

## Determination of Solar Radiation of Five Different Locations of Bangladesh Using Angstrom-Prescott model

Suman Saha<sup>\*</sup>, Md. Shameem Hassan Bhuiyan and M.A. K. Mallik

*Bangladesh Meteorological Department and  
e-mail: mars0742@gmail.com*

### ABSTRACT

To determine the monthly mean solar radiations using Ångström-Prescott equation over five (05) meteorological stations of Bangladesh Meteorological Department, location (latitude and longitude) and monthly mean bright sunshine hours observed are analyzed for the year 2017. In this paper, forward calculation analysis is performed to calculate. We tried to make a comparison among solar radiation on horizontal surface with different stations. Then the recorded solar radiation of two stations (Dhaka and Satkhira) is also compared. In conclusion, good agreement between solar radiation measured and estimated is shown.

**Keywords:** Bangladesh, Bright Sunshine Hours, Solar Radiation.

### 1. INTRODUCTION

Solar Energy is one of the most important renewable energies in the world. At present we are using conventional fossil fuels as a fastest method to consume energy for daily life which creates environmental degradation through emitting pollutant gaseous. Irradiation will play key role for future generation to fill the demand for sustainable energy sources with having no pollutions. The direct way to find Solar Radiation (SR) for a location is recorded by Pyranometer. In Bangladesh very few stations (only 4 stations) have such measurement to record directly global solar radiation. The another way to determine SR is to use the very common parameter bright sunshine hours associated with meteorological station data like location, elevation [1] in empirical model equation. This is called sunshine-based model. The bright sunshine hours is used as input parameter of Sunshine-based models while others use additional climatological data together with bright sunshine hours. In some of the models geographical and seasonal parameters are also taken into account to reflect the latitudinal and seasonal variation of the air mass. For this it is important to develop one dimensional correlation to estimate SR for specific locations. The most and commonly used model in most of the countries is Angstrom-Prescott model which is based on correlation of global solar radiation with sunshine hours. Angstrom [2]. proposed the first empirical equation employing sunshine hours for the estimation of global solar radiation. Then Prescott and Page [3, 4] modified Angstrom correlation. Many researchers have employed hours of bright sunshine to estimate solar radiation [5–9]. Empirical models which have been used to calculate solar radiation are usually based on astronomical factors, geographical factors, geometric factors, physical factors and meteorological factors [10]. For my country Islam et al [2016][11] estimated solar radiation on horizontal surface using various meteorological parameters but not compared with directly recorded SR. The objective of my study is to develop a correlation employing bright sunshine hours with SR of that place where no instrument to record solar radiation directly was installed. For this the coefficients regarding polynomial are derived by using forward calculation. These coefficients are generally valid for estimating the radiation in location of similar latitude and altitude.

### 2. THEORY & METHODOLOGY

The simplest model used to estimate monthly average daily solar radiation on horizontal surface is the well-known Ångström-type regression equation given in 1924

$$\frac{\bar{H}}{\bar{H}_c} = a + b \frac{\bar{n}}{N}$$

where,  $\bar{H}$  = Monthly average daily radiation on horizontal surface (Wh/m<sup>2</sup>/day)

$\bar{H}_c$  = Average clear-sky daily radiation for location and month in question

a, b are Empirical Constants based on location

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

$\bar{N}$ = Monthly average of maximum possible daily hours of bright sunshine

Prescott(1940) and Page (1964) modified that equation in terms of the clearness index through two constants (a and b) depending on the location, the monthly average daily hours of bright sunshine and the day length of the average day of the month which is

$$\frac{H}{H_0} = a + b \frac{N}{N_0}$$

$H$ = Monthly average daily global radiation on horizontal surface

$H_0$ =Monthly average total radiation on the extraterrestrial horizontal surface (MJ/  $m^2$ /day)

$N$ =Monthly average daily hours of bright sunshine

$N_0$ =Monthly average of maximum possible daily hours of bright sunshine

Sunshine Hour Data recorded from (Campbell-Stokes sunshine recorder)

$\frac{H}{H_0}$ = Monthly average clearness index

$\frac{N}{N_0}$  = Fraction of sunshine hours or monthly average of the maximum possible daily hours of bright sunshine

**Table01:** Estimated Angles of declination for various month of a year [12]:

| Month     | d for <i>i</i> th day of the month | For the average day of the month |                    |                      |
|-----------|------------------------------------|----------------------------------|--------------------|----------------------|
|           |                                    | date                             | D, day of the year | Angle of declination |
| January   | <i>i</i>                           | 17                               | 17                 | -20.9                |
| February  | 31+ <i>i</i>                       | 16                               | 47                 | -13.0                |
| March     | 59+ <i>i</i>                       | 16                               | 75                 | -2.4                 |
| April     | 90+ <i>i</i>                       | 15                               | 105                | 9.4                  |
| May       | 120+ <i>i</i>                      | 15                               | 135                | 18.8                 |
| June      | 151+ <i>i</i>                      | 11                               | 162                | 23.1                 |
| July      | 181+ <i>i</i>                      | 17                               | 198                | 21.2                 |
| August    | 212+ <i>i</i>                      | 16                               | 228                | 13.5                 |
| September | 243+ <i>i</i>                      | 15                               | 258                | 2.2                  |
| October   | 273+ <i>i</i>                      | 15                               | 288                | -9.6                 |
| November  | 304+ <i>i</i>                      | 14                               | 318                | -18.9                |
| December  | 334+ <i>i</i>                      | 10                               | 344                | -23.0                |

$\delta$  is the declination angle defined by Cooper [13] in 1969:

$$\delta = 23.45 \sin [360(\frac{d+284}{365})]$$

Here, d= average day of the month for 1 to 365 days

Sunset Hour angle is

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta) ;$$

$\phi$ = Latitude of respective stations given in table 02

$\delta$ = Declination Angle

**Table02:** Location of the selected meteorological stations (BMD) over Bangladesh:

| Meteorological Stations | Latitude(N) | Longitude(E) | Elevation(m) |
|-------------------------|-------------|--------------|--------------|
| Dhaka                   | 23.78       | 90.38        | 8.45         |
| Teknaf                  | 20.86       | 92.30        | 5            |
| Satkhira                | 22.71       | 89.08        | 3.96         |
| Sylhet                  | 24.90       | 91.88        | 33.53        |
| Sydpur                  | 25.75       | 88.91        | 39.6         |

Maximum possible daily hours of bright sunshine is defined by  $N_0 = 2/15\omega_s$

Extra-terrestrial horizontal surface solar radiation is defined as [13]:

$$H_0 = \frac{24}{\pi} G_{sc} \times 3600 \times \left[ 1 + 0.033 \cos \frac{360 \times d}{365} \right] \left[ \frac{\pi}{180} \omega_s \sin \varphi \sin \delta + \cos \varphi \cos \delta \sin \omega_s \right]$$

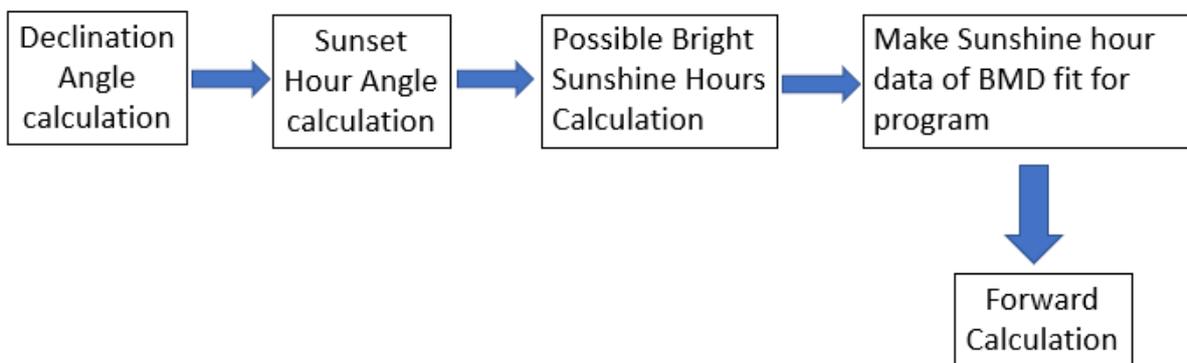
Here,

$G_{sc}=1.367KW/m^2=$  solar constant (W/m<sup>2</sup>)

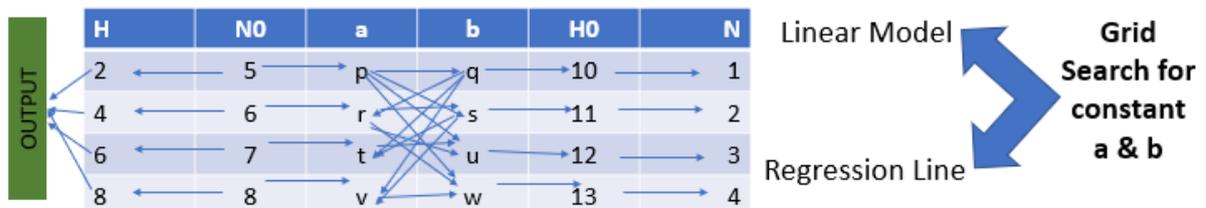
It is adopted by the American Society for Testing and Materials (ASTM) in 2000[14].

When the sun is closest to the earth in the northern hemisphere, on January 3, the solar heat on the outer edge of the earth’s atmosphere is about 1400 W/m<sup>2</sup>; and when the sun is farthest away, on July 4, it is about 1330 W/m<sup>2</sup>.

The algorithm to calculate solar radiation (MJ/m<sup>2</sup>d<sup>-1</sup>) and associated clearness index, fraction of sunshine duration, daily extraterrestrial solar radiation (MJ/m<sup>2</sup>d<sup>-1</sup>) is given below.



After that the Forward Calculation analysis is performed using software R. A way of processing of forward calculation is given below:

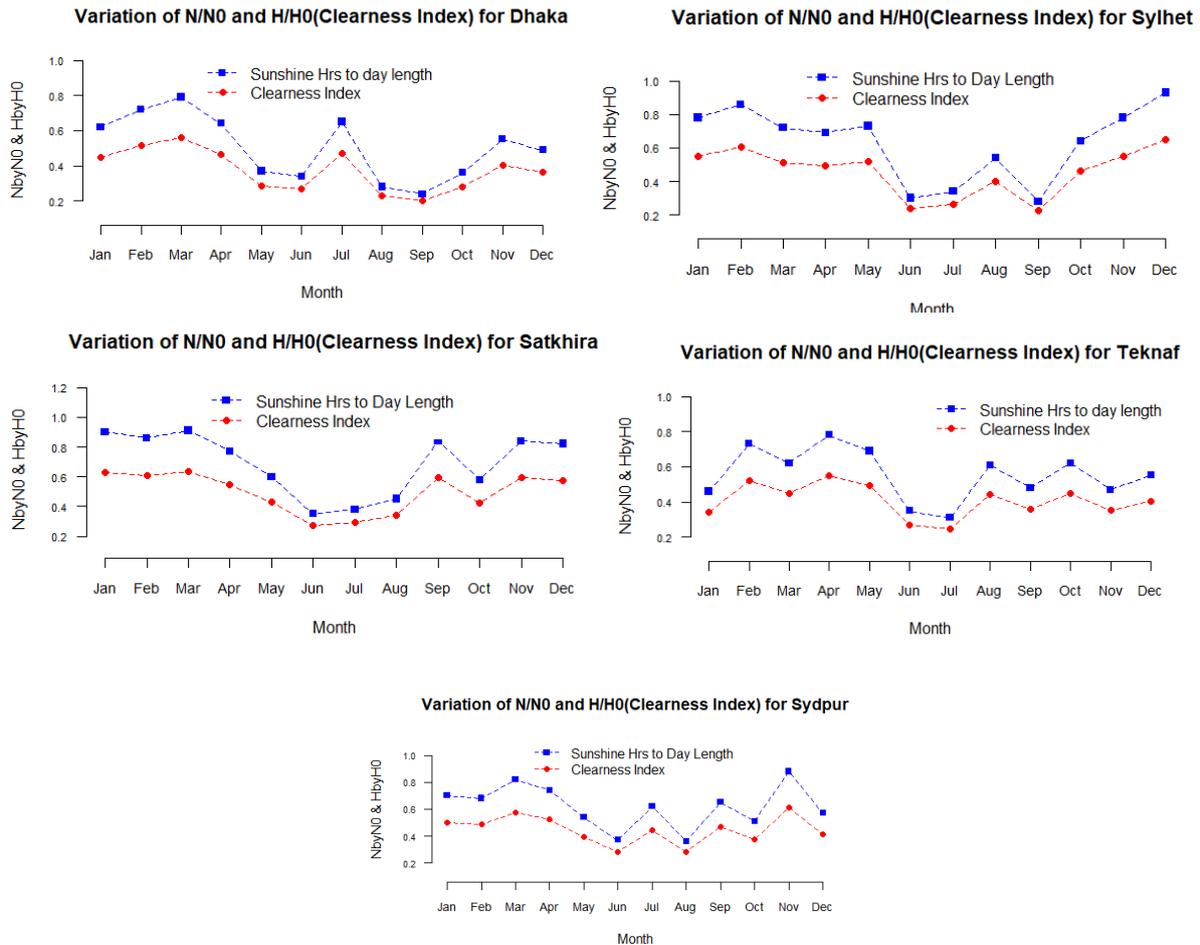


### 3. REESULTS & DISCUSSION

It is manifested that clearness index and sunshine hours vary with period of the year 2017, condition of the sky and the location.

The plot shows that the n/n0 sunshine hour index observed minimum at September in Dhaka (0.24) indicates the overcast/cloud covered skies and more aerosols. The maximum value of sunshine hour index was observed at December in Sylhet (0.93) suggesting the more clear skies with fewer aerosols. Similarly high values of the clearness index were observed the highest value December was at Sylhet (0.65) of high elevation (elevation 33.5 m) and the least of minimum values at September was in Dhaka (0.20) because of high clearness index.

The data is processed to determine the empirical constants ‘a’ and ‘b’ of Prescott equation. We have considered the value of ‘a’ and ‘b’ in grid size 1681 per month in the interval 0.0005. The linear model shows the values of empirical constant as below shown in table 03 for different stations.



**Figure 01:** Comparison of bright sunshine hours to day length with clearness index stationwise.

The plot shows that the  $n/n_0$  sunshine hour index observed minimum at September in Dhaka (0.24) indicates the overcast/cloud covered skies and more aerosols. The maximum value of sunshine hour index was observed at December in Sylhet (0.93) suggesting the more clear skies with fewer aerosols. Similarly high values of the clearness index were observed the highest value December was at Sylhet (0.65) of high elevation (elevation 33.5 m) and the least of minimum values at September was in Dhaka (0.20) because of high clearness index.

The data is processed to determine the empirical constants ‘a’ and ‘b’ of Prescott equation. We have considered the value of ‘a’ and ‘b’ in grid size 1681 per month in the interval 0.0005. The linear model shows the values of empirical constant as below shown in table 03 for different stations.

**Table 03:** The coefficients ‘a’ and ‘b’ measured for the selected station location over Bangladesh

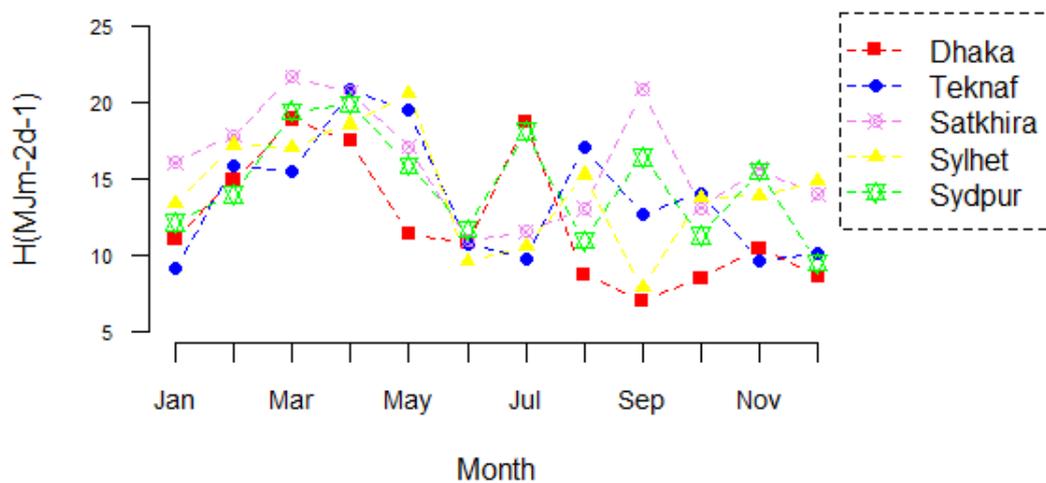
| Station Name | a       | b       |
|--------------|---------|---------|
| Dhaka        | 0.04498 | 0.65100 |
| Teknaf       | 0.04498 | 0.65002 |
| Satkhira     | 0.04501 | 0.64997 |
| Sylhet       | 0.04503 | 0.64993 |
| Sydpur       | 0.04509 | 0.64987 |

The estimated SR and the measured SR using the above coefficients are shown in table 04 station wise for the 12 month of the year 2017.

**Table 04:** Monthly mean daily global SR measured and estimated SR are as follows

| Stn | Dhaka            |                  | Teknaf           |                  | Satkhira         |                  | Sylhet           |                  | Sydpur           |                  |
|-----|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| Mon | H <sub>est</sub> | H <sub>mes</sub> |
| Jan | 11.07505         | 11.09155         | 9.092709         | 9.094808         | 16.0352          | 16.03881         | 13.37377         | 13.37297         | 12.11247         | 12.11585         |
| Feb | 14.91292         | 14.93083         | 15.80766         | 15.8078          | 17.84089         | 17.84653         | 17.17335         | 17.17188         | 13.9667          | 13.9701          |
| Mar | 18.86995         | 18.89714         | 15.53788         | 15.53518         | 21.64648         | 21.65047         | 17.03952         | 17.03885         | 19.39808         | 19.40056         |
| Apr | 17.46936         | 17.49314         | 20.83186         | 20.83364         | 20.68254         | 20.68722         | 18.53866         | 18.53353         | 19.89327         | 19.89546         |
| May | 11.39934         | 11.41435         | 19.51186         | 19.51163         | 17.11743         | 17.11766         | 20.57857         | 20.57857         | 15.8518          | 15.85661         |
| Jun | 10.76575         | 10.78248         | 10.75275         | 10.75103         | 10.95857         | 10.96321         | 9.595819         | 9.592768         | 11.66968         | 11.6712          |
| Jul | 18.71847         | 18.74493         | 9.773377         | 9.77532          | 11.52797         | 11.53136         | 10.53819         | 10.53382         | 18.11107         | 18.1157          |
| Aug | 8.714657         | 8.726822         | 17.00774         | 17.01078         | 13.02735         | 13.02805         | 15.26111         | 15.25811         | 10.92387         | 10.92915         |
| Sep | 7.011861         | 7.017013         | 12.68228         | 12.68469         | 20.85072         | 20.85416         | 7.886687         | 7.886551         | 16.40413         | 16.40559         |
| Oct | 8.422802         | 8.432651         | 14.02855         | 14.02532         | 13.05796         | 13.05819         | 13.75413         | 13.75486         | 11.28816         | 11.28952         |
| Nov | 10.42938         | 10.44306         | 9.620849         | 9.620373         | 15.63532         | 15.63706         | 13.88112         | 13.87725         | 15.49365         | 15.4939          |
| Dec | 8.616391         | 8.626455         | 10.14765         | 10.14623         | 13.96676         | 13.9681          | 14.83221         | 14.82986         | 9.478433         | 9.477061         |

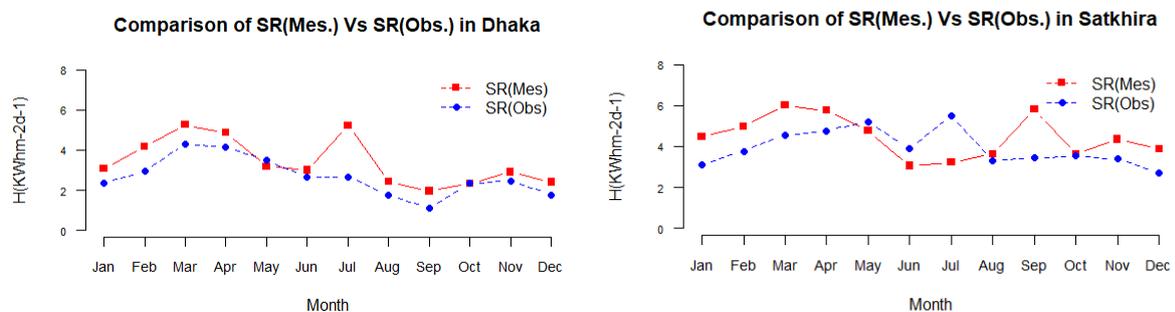
Now the overview of solar radiation measured of 05 meteorological stations for the year 2017 is shown in figure 02.



**Figure 02:** Comparison of solar radiation measured between 05 meteorological stations of BMD.

The plot above describes the minimum measured monthly mean daily radiation on the horizontal surfaces were measured in September characterized by more cloudy days at Dhaka (1.951). And maximum values were measured in March at Satkhira (6.02) which is characterized by more clear skies and less aerosols. The maximum solar radiation is measured among 05 stations in Satkhira at the month September and the minimum is found for Dhaka station at September also. On average yearly solar radiation is determined in Syedpur and Satkhira station. The result shows the environment altitude and location dependency of the radiation.

Now the solar radiation measured using the coefficients of table 02 for Dhaka and Satkhira station in units MJ m<sup>-2</sup>d<sup>-1</sup> multiplying by 0.274 is converted to KWhm<sup>-2</sup>d<sup>-1</sup>



**Figure 03:** Comparison of solar radiation measured with observed solar radiation of 02 stations of BMD.

Figure 03 presents the comparison of solar radiation recorded in at the station with measured though Ångström- Prescott equation in. For 1<sup>st</sup> panel, the solar radiation for the monthly July varies much. More rainy days and overcast cloud sky may cause the shortage of coming irradiation. Otherwise, the equation developed here is well correlated with observed data. For the 2<sup>nd</sup> panel, the solar radiation varies for the two month July and September. Otherwise, the correlation result is moderately good.

#### 4. CONCLUSION

The database of the solar radiation at any locations is very useful for that particular locality as well as for the broader world community [15] for a sustainable future energy. Important finding of this work through the forward calculation to determine monthly mean global solar radiation using bright sunshine hour to day length and clearness index lead the development of this proposed model. Good agreement has been found between measured and estimated global solar radiation predicted by linear regression equations is the place where high potential of global solar radiation was observed and least variation was observed at Dhaka and Satkhira. But it is also obvious that ample solar radiation is observed at all sites determined here in Bangladesh. The proposed correlation equation may be used to estimate daily and monthly mean daily solar radiation for the locations of similar geographical characteristics and also can be used to estimate the missing daily/monthly mean daily solar radiation at the respective site.

#### REFERENCES

1. C. Augustine and M. N. Nnabuchi, 2009: Relationship between Global Solar Radiation and Sunshine Hours for Calabar, Port Harcourt and Enugu, Nigeria. *International J. of Physical Sciences*, 4( 4), 182-188.
2. A. Angstrom, 1924: Solar terrestrial radiation, *Quarterly J. of the Royal Meteorological Society*, 50,121–126.
3. J. A. Prescott, 1940: Evaporation from water surface in relation to solar radiation. *Transactions of The Royal Society of South Australia*. 40, 114–118.
4. J. K. Page, 1961: *Proceedings of the UN Conf. On New sources of Energy*, 4, 378.
5. Black J. N. 1956: *Arch. Met. Geoph. Biokl*, 7, 165.
6. Bahel et al., 1987: *Energy*, 12, 131
7. Rietveld M. R. 1978: A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. *Agric Meteorol.*, 19, 243-252.
8. Togrul I. T., Togrul H. and Dugyu E. 2000: Estimation of global solar radiation under clear sky radiatin in Turkey. *Renewable Energy*, 19, 271-287.
9. Udo S. O. ,2002: Contribution ti the relationship between solar radiation of sunshine duration of the tropics, A case study of experimental data at Ilorin Nigeria. *Turks J. Phys.*, 26, 229 – 236.
10. A. A. Dehghan, F. Besharat and A. R. Faghig, 2013: Empirical Models for Estimating Global Solar Radiation: A Review and Case Study. *Renewable and Sustainable Energy Review*, Vol. 21, 798-821. doi:10.1016/j.rser.2012.12.043.
11. Islam M., A., Alam M., S., Sharker K., K., Nandi S., K., 2016: Estimation of Solar Radiation on Horizontal and Tilted Surface over Bangladesh “*Computational Water, Energy, and Environmental Engineering*. 5, 54-69.
12. P. I. Cooper, 1969: The absorption of radiation in solar stills. *Solar Energy*, 12(3)333–346.
13. S. A. Klein, 1977: Calculation of monthly average insolation on tilted surfaces. *Solar Energy*, 19(4), 325–329.
14. J. A. Duffie and W. A. Beckman, 1991. *Solar Engineering of Thermal Processing*, Chapter 01, 5-6
15. O. Sunday, 2011: Estimation of Global and Diffuse Solar Radiations for Selected Cities in Nigeria,” *International Journal of Energy and Environmental Engineering*. 2(3), 11-33.
16. Bangladesh Meteorological Department (BMD).