EMPIRICAL MODEL FOR THE ESTIMATION OF GLOBAL SOLAR RADIATION IN DHAKA, BANGLADESH

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Abstract

This work proposes the coefficients for Angstrom-Prescott type of model for the estimation of global solar radiation in Dhaka, Bangladesh using the relative sunshine duration alongside the measured global solar radiation data (1983-2010). The model constants a and b obtained in this investigation for Dhaka are 0.23 and 0.57 respectively. The correlation coefficient of 87% between the clear sky index and relative sunshine duration, as well as the coefficient of determination of 75.7 obtained shows that this model fits the data very well. Consequently, the developed model in this work can be used with confidence for Dhaka and other locations with similar climate conditions.

***Keywords**: solar radiation, regression, extra terrestrial radiation, sunshine hours, empirical model.*

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1. INTRODUCTION

The design of a solar energy conversion system requires precise knowledge regarding the availability of global solar radiation and its components at the location of interest. An accurate knowledge of the solar radiation data for a particular location is a pre requisite, in estimating the thermal performance and economic viability of solar energy systems. Since the solar radiation reaching the earth's surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is essential. The availability of these data may be of the form of types of irradiance, total, diffuse, direct, surface placement and horizontal, inclined, facing south or deviated from south or in terms of time: hourly, daily, monthly or yearly. Each of these forms is important and has particular usage in specific applications.

A number of authors have proposed various empirical relationships for the estimation of daily global solar radiation on horizontal surface. Various climatologically parameters such as sunshine hours, relative humidity, maximum and minimum temperatures, cloud covers and geographical location were employed by these authors for the development of their estimation formulae.

Angstrom (1924), Black.et.al (1954), Glover and McCulloch (1958) and Smith (1976) used sunshine hours to estimate the average solar radiation. Liu and Jordan (1960), Krieth (1962), Sharma and Pal (1965), and Whiller (1965) used declination angle and latitude in their formula. Many researchers have employed hours of bright sunshine to estimate solar radiation [3-4], [7-13]. Other workers e.g. Reddy, Glover and McCulloch derived their equations by using humidity, sunshine duration, relative humidity, temperature and latitude of the locations under study.

In this work, the estimation of monthly average daily global solar radiation on horizontal surface is made at Dhaka, employing the most common weather parameter, the sunshine hours available from NASA surface meteorology and solar energy: Inter-annual variability and Bangladesh Meteorology Department [5-6].

Firstly, the evaluation of Regression Coefficients 'a' and 'b' for Dhaka is made by using Angstrom method. The coefficients are then used to predict the monthly average daily global solar radiation. Secondly, a comparison of various correlations suggested to predict the insulation, is made, and the choice of best correlation is discussed.

2. METHODOLOGY

The extra terrestrial solar radiation on a horizontal surface H_0 is a function only of latitude and independent of other locational parameters. As the solar radiation passes through the earth's atmosphere, it is further modified by processes of scattering and absorption due to the presence of cloud and atmospheric particles. Hence, the daily global solar insulation incident on a horizontal surface H is very much location specific and less than the extra terrestrial irradiation.

The original Angstrom type regression equation related monthly average daily radiation to clear day radiation at the location and average fraction of possible sunshine hours

$$\frac{\overline{H}}{\overline{H_0}} = a + b\frac{\overline{n}}{\overline{N}} \qquad (1)$$

Where,
$\overline{H}$ = monthly average daily radiation on a horizontal surface
$\overline{H}_0$ = Monthly average daily extraterrestrial radiation
a, b =Empirical constants
$\overline{n}$ =Monthly average daily hours of bright sunshine
$\overline{N}$ =Monthly average of the maximum possible daily hours of sunshine or day length

The extra terrestrial solar radiation on a horizontal surface is calculated from the following equation [1]:

$$H_0 = \frac{24 \times 3600 \times I_{sc}}{\pi}\left(1 + 0.033cos\left(360\frac{d}{365}\right)\right) \qquad (2)$$

Where,
$I_{sc} = 1367Wm^{-2}$ is the solar constant and H_0 is in Jm^{-2}
d is day number, ϕ is the latitude of the location, δ is the declination angle given by

$$\delta = 23.45\ sin\left(360\frac{284+d}{365}\right) \qquad (3)$$

and ω is the sunset hour angle given by

$$\omega = cos^{-1}(-tan\phi\ tan\delta) \qquad (4)$$

The maximum possible sunshine duration N is then given by

$$N = \frac{2}{15}\omega \qquad (5)$$

In this paper H_0 and N were computed for each month by using equations (2) and (5) respectively. The regression constants a and b in equation (1) have been calculated from the values of $\frac{\overline{H}}{H_0}$ and $\frac{\overline{n}}{\overline{N}}$. The values of monthly average daily global radiation H and the average number of hours of sunshine were obtained from daily measurements covering the period $1983-2010$ [5-6]. The method of least squares was used to obtain the constants a and b as follows:

$$b = \frac{m\sum\left(\frac{n}{N}\right)\left(\frac{H}{H_0}\right) - \left(\sum\left(\frac{n}{N}\right)\right)\left(\sum\left(\frac{H}{H_0}\right)\right)}{m\sum\left(\frac{n}{N}\right)^2 - \left(\sum\left(\frac{n}{N}\right)\right)^2}$$

$$a = \frac{\sum\left(\frac{H}{H_0}\right)}{m} - b\frac{\sum\left(\frac{n}{N}\right)}{m}$$

To compute values of $\overline{H}_{est}$ (also known) as estimated H the values of a and b were used in equation (1). The deviation between the estimated and measured values was determined using the following statistical parameters:

Mean Bias Error, MBE= $\frac{\sum(H_{estimated} - H_{measured})}{m}$

Root Mean Square Error,

RMSE= $\sqrt{\frac{\sum(H_{estimated} - H_{measured})^2}{m}}$

Where, m is the total number of observation points. The correalation coefficient r between estimated and measured radiation values is

$$r = \frac{\sum(H_{estmated} - \overline{H}_e)(H_{measured} - \overline{H}_m)}{\sqrt{\sum(H_{estmated} - \overline{H}_e)^2 \sum(H_{measured} - \overline{H}_m)^2}}$$

Where, $\overline{H}_e$ is the arithmetic mean value of the m estimated values of the global solar radiation, $\overline{H}_m$ is the arithmetic mean value of the m measured values.

The result of our model was compared with other previously stated models. The compared models are:
Reitveld's model [8]: an interesting correlation which is believed to be applicable anywhere in the world

$$\frac{H}{H_0} = 0.18 + 0.62\frac{n}{N}$$

Glover and McCulloch [10] (ibid): which relates a correlation model that takes into account the latitude effect as

$$\frac{H}{H_0} = 0.29cos\varphi + 0.52\left(\frac{n}{N}\right)$$

Fagbenle's model [11]:developed by Fagbenle which was believed to be suitable for the rain forst climatic zone as

$$\frac{H}{H_0} = 0.28 + 0.39\frac{n}{N}$$

Fre're's model [12]: this model is quoted by Nguyen as $\frac{H}{H_0} = a + b\left(\frac{n}{N}\right)$, $a = -0.27 + 1.75\left(\frac{n}{N}\right) - 1.34\left(\frac{n}{N}\right)^2$, $b = 1.32 - 2.90\left(\frac{n}{N}\right) + 2.30\left(\frac{n}{N}\right)^2$

Turton's model [7]: which developed average regression constants for the humid tropical countries as

$$\frac{H}{H_0} = 0.30 + 0.40\left(\frac{n}{N}\right)$$

Bahel et al model [9]: Bahel et al developed the model as

$$\frac{H}{H_0} = 0.16 + 0.87\left(\frac{n}{N}\right) + 0.61\left(\frac{n}{N}\right)^2 + 0.349\left(\frac{n}{N}\right)^3$$

Our model:

$$\frac{H}{H_0} = 0.23 + 0.57\left(\frac{n}{N}\right) \qquad (6)$$

The seven model listed above were applied to the sunshine data at Dhaka. The calculated and measured values of average daily global radiation on the horizontal surface were compared, to find the best correlation that will fit the measured global solar radiation.

3. RESULTS AND DISCUSSION

As can be seen in table 1, Reitvelt, Bahel et.el and our model has the best correlation coefficient while the lowest correlation coefficient is from Turton and fegbenle's model. The accuracy of each model used in the estimation of global solar radiation is tested by calculating the mean bias error (MBE %) and the root mean square error (RMSE %) respectively. It was observed that the lower the RMSE%, the more accurate the equation used. Positive MBE% shows over estimation and a negative MBE% shows under estimation. So from the table 1 it is seen that though Bahel.et.al method has the highest correlation coefficient (93%) but at the same time it has a serious RMSE (61%) and also a major MBE (53%). On the other hand, our model has the lowest over estimation (MBE 2.4%). The RMSE% values, which are a measure of the accuracy of estimation, have been found to be the minimum for our model (10.4) as shown in table 1. Standard Estimate error for our model is negligible and also the lowest among all models discussed here.

Table 1: Statistical test result of models applied for Dhaka

MODEL	a	b	%MBE	%RMSE	r	SEE
REITVELT	0.18	0.62	5.62	10.6	0.89	1.94
GLOVER	0.27	0.52	2.76	19.45	0.83	1.98
FEGBENLE	0.28	0.39	-7.56	12.52	0.76	2.3
TURTON	0.3	0.4	-2.64	10.97	0.75	2.01
FRE'RE	$-0.27 + 1.75\left(\frac{n}{N}\right) - 1.34\left(\frac{n}{N}\right)^2$	$1.32 - 2.90\left(\frac{n}{N}\right) + 2.30\left(\frac{n}{N}\right)^2$	-3.86	10.62	0.8	1.95
BAHEL ET AL	$0.16 + 0.87\left(\frac{n}{N}\right) + 0.61\left(\frac{n}{N}\right)^2 + 0.349\left(\frac{n}{N}\right)^3$		52.68	61.07	0.93	11.2
OUR MODEL	0.23	0.57	0.48	9.43	0.87	1.73

Table 2 shows the comparison between measured and estimated global solar radiation in Dhaka. As seen in table 2 the values of the clearness index K_T for the atmosphere in Dhaka indicates poor sky condition in June-September where $\frac{n}{N}$ goes as low as 0.32 and K_T values reach minimum, i.e. 0.38 (for July) and 0.40 (for August). This is due to the fact that June-September corresponds to the monsoon season in this part of the world, with less sunshine hours and heavy cloudy sky.

The monthly average daily global solar radiation estimated through the proposed model for Dhaka are given in table 3 along with the measured values and the estimated values from the other models. It is very encouraging to observe a very fine agreement between measured and estimated values obtained from our correlation.

In the present work, the low percentage error suggests that equation (6) can be used with confidence for Dhaka and also for other locations with similar climatologically conditions. This statement is also supported by the high value of correlation coefficient.

The distribution of average global solar radiation ($MJ/m^2/day$) on a horizontal surface for different months in Dhaka, Bangladesh is shown in figure 1 while figure 2 shows the monthly average daily bright sunshine hours on horizontal surface.

Table 2: Monthly average data of solar radiation and relative daily brightness in Dhaka

Month	Day length N(hr)	Sunset angle ω_s degree	Extra terrestrial radiation $H_0(MJ/m^2)$	Radiation measured $H\ (MJ/m^2)$	Radiation estimated	Climate index $K_T = \frac{H}{H_0}$	Relative sun shine hour($\frac{n}{N}$)
Jan	10.71	80.34	25.16	15.69	12.964095	0.62	0.500467
Feb	11.22	84.18	29.31	17.71	17.640858	0.6	0.652406
Mar	11.86	88.95	34.06	20.12	19.587085	0.59	0.605396
Apr	12.56	94.17	37.8	20.74	22.503339	0.55	0.640924
May	13.15	98.60	39.71	19.08	21.319891	0.48	0.538403
Jun	13.44	100.80	40.21	16.31	17.126947	0.41	0.34375
Jul	13.31	99.81	39.78	15.19	16.372563	0.38	0.318557
Aug	12.81	96.06	38.23	15.37	15.750402	0.4	0.319282
Sep	12.13	90.97	35.14	14.51	14.918422	0.41	0.341303
Oct	11.43	85.74	30.67	15.41	16.123887	0.5	0.51881
Nov	10.85	81.35	26.14	15.45	15.583777	0.59	0.642396
Dec	10.57	79.25	23.8	15.16	11.827046	0.64	0.468307

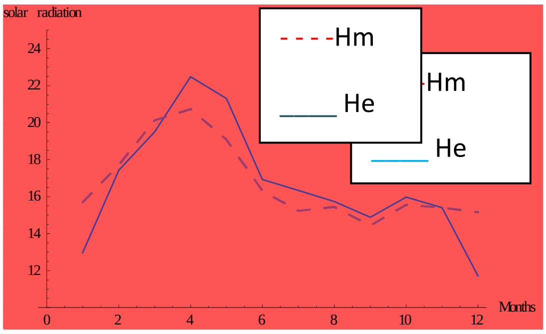

Fig 1: Monthly average daily global radiation in MJ/m^2 (1983-2010)

From figure 1 it is seen that maximum global solar radiation is received in the months of March, April or May (over 20 $MJ/m^2/day$).

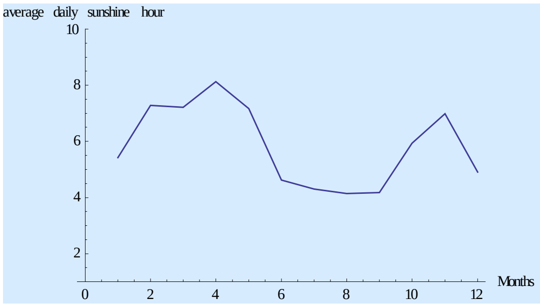

Fig 2: Monthly average daily bright sunshine hour

In monsoon and winter months the solar radiation receipt is lowest which is in the range of 14-15 $MJ/m^2/day$.

Table 3: Estimation of monthly average daily global solar radiation from various models for Dhaka

Month	$H_{measured}$	Reitveld's model	McCulloch model	Fagbenle's model	Bahel et al	Turton's mode	Frere's model	Our model
Jan	15.69	12.21	13.20	11.83	19.72	12.46	12.33	12.964095
Feb	17.71	16.739	17.49	15.37	30.71	16.14	16.19	17.640858
Mar	20.12	18.61	19.62	17.33	32.93	18.20	18.20	19.587085
Apr	20.74	21.71	22.68	19.93	39.82	20.92	20.99	22.503339
May	19.08	20.43	21.86	19.47	34.23	20.47	20.36	21.319891
Jun	16.31	15.74	17.99	16.62	21.75	17.56	17.04	17.126947
Jul	15.19	15.075	17.39	16.13	20.41	17.05	16.49	16.372563
Aug	15.37	14.49	16.71	15.50	19.61	16.38	15.85	15.750402

Sep	14.51	13.68	15.64	14.44	18.90	15.26	14.81	14.918422
Oct	15.41	15.04	16.22	14.52	24.51	15.28	15.14	16.123887
Nov	15.45	14.73	15.43	13.57	26.79	14.25	14.29	15.583777
Dec	15.16	11.01	12.05	10.87	17.12	11.46	11.29	11.827046

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