Emperical Computation of Solar Radiation and Determination of Regression Coefficients for Khulna City

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Abstract

This study is accomplished to calculate global, diffuse and direct solar radiation empirically on a horizontal surface for the divisional district "Khulna" in Bangladesh (latitude 22o47´N and longitude 89o34´E) as well as to predict correlations for it by using several meteorological data for 32 years between 1980 and 2012. The global radiation is found to be maximum in the month of April and minimum in the month of December here. The estimated values of the Angstrom's regression constants a and b are 0.2388 and 0.5228 respectively. The other regression constants were also computed and the correlations proposed for Khulna can be used in future for the estimation of global, diffuse and direct solar radiation if the meteorological parameters remain available.

Keywords: global radiation, diffuse radiation, direct radiation, regression constant, solar

1. Introduction

The energy indeed plays a vital role in development and welfare of human being. There exists a direct correlation between the development of a country and its consumption of energy. World reserve of conventional energy sources are limited and will be used up once. Therefore, the whole world is looking for non-exhaustible energy sources for their future. Among the all non-conventional energies, solar energy is the most viable option if it can be used in a cost effective manner. Moreover solar energy conversion technology is environmentally sound. As the solar energy intercepted by the earth in one year is ten times more than the total fossil resources including undiscovered and unexplored non-recoverable reserves [1], it is expected that the present worldwide research and development program on solar energy will help to solve the future energy crisis of the world.

The installation of solar energy conversion systems over any place requires clear information about the availability of sunlight for their optimal use. Solar radiation is not uniform over all places on the earth which again varies from time to time. Bangladesh, being situated between 20o34´and 26o34´north latitude, 88o01´ and 92o41´east longitude, is heavenly gifted with abundant sunshine for minimum of 8 months in a year. Therefore, the prospect of utilization of solar energy is very bright. But solar radiation data are not available in many locations of Bangladesh due to absence or malfunction of measuring instruments. However, the meteorological department of Bangladesh is recording the climatological data such as sunshine hour, temperature, humidity etc. for most of the districts. These data can be readily used in empirical models to compute the global solar radiation and its components at any location. We, therefore, used these data to compute empirically the global, diffuse and direct solar radiation over Khulna as well as to determine the values of all the regression coefficients for it.

2. Estimation of Radiation

Many researchers throughout the world have estimated the values of solar radiation and its components for different areas of the world utilizing different formulas [2-12]. Here, for estimation of global solar radiation G, the formula proposed by H.P. Garg and S.N. Garg [13] is used given by Equation (1).

$$G = G_o \, (0.414 + 0.400 \, n/N - 0.0055 \, W_{at}) \tag{1}$$

Where Go is the extraterrestrial radiation, n/N is the ratio of sun shine hour and day length and Wat is the atmospheric water content per unit volume described in Eq (1d). From geometrical consideration extraterrestrial daily global solar radiation (Go) on a horizontal surface for each station is given by Equation (1a)

$$G_o = 0.01163 \{ (24F)/\pi \} (\cos\varphi \cos\delta \cos.W_s + \sin\varphi \sin\delta.W_s) \tag{1a}$$

Where F is a unit of conversion factor given in Equation (1b), φ is the latitude in radians, δ is the solar declination given in Equation (1e) and Ws is the sunset angle given in Equation (1c)

$$F = 1.95 \times 60.0 (1 + 0.033 \cos 360 \times d \, /365) \tag{1b}$$

$$Ws = \cos^{-1}(-\tan\varphi \, \tan\delta) \, radians \tag{1c}$$

$$W_{at} = H_{rel} (4.7923 + 0.3647T + 0.0055T^2 + 0.0003T^3) \tag{1d}$$

And,

$$\delta = [23 + (27/60)] \sin(360d/365) \tag{1e}$$

Where T is the ambient temperature in oC for the fractional sunshine duration n/N, Hrel is the relative humidity and d being the number of days after spring equinox (21st march).

For estimation of diffuse radiation (D), the formula proposed by M. Hussain [14] is used given by Equation (2).

$$D = G_o \{ 0.306 - (0.165 \times n/N) + 0.0025 \, W_{at} \} \tag{2}$$

For estimation of direct or beam radiation (I), the subtraction method [15] is used given by Equation (3).

$$I = G - D \tag{3}$$

Hence it should be noted that all the radiation data are estimated in the unit of Kwh/m2 – day.

3. Determination of Regression Coefficient

Angstrom correlation [16] modified by Prescott [17], given in Eq (4), for estimation of global radiation is generally employed all over the world. So, firstly the values of the Regression coefficients (a and b) are determined for Khulna

$$G/G_o = a + b \, (n/N) \tag{4}$$

Secondly, from Page correlation [18], given in Equation (5), for diffuse radiation, the values of the correlation coefficients (c and d) for this station are determined

$$D/G = c + d\,(G/G_o) \tag{5}$$

From Angstrom like correlation [19], given in Equation (6), for predicting diffuse radiation over Khulna the values of the coefficients c′ and d′ are determined

$$D/G_o = c' + d'\,(n/N) \tag{6}$$

Thirdly, from both Page like and Angstrom like correlations [20], given in Equation (7 and 8), for estimation of direct solar radiation, the values of the correlation coefficients e, f, e′ and f′ are determined for Khulna

$$I/G = e + f\,(G/G_o) \tag{7}$$

$$I/G_o = e' + f'\,(n/N) \tag{8}$$

To estimate diffuse and direct solar radiation directly from global solar radiation [21-22], the values of the coefficients co, do, eo and fo are determined

$$D/G = c_o + d_o\,(n/N) \tag{9}$$

$$I/G = e_o + f_o\,(n/N) \tag{10}$$

4. Results and Discussions

The fluctuations of monthly average Global, Diffuse and Beam solar radiation of Khulna throughout the year is shown in Figure 1. It is clear from the figure that the first peak in the global solar radiation occurs in April/May (summer season). In this period, both sunshine hour and temperature are high. But the second peak occurs in August (autumn season) which is not so prominent, due to short sun shining period although there is high temperature available. Again, in November/December (winter season), though there is enough sun shining periods but the temperature is low. Therefore, it results in low global solar radiation.

The diffuse solar radiation depends on relative humidity and atmospheric water content. It increases with the decrease of sun shining hour and increase of atmospheric water content. Therefore, the diffuse radiation is maximum in June/July (rainy season) and minimum in December/January (winter season).

The direct solar radiation is directly related to sunshine duration and is, therefore, maximum in March/April (summer season) and minimum in July (rainy season).
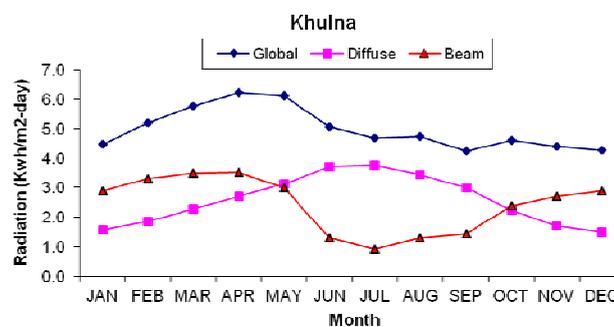
Figure 1. Monthly variation of Global, diffuse and beam solar radiation on a horizontal surface for Khulna

The year to year seasonal fluctuations of Gobal solar radiation and the variation of annually averaged global solar radiation is shown in Figure 2 and 3 respectively. There is up and down of global solar radiation in the graph but no cyclic pattern or symmetric variation of radiation is found. From   Figure 2 it is clear that the monthly average Global radiation is maximum in the month of April.
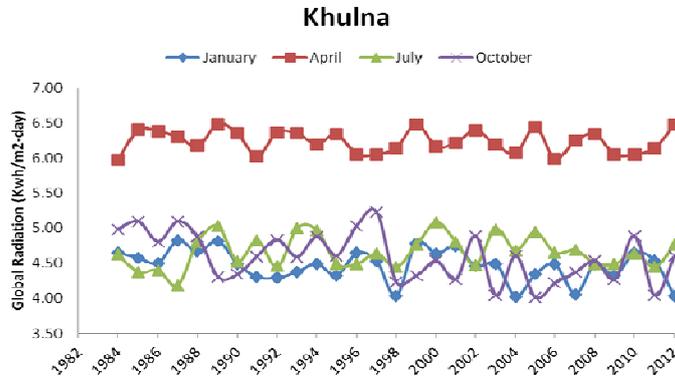
Figure 2. Year to year seasonal variation of Global solar radiation for Khulna
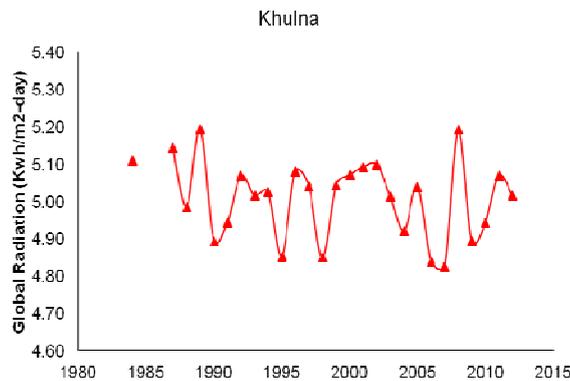
Figure 3. Variation of annually averaged global solar radiation for Khulna

Using the estimated data in the empirical formula given in Equation (1 to 3), several correlations are developed Equation (4 to 10) and the corresponding regression coefficients (given in Table 2) are determined for the station Khulna. The graphical representations of these correlations are described in the following figures (Figure 4 to 10):
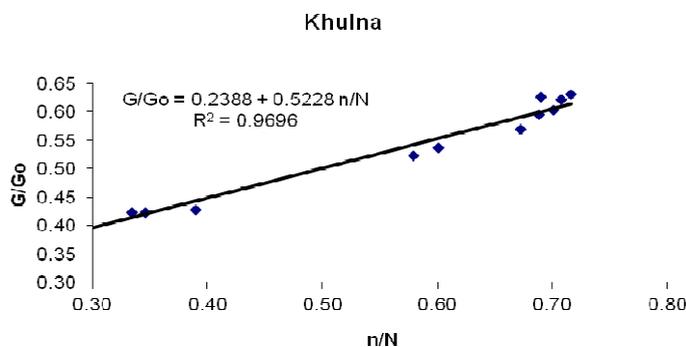
Figure 4. Correlation between n/N and G/Go for coefficient a and b
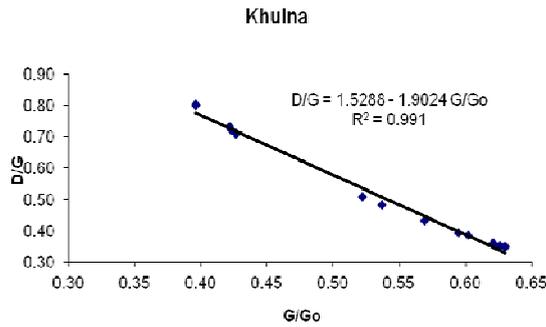
Figure 5. Correlation between G/Go and D/G for coefficient c and d
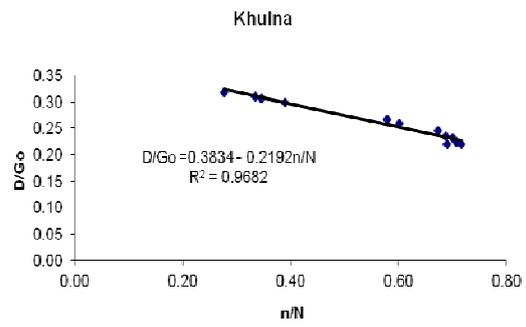
Figure 6. Correlation between n/N and D/Go for coefficient c' and d'
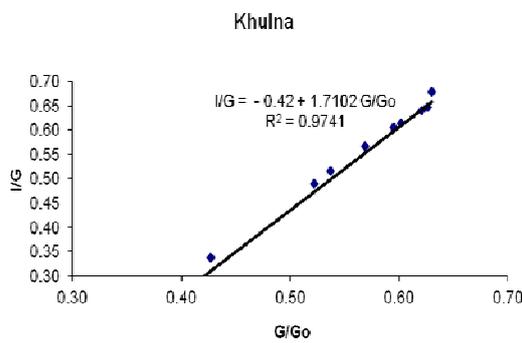
Figure 7. Correlation between G/Go and I/G for coefficient e and f
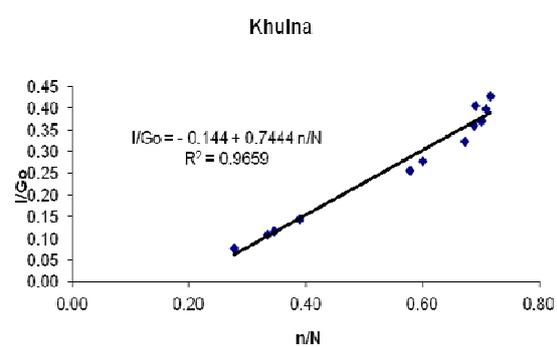
Figure 8. Correlation between n/N and I/Go for coefficient e' and f'
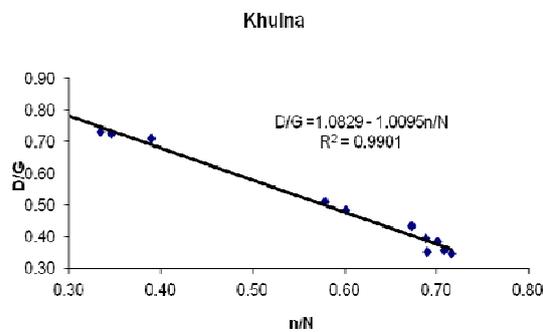
Figure 9. Correlation between n/N and D/G for coefficient co and do
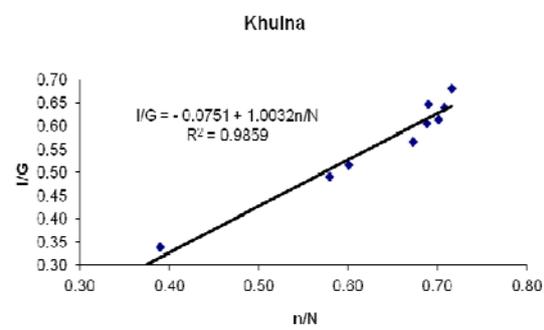
Figure 10. Correlation between n/N and I/G for coefficient eo and fo

Here, Figure 4 represents the correlation between n/N and G/Go (Equation 4) and the values of the regression coefficients a and b are determined for the station Khulna. Similarly Figure 5 to Figure 10 represent the correlations given in Equation (5) to Equation (10) respectively and the values of the coefficients c, d, c´, d´, e, f, e´, f´, co, do, eo and fo are determined from these figures. The values of the regression coefficients are represented in Table 2 and Table 3.

Table 2. The computed values of regression coefficients for Khulna

a	b	c	d	c´	d´	e	f	e´	f´
0.2388	0.5228	1.5288	-1.9024	0.3830	-0.2192	-0.4200	1.7102	-0.1440	0.7444

The value of the sum of the regression constants (a + b) which represent the maximum clearness index (when n/N = 1) is found to be 0.7616.

Using the values of the coefficients a and b for Khulna, a linear equation recommended for the estimation of monthly average global solar radiation over Khulna is given by the Equation (11)

$$G/Go = 0.2388 + 0.5228(n/N) \tag{11}$$

Which implies that about 23.88% of extraterrestrial radiation over Khulna penetrates the atmosphere on a fully cloudy day (n=0) and about 76.16% on a clear sky day respectively.

Table 3 shows the values of the correlation coefficients co, do, eo and fo Equation (9-10) for Khulna.

Table 3. The values of new correlation coefficients for Khulna

Station	c_o	d_o	e_o	f_o
Khulna	1.0829	-1.0095	-0.0751	1.0032

Using the values of the coefficients in Equation (5) – Equation (10), the linear equations recommended for the estimation of monthly average diffuse and direct solar radiation over Khulna are:

$$D/G = 1.5288 - 1.9024(G/Go) \tag{12}$$

$$D/Go = 0.3834 - 0.2192(n/N) \tag{13}$$

$$D/G = 1.0829 - 1.0095(n/N) \tag{14}$$

$$I/G = -0.4200 + 1.7102(G/Go) \tag{15}$$

$$I/Go = -0.1440 + 0.7444(n/N) \tag{16}$$

$$I/G = -0.0751 + 1.0032(n/N) \tag{17}$$

5. Conclusion

Investments on solar energy systems in any place require information of the availability of solar energy for its optimum use. But the measured radiation data for a long period are not available all over Bangladesh. The correlations proposed for Khulna in this study can be used in future for estimation of solar radiations if the data of some common meteorological parameters are available. From the study it is clear that Khulna city is endowed with sufficient solar radiation throughout the year. Therefore, solar energy systems can be one of the best options of energy supply in this city if it can be used in a cost effective manner. The correlations proposed for Bangladesh in this study can be used in future for estimation of solar radiations if the meteorological data are collected.

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