# Tilted And Horizontal Solar Radiation For 6 Zones In Bangladesh

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**Abstract:** This study proposes a procedure that was adopted for the development of a linear regression model for estimating solar radiation on horizontal and tilted surfaces for 6 divisions in Bangladesh. The correlations, the simulated global solar radiation on tilted surface and the simulated diffuse solar radiation on a horizontal surface for each location are discussed elaborately. The solar radiation values obtained were compared with the measured values. The results of the global solar radiation show that the areas of greatest solar potential are Rajshahi > Dhaka > Sylhet > Chittagong > Khulna > Barishal and the months of the year with the highest tilted solar radiation are November, December, January and February.

**Key word:** solar radiation, tilted radiation, Angstrom constants, solar potential, horizontal radiation, diffuse radiation, surface albedo.

## INTRODUCTION:

Renewable energy sources strongly depend on the microclimate, weather conditions and climatological phenomena. For this reason any application requires an assessment of the resource. This evaluation comprises the determination of the amount of available energy to be used in an application. Solar systems use different components of the solar radiation, so that assessment may require different measurement systems. Similarly, the level of detail with which should be known each component can be very different from one application to another. The assess of the solar potential of Bangladesh was made mainly using information from NASA surface meteorology [4] and solar energy and Bangladesh Meteorology Department [6] and also from UNEP SWERA-country report of Bangladesh [5]. This information is processed to be transformed from meteorological information to energy information. Although this has been a breakthrough in the estimation of energy resources, expert recommend site measurement before sizing a solar or wind project.


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## ESTIMATION OF MONTHLY GLOBAL RADIATION ON A HORIZONTAL SURFACE:

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

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

Where, $\bar{H}$ = monthly average daily radiation on a horizontal surface

$\bar{H}_0$ = Monthly average daily extraterrestrial radiation

$a, b$ =Empirical constants

$\bar{n}$ =Monthly average daily hours of bright sunshine

$\bar{N}$ =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 [2]:

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

Where, $I_{sc} = 1367Wm^{-2}$ is the solar constant and $H_0$ is in $Jm^{-2}$

$d$ is day number, $\phi$ is the latitude of the location, $\delta$ is the declination angle given by

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

and $\omega$ is the sunset hour angle given by

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

The maximum possible sunshine duration $N$ is then given by $N = \frac{2}{15}\omega$ (5)

## ESTIMATION OF MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE:

We turn next to the general problem of calculation of radiation on tilted surfaces when only the total radiation on a horizontal surface is known. For this we need the directions from which the beam and diffuse components reach the surface. The direction from which diffuse radiation is received, i.e., its distribution over the sky dome, is a function of conditions of cloudiness and atmospheric clarity, which are highly variable. The angular distribution of diffuse is to some degree a function of the reflectance $\rho_g$ (the surface Aledo) of the ground. A high reflectance results in reflection of solar radiation back to the sky, which in turn may be scattered to account for horizon brightening. It is necessary to know or to be able to estimate the solar radiation on tilted surfaces such as flat plate collectors, windows or other passive system receivers. The incident solar radiation is the sum of a set of radiation streams including beam radiation, the three components of diffuse radiation from the sky, and radiation reflected from the various surfaces seen by the tilted surface. The total radiation on this surface can be written as [1]:

$$\overline{H_T} = \overline{H}\left(1 - \frac{\overline{H_d}}{\overline{H}}\right)\overline{R_b} + \overline{H_d}\left(\frac{1+\cos\beta}{2}\right) + \overline{H}\rho_g\left(\frac{1-\cos\beta}{2}\right) \quad (6)$$

Where, $\overline{H_d}$ is the diffuse component of total global radiation, $\overline{R_b}$ is the monthly average daily geometric factor, $\beta$ is slope of the surface and $\rho_g$ is the surrounding diffuse reflectance for the total solar radiation of the location. The geometric factor $\overline{R_b}$ is calculated from the following equation:

$$\overline{R_b} = \frac{\cos(\varphi-\beta)\cos\delta\ \sin\omega_s + (\pi/180)\,\omega_s \sin(\varphi-\beta)\sin\delta}{\cos\varphi\ \cos\delta\ \sin\omega_s + (\pi/180)\,\omega_s \sin\varphi\ \sin\delta} \quad (7)$$

Where, $\omega_s$ is the effective surface sunset hour angle and corresponds to the smaller value from

$$\omega_s = \cos^{-1}(-\tan\varphi\ \tan\delta)$$
$$\omega_s = \cos^{-1}(-\tan(\varphi-\beta)\ \tan\delta) \quad (8)$$

## PROCEDURE FOR THE CALCULATION OF MONTHLY AVERAGE DAILY RADIATION ON HORIZONTAL SURFACE:

The monthly average global solar radiation was calculated using data from NASA Surface Meteorology and Solar Energy and from 6 Meteorological stations of Bangladesh.

**Table 1:** Location of the 6 meteorological stations

| Station Name | Latitude (degree) | Longitude (degree) | Altitude (meter) |
|---|---|---|---|
| Dhaka | 23.71 | 90.41 | 22 |
| Chittagong | 22.33 | 91.83 | 10 |
| Barishal | 22.7 | 90.37 | 8.54 |
| Khulna | 22.82 | 89.55 | 6.88 |
| Sylhet | 24.89 | 91.87 | 23.03 |
| Rajshahi | 24.37 | 88.6 | 26.38 |

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 $\frac{\bar{n}}{\bar{N}}$. 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 *2003 – 2010*. 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 evaluate the developed model for each zone, three error statistics were used, namely, the mean absolute percentage error (MAPE), mean bias error (MBE), and root mean square error (RMSE). The MAPE is an indicator of accuracy in which it usually expresses accuracy as a percentage, MBE is an indicator for the deviation of the predicted values from the measured data and RMSE provides information on the short term performance of the models and is a measure of the variation of the predicted values around the measured data.

$$\text{MBE} = \frac{\sum(H_{estimated} - H_{measured})}{m} \quad (9)$$

$$\text{RMSE} = \sqrt{\frac{\sum(H_{estimated} - H_{measured})^2}{m}} \quad (10)$$

$$\text{MAPE} = \frac{1}{m}\left(\sum_{i=1}^{m}\left(\frac{(H_{estimated} - H_{measured})}{H_{measured}}\right)\right) \quad (11)$$

where, $m$ is the total number of observation points. The correlation coefficient $r$ between estimated and measured radiation values is

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

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

## PROCEDURE FOR THE CALCULATION OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACES:

The first step to calculate the average monthly solar radiation on tilted surface is to calculate $R_b$ using equation (7) and the relationship $H_d/H$ from the measured data or using any of the correlations presented in [6]. In this work, the two methods for $H_d/H$ ratio calculation were used. Equations for these correlations are as follows:

For $\omega_s \leq 81.4^0$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^{\ 2} - 2.137\bar{K}_T^{\ 3} \qquad (12)$$

And for $\omega_s > 81.4^0$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^{\ 2} - 1.821\bar{K}_T^{\ 3} \qquad (13)$$

For known $R_b$ and $H_d/H$ ratio, monthly average daily radiation on tilted surface was calculated. The tilted angle $(\beta)$ is considered as equal to the latitude of respective places while annual solar radiation is maximum.

## RESULTS AND DISCUSSION

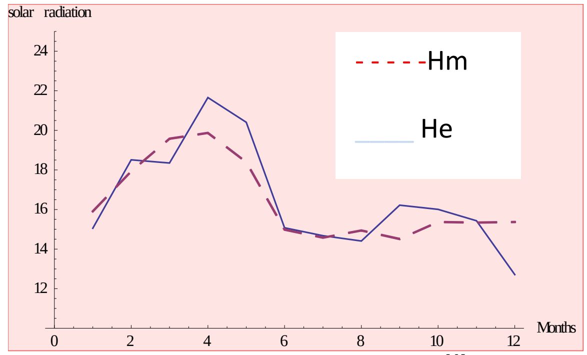
### DETERMINATION OF ANGSTROM CONSTANTS

Values of regression constants, along with the correlation coefficient $(r)$ and the values of the MBE, MAPE and RMSE for the 6 zones are summarized in table 2.

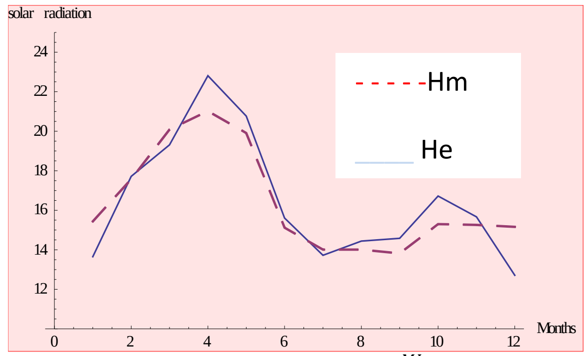
**Table 2.** Regression constants and the corresponding values of MAPE, MBE and RMSE:

| STATION NAME | a | b | r | MAPE % | MBE | RMSE |
|---|---|---|---|---|---|---|
| Dhaka | 0.23 | 0.57 | 0.87 | -0.5035 | -0.0196 | 1.5774 |
| Chittagong | 0.15 | 0.63 | 0.99 | 7.18 | 0.1415 | 1.31 |
| Barishal | 0.17 | 0.6 | 0.91 | 0.2513 | 0.0526 | 1.1912 |
| Khulna | 0.17 | 0.6 | 0.92 | 3.16 | 0.0838 | 1.19 |
| Rajshahi | 0.19 | 0.61 | 0.77 | 1.87 | 0.2699 | 2.02 |
| Sylhet | 0.21 | 0.59 | 0.79 | 0.58 | 0.0294 | 1.3755 |

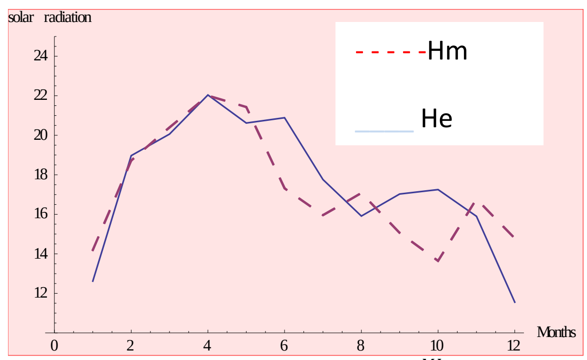
From the result it is clear that there is a good fitting between the clearness index $\frac{\bar{H}}{H_0}$ and the relative possible number of sunshine hours $\frac{\bar{n}}{\bar{N}}$ for all the analyzed zones. Figure 1 shows the comparison between observed and predicted values of monthly average daily global solar radiation.



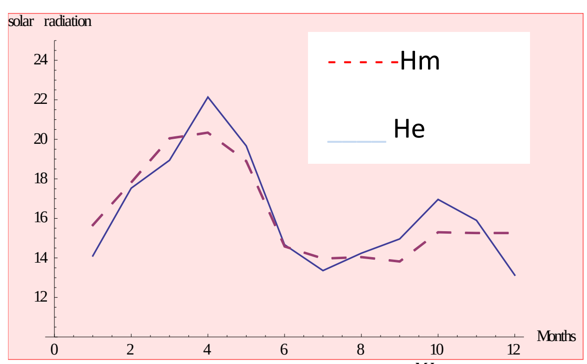

a) Solar radiation in Chittagong $(\frac{MJ}{m^2})$



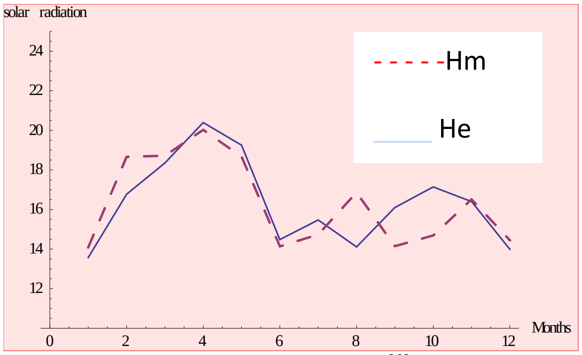

b) Solar radiation in Khulna $(\frac{MJ}{m^2})$



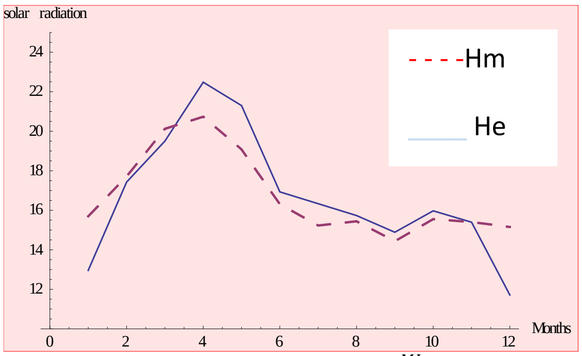

c) Solar radiation in Rajshahi $(\frac{MJ}{m^2})$




d) Solar radiation in Barishal $(\frac{MJ}{m^2})$




e) Solar radiation in Sylhet ($\frac{MJ}{m^2}$)




f) Solar Radiation in Dhaka ($\frac{MJ}{m^2}$)

**Figure1.** Comparison between measured (Hm) and estimated (He) values of H a) Chittagong b) Khulna c) Rajshahi d) Barishal e) Sylhet f) Dhaka

The results show that in case of not having measured values of global solar radiation on a horizontal surface, could be used the Angstrom equations obtained in this study.

## ESTIMATION OF THE MONTHLY AVERAGE DAILY GLOBAL SOLAR RADIATION ON TILTED SURFACE

The first step to calculate the global solar radiation on tilted surface is to calculate the ratio $H_d/H$ . Table 3 shows the values of global solar radiation and monthly average diffuse radiation on a horizontal surface for the 6 analyzed areas.

**Table 3.** Monthly global and diffuse radiation for the 6 zones:

| | Dhaka | | Chittagong | | Barishal | | Khulna | | Rajshahi | | Sylhet | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H$ | $H_d$ | $H$ | $H_d$ | $H$ | $H_d$ | $H$ | $H_d$ | $H$ | $H_d$ | $H$ | $H_d$ |
| Jan | 15.69 | 3.69 | 15.9 | 4.53 | 15.66 | 4.58 | 15.44 | 4.65 | 14.19 | 4.52 | 14.08 | 4.61 |
| Feb | 17.71 | 5.89 | 17.93 | 6.06 | 17.82 | 6.02 | 17.57 | 5.43 | 18.72 | 4.91 | 18.66 | 4.85 |
| Mar | 20.12 | 6.76 | 19.58 | 7.13 | 20.05 | 7.13 | 20.09 | 6.31 | 20.4 | 6.09 | 18.72 | 6.28 |
| Apr | 20.73 | 8.80 | 19.87 | 8.15 | 20.34 | 7.96 | 21.02 | 7.14 | 22.01 | 6.94 | 20.02 | 7.26 |
| Ma | 19.08 | 9.55 | 18.4 | 8.62 | 18.9 | 8.47 | 19.91 | 7.73 | 21.43 | 7.64 | 18.67 | 7.86 |
| Jun | 16.31 | 9.04 | 14.98 | 8.53 | 14.58 | 8.12 | 15.12 | 7.99 | 17.32 | 8.11 | 14.13 | 8.01 |
| Jul | 15.22 | 9.10 | 14.58 | 8.30 | 13.97 | 8.31 | 14.01 | 7.86 | 15.96 | 7.98 | 14.73 | 7.94 |
| Aug | 15.44 | 8.4 | 14.94 | 8.15 | 14.04 | 7.99 | 14.01 | 7.61 | 17.07 | 7.61 | 16.86 | 7.64 |
| Sep | 14.43 | 7.78 | 14.51 | 7.58 | 13.82 | 7.54 | 13.82 | 7.07 | 15.06 | 6.94 | 14.14 | 6.91 |
| Oct | 15.55 | 6.85 | 15.37 | 6.59 | 15.3 | 6.71 | 15.3 | 6.09 | 13.64 | 5.98 | 14.68 | 5.88 |
| Nov | 15.41 | 5.47 | 15.34 | 5.45 | 15.26 | 5.56 | 15.26 | 4.96 | 16.77 | 4.31 | 16.51 | 4.42 |
| Dec | 15.15 | 3.24 | 15.37 | 4.24 | 15.26 | 4.21 | 15.16 | 4.29 | 14.78 | 4.01 | 14.44 | 4.11 |

Table 4 presents the results of global solar radiation on tilted surface. It is noted that in months January to March and October to December, global solar radiation on tilted surface increases in almost all areas. The areas with the greatest potential are Rajshahi > Dhaka > Sylhet > Chittagong > Khulna > Barishal.

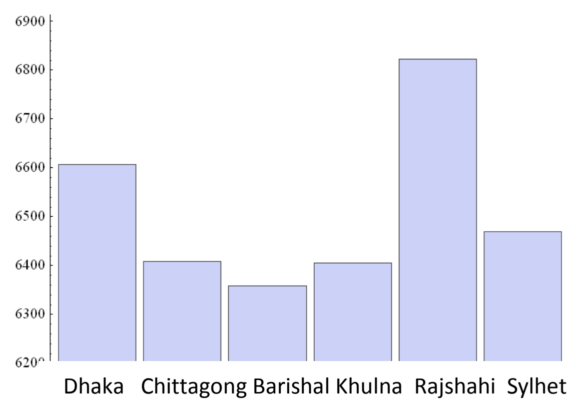



**Figure 2:** Annual solar potential ($MJ/m^2$) in Different cities in Bangladesh.

**Table 4.** Monthly average daily solar radiation on tilted surface (tilt angle is equal to the latitude of respective location):

| | Dhaka ( $MJ/m^2$) | Chittagong $MJ/m^2$ | Barishal $MJ/m^2$ | Khulna $MJ/m^2$ | Rajshahi $MJ/m^2$ | Sylhet $MJ/m^2$ |
|---|---|---|---|---|---|---|
| Jan | 21.34 | 20.36 | 20.10 | 19.48 | 16.23 | 17.64 |
| Feb | 21.43 | 20.86 | 20.86 | 20.73 | 23.06 | 20.32 |
| Mar | 21.67 | 20.77 | 21.30 | 21.55 | 21.76 | 19.89 |
| Apr | 19.91 | 19.43 | 19.90 | 20.58 | 21.55 | 19.91 |
| May | 17.08 | 17.10 | 17.53 | 18.36 | 19.03 | 17.65 |
| Jun | 14.41 | 13.78 | 13.39 | 13.81 | 18.64 | 13.16 |
| Jul | 13.71 | 13.54 | 13.00 | 12.94 | 16.19 | 14.15 |
| Aug | 14.49 | 14.31 | 13.45 | 13.40 | 15.20 | 13.45 |
| Sep | 14.56 | 14.71 | 13.98 | 14.06 | 17.55 | 16.52 |
| Oct | 17.67 | 17.04 | 16.92 | 17.30 | 19.79 | 19.77 |
| Nov | 19.83 | 18.76 | 18.61 | 18.99 | 20.57 | 21.44 |
| Dec | 21.32 | 20.17 | 20.14 | 19.55 | 15.22 | 19.01 |
| Annual total | 6607 | 6408 | 6358 | 6406 | 6823 | 6470 |

## CONCLUSIONS:

This study establishes that the linear regression model proposed by Angstrom can be applied to the data of the 6 analyzed areas of Bangladesh. This is of great importance since it is always possible to have measured data for sizing solar processes. From the measured data it was established that global solar radiation in most of the analyzed areas increases in January to March and October to December. It was also determined that the areas with the greatest potential are Rajshahi > Dhaka > Sylhet > Chittagong > Khulna > Barishal.

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