e., for ±1/2, ±3/2, ±5/2, ±7/2, ±9/2, ±11/2, ±13/2 hours before and after solar noon and the computed values for different months are symmetrical about solar noon whereas for many months experimental data show a clear asymmetry. To obtain improved prediction, the hour angles ω corresponding to clock times have been used in the model to take into account the difference between solar time and clock time for each month for each station. Values of r_G show the morning-afternoon asymmetry and agree fairly well with experimental data with standard deviation for different hours between 0.004 and 0.009. The rms error is about 6% between 10:00 am and 2:00 pm.

Introduction:

Data on hourly global solar radiation arriving at the horizontal surface of the earth are not available for most locations due to lack of pyranometer stations around. It is unfortunately true for Bangladesh where hourly global radiation data is only available for Dhaka for a few years. However one may develop excellent correlations between sunshine duration and global radiation and produce long-term values of daily G for all months of the year where hourly values of solar radiation have been measured for a year or more while sunshine data are available for many years. Therefore hourly global radiation values can be computed for many locations with the help of computed daily radiation and computed r_G. It may be mentioned that accurate determination of hourly solar radiation received during the average day of each month is a prerequisite in different solar energy applications, particularly in design methods. Hourly global radiation allows computation of tilt factors to estimate hourly radiation received by fixed or tracking tilted surfaces of solar collectors to predict performances of solar devices or to optimize their designs. This is also important to study or predict the performance of the systems, which could be used daytime without a backup system such as water pumping for irrigation or household in rural areas.

Computation of solar time hourly global radiation:

As early as 1960, Liu and Jordan propounded the idea that the ratio of monthly mean hourly to daily global radiation r_G is the same as the ratio of hourly to daily extraterrestrial radiation and

$$r_G = \frac{\pi}{24}\left[\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{2\pi\omega_s}{360}\cos\omega_s}\right] \qquad \text{.......................................(1)}$$

The model was modified by Collares-Pereira and Rabl [1] and later by Gueymard [2] to the form

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$$r_G = (a + b\cos\omega).\frac{1}{f}\cdot\frac{\pi}{24}\left[\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \frac{2\pi\omega_s}{360}\cos\omega_s}\right] \quad \text{..............................(2)}$$

where, $a = 0.4090 + 0.5016\sin(\omega_s - 60)$, $b = 0.6609 + 0.4767\sin(\omega_s - 60)$

and $$f = a + 0.5b\left[\frac{\frac{2\pi\omega_s}{360} - \sin\omega_s.\cos\omega_s}{\sin\omega_s - \frac{2\pi\omega_s}{360}\cos\omega_s}\right]$$

A number of models [3] are available for computing hourly global fraction r_G which when multiplied with daily G, gives the hourly radiation. Among them it has been shown that [2] CPRG model given by equation (1) gives best results when performed on 135 different sites for a large range of geographic and climatic conditions (latitude 82.5^0N to 67.6^0S). In an earlier work it was also seen that for global fraction computation, CPRG model gives excellent predictions for Dhaka.

The computed values of r_G are derived for Dhaka (23.77^0N, 90.38^0E), Chittagong (22.27^0N, 91.82^0E) and Bogra (24.85^0N, 89.37^0E) for $\omega = \pm7.5^0$, $\pm22.5^0$, $\pm37.5^0$, $\pm52.5^0$, $\pm67.5^0$, $\pm82.5^0$ and $\pm97.5^0$ i.e., for ±1/2, ±3/2, ±5/2, ±7/2, ±9/2, ±11/2, ±13/2 hours before and after solar noon and the computed values for different months are symmetrical about solar noon. They are given in Table 1. According to equation (2), r_G depends on sunrise or sunset hour angle (ω_s), which depends on latitude of the location. It is seen that value of r_G does not vary considerably on latitude of the location for Bangladesh with small variation of latitude. This is shown for Bogra, Dhaka and Chittagong having latitude of 24.85^0N, 23.77^0N and 22.27^0N respectively.

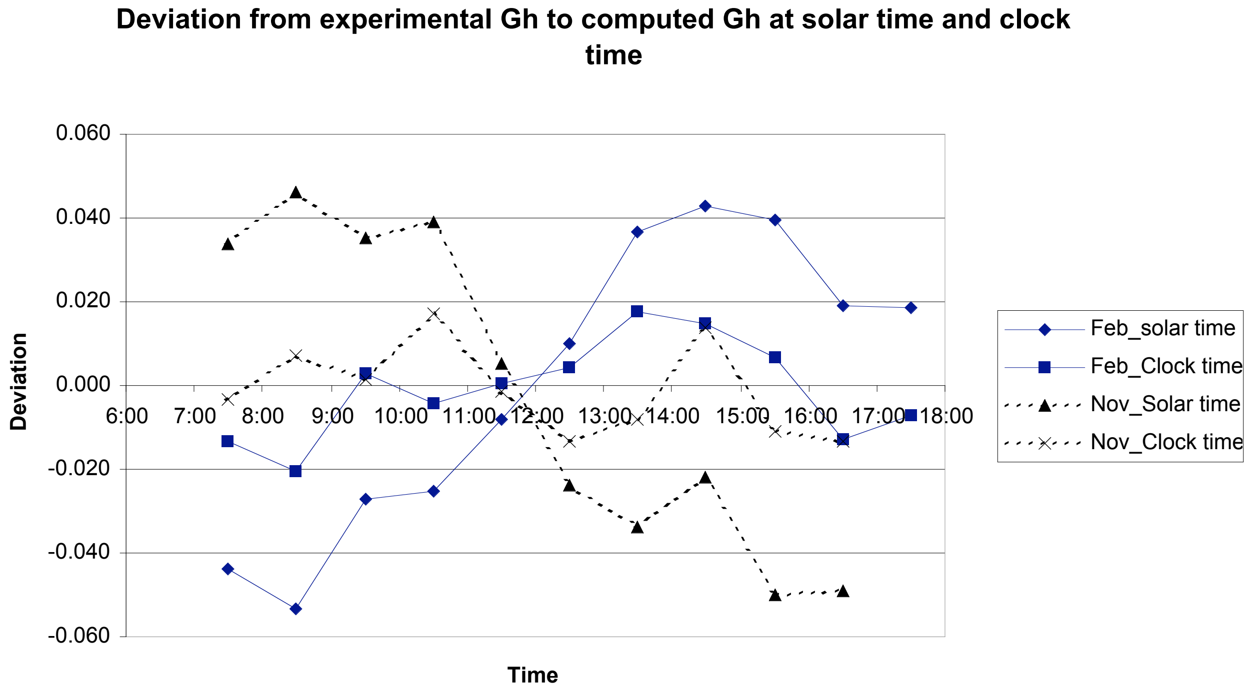
Computation of clock time hourly global radiation:

For many months experimental data of hourly global radiation show a clear asymmetry. This is because, solar time and clock time differ from day to day at a location and also from location to location depending on the longitude. As shown in Table 2, a difference between clock time and solar time exists for each location. For Dhaka it is maximum in October, November and lowest in April and June. For other locations it also varies from month to month. As a result at any location computed hourly global radiation fraction r_G does not agree at the above mentioned hour angles with the experimental values at the corresponding clock time particularly when the time difference is large.

Therefore, to obtain improved prediction, the hour angles ω corresponding to clock times have been used in the model to take into account the difference between solar time and clock time for each month for each station. For example, at Dhaka in January when clock time is 12:30, solar time is 12:22, therefore for calculating r_G the hour angle is -5.5^0. For 11:30 the hour angle is 9.5^0 and r_G differs between 11:30 and 12:30. Thus global radiation fraction were computed for Bogra, Dhaka and Chittagong which are situated in eastern, central and western region of the country with the longitudes of 89.37^0E, 90.38^0E and 91.82^0E respectively. The values of r_G at clock time are given in Table 3.

Figure 1 shows the deviation from hourly global radiation measured at clock time during 1986-1987 and 1992 to the calculated hourly radiation at solar time as well as clock time for February and November. It is clearly seen that deviation reduces significantly for clock time calculations.

Figure 1: Deviation for experimental G_h to computed G_h at solar time and clock time



To verify whether table 3 works for any location of Bangladesh, the hourly data of Dhaka has been calculated from clock time r_G of Chittagong and Bogra. These computed data were compared with experimental hourly data of Dhaka of the duration 1986-1989 and 1992. The overall error was less than 5% for the data derived from Chittagong and were less than 4% for the data derived from Bogra. When hourly G was computed from r_G of Dhaka and compared with experimental data of Dhaka, then the error reduces to 1.5%. It may be mentioned here that the error is higher for the hours at early morning and late afternoon. Since the whole country has been divided into three sectors, it is clear that the computation of any location will be fairly accurate since the error for Dhaka were quite small even computed with r_G of other sectors. Therefore in general r_G of Dhaka can be used for evaluation of G_h of any location and for better prediction one can use r_G of Bogra, Dhaka and Chittagong for locations in eastern, central and western respectively.

Conclusion:

In this paper a data table has been presented which can be used to calculate hourly global radiation data for any location of Bangladesh. For calculation of r_G at solar time and clock time, CPRG model has been used which gives least deviation for Dhaka. The computational hourly data of any location with r_G of the representative station of the sector where the location lies, gives quite good prediction since the deviation is less than 5%, which is comparable with statistical and experimental errors.

References:

1. Collares-Pereira M, Rabl A. The average distribution of solar radiation – correlation between diffuse and hemispherical and between daily and hourly insolation values. Solar Energy, 1979;22:155.
2. Gueymard C. Prediction and performance assessment of mean hourly global radiation. Solar Energy, 2000;68:285-303.
3. Duffie JA, Beckman WA. Solar Engineering of Thermal Processes, John Wiley, 1980.

Table 1: Computed r_G at three locations for different hour angles of sun

Month	Station	Hour Angle						
		±7.5^0	**±22.5^0**	**±37.5^0**	**±52.5^0**	**±67.5^0**	**±82.5^0**	**±97.5^0**
Jan	Bogra	0.156	0.139	0.108	0.068	0.028		
	Dhaka	0.156	0.138	0.107	0.069	0.029		
	Cht	0.154	0.138	0.107	0.069	0.030		
Feb	Bogra	0.150	0.134	0.106	0.071	0.034	0.002	
	Dhaka	0.150	0.134	0.106	0.071	0.035	0.003	
	Cht	0.149	0.134	0.106	0.071	0.035	0.004	
Mar	Bogra	0.142	0.129	0.105	0.073	0.041	0.011	
	Dhaka	0.142	0.129	0.105	0.073	0.041	0.011	
	Cht	0.142	0.129	0.104	0.073	0.041	0.011	
Apr	Bogra	0.135	0.124	0.102	0.075	0.045	0.018	
	Dhaka	0.136	0.124	0.102	0.075	0.045	0.018	
	Cht	0.136	0.124	0.103	0.075	0.045	0.018	
May	Bogra	0.130	0.120	0.100	0.076	0.049	0.023	0.002
	Dhaka	0.130	0.120	0.101	0.076	0.048	0.023	0.001
	Cht	0.131	0.120	0.101	0.075	0.048	0.022	0.001
Jun	Bogra	0.127	0.117	0.099	0.076	0.050	0.025	0.005
	Dhaka	0.128	0.118	0.100	0.076	0.050	0.025	0.004
	Cht	0.129	0.119	0.100	0.076	0.049	0.024	0.003
Jul	Bogra	0.128	0.118	0.100	0.076	0.049	0.025	0.003
	Dhaka	0.129	0.119	0.100	0.076	0.049	0.024	0.003
	Cht	0.130	0.119	0.100	0.076	0.049	0.023	0.002
Aug	Bogra	0.133	0.122	0.101	0.075	0.047	0.021	
	Dhaka	0.133	0.122	0.102	0.075	0.047	0.020	
	Cht	0.134	0.122	0.102	0.075	0.046	0.020	
Sep	Bogra	0.139	0.127	0.104	0.074	0.043	0.014	
	Dhaka	0.139	0.127	0.104	0.074	0.043	0.014	
	Cht	0.139	0.127	0.104	0.074	0.043	0.014	
Oct	Bogra	0.147	0.132	0.106	0.072	0.037	0.006	
	Dhaka	0.146	0.132	0.106	0.072	0.037	0.007	
	Cht	0.146	0.132	0.105	0.072	0.038	0.007	
Nov	Bogra	0.154	0.137	0.107	0.069	0.031		
	Dhaka	0.153	0.137	0.107	0.070	0.031		
	Cht	0.153	0.136	0.107	0.070	0.032		
Dec	Bogra	0.158	0.140	0.108	0.067	0.026		
	Dhaka	0.157	0.140	0.108	0.068	0.027		
	Cht	0.156	0.139	0.107	0.068	0.029		

Table 2: Difference between clock time and solar time in minutes

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bogra	-12	-17	-12	-3	1	-3	-8	-6	3	12	12	1
Dhaka	-8	-13	-8	1	5	1	-4	-2	7	16	16	5
Chittagong	-2	-7	-2	7	11	7	2	4	13	22	21	11

Table 3: Predicted values of global fraction $r_G=G_h/G_d$ using CPRG model for clock times of three stations

Month	Station	Clock time													
		5:30	**6:30**	**7:30**	**8:30**	**9:30**	**10:30**	**11:30**	**12:30**	**13:30**	**14:30**	**15:30**	**16:30**	**17:30**	**18:3**
Jan	Bogra			0.021	0.060	0.100	0.134	0.154	0.158	0.144	0.115	0.076	0.036		
	Dhaka			0.024	0.063	0.103	0.135	0.154	0.157	0.142	0.112	0.074	0.034		
	Cht			0.029	0.068	0.106	0.137	0.154	0.155	0.138	0.108	0.070	0.032		
Feb	Bogra			0.025	0.060	0.097	0.128	0.147	0.152	0.140	0.115	0.081	0.044	0.011	
	Dhaka			0.027	0.063	0.099	0.129	0.147	0.151	0.139	0.113	0.079	0.042	0.009	
	Cht			0.031	0.067	0.102	0.131	0.148	0.150	0.136	0.110	0.076	0.039	0.007	
Mar	Bogra		0.006	0.034	0.067	0.099	0.125	0.141	0.144	0.133	0.110	0.080	0.047	0.016	
	Dhaka		0.008	0.036	0.069	0.101	0.126	0.141	0.143	0.131	0.108	0.078	0.045	0.015	
	Cht		0.010	0.040	0.072	0.104	0.128	0.142	0.142	0.130	0.105	0.074	0.042	0.012	
Apr	Bogra		0.017	0.044	0.073	0.101	0.123	0.135	0.136	0.124	0.104	0.076	0.047	0.019	
	Dhaka		0.018	0.046	0.075	0.103	0.124	0.136	0.135	0.124	0.102	0.074	0.045	0.018	
	Cht		0.021	0.048	0.078	0.105	0.126	0.137	0.135	0.122	0.100	0.071	0.042	0.015	
May	Bogra	0.002	0.024	0.049	0.076	0.101	0.120	0.130	0.130	0.119	0.100	0.075	0.048	0.023	
	Dhaka	0.003	0.025	0.051	0.078	0.102	0.121	0.131	0.130	0.119	0.099	0.073	0.046	0.021	
	Cht	0.004	0.027	0.053	0.080	0.105	0.123	0.132	0.130	0.117	0.097	0.070	0.043	0.018	
Jun	Bogra	0.004	0.024	0.049	0.075	0.098	0.117	0.127	0.128	0.118	0.100	0.077	0.051	0.027	0.00
	Dhaka	0.004	0.025	0.050	0.076	0.100	0.118	0.128	0.128	0.118	0.099	0.075	0.049	0.025	0.00
	Cht	0.005	0.027	0.052	0.079	0.102	0.120	0.129	0.128	0.117	0.097	0.073	0.046	0.021	0.00
Jul	Bogra	0.001	0.021	0.046	0.072	0.097	0.116	0.128	0.129	0.120	0.103	0.079	0.053	0.028	0.00
	Dhaka	0.005	0.022	0.047	0.074	0.099	0.118	0.129	0.129	0.120	0.101	0.077	0.051	0.026	0.00
	Cht	0.003	0.024	0.050	0.076	0.101	0.120	0.130	0.130	0.119	0.100	0.075	0.048	0.023	0.00
Aug	Bogra		0.018	0.044	0.072	0.099	0.120	0.132	0.133	0.123	0.104	0.078	0.050	0.023	
	Dhaka		0.019	0.046	0.074	0.101	0.121	0.133	0.133	0.123	0.102	0.076	0.048	0.021	
	Cht		0.021	0.047	0.076	0.103	0.123	0.134	0.133	0.122	0.101	0.074	0.046	0.019	
Sep	Bogra		0.016	0.044	0.076	0.105	0.127	0.139	0.139	0.126	0.102	0.073	0.041	0.013	
	Dhaka		0.017	0.046	0.078	0.107	0.129	0.140	0.138	0.124	0.100	0.070	0.039	0.011	
	Cht		0.020	0.049	0.081	0.109	0.130	0.141	0.138	0.123	0.098	0.067	0.036	0.009	
Oct	Bogra		0.012	0.044	0.079	0.112	0.136	0.148	0.145	0.128	0.099	0.065	0.030	0.001	
	Dhaka		0.014	0.046	0.081	0.114	0.137	0.148	0.144	0.126	0.097	0.063	0.029	0.000	
	Cht		0.017	0.050	0.085	0.116	0.139	0.148	0.142	0.123	0.094	0.059	0.026		
Nov	Bogra		0.003	0.038	0.077	0.114	0.142	0.156	0.152	0.132	0.100	0.061	0.023		
	Dhaka		0.006	0.041	0.080	0.116	0.143	0.155	0.151	0.130	0.098	0.059	0.022		
	Cht		0.011	0.046	0.084	0.119	0.144	0.154	0.148	0.127	0.094	0.056	0.019		
Dec	Bogra			0.027	0.068	0.108	0.141	0.159	0.158	0.140	0.107	0.067	0.026		
	Dhaka			0.031	0.071	0.111	0.142	0.158	0.157	0.137	0.105	0.064	0.024		
	Cht			0.036	0.076	0.114	0.143	0.158	0.154	0.134	0.101	0.061	0.022		