

PRE-ASSESSMENT MODELS OF GLOBAL SOLAR RADIATION USING SUNSHINE DURATION IN MAIDUGURI

By

R. Luqman^{}, S. Shodiya^{**}, G. M. Ngala^{**}, M. B. Oumarou^{**}, A. B. Muhammad^{**}**^{*}Department of Mechanical Engineering,
Federal Polytechnic Mubi**^{**}Department of Mechanical Engineering,
University of Maiduguri, Maiduguri, Nigeria.***ABSTRACT**

The monthly daily average solar energy parameters measured in Maiduguri (11.85°N, 13.08°E, altitude 354m) for a period of thirteen years (1996 – 2010) were obtained from the Nigerian Meteorological Agency, Maiduguri, Borne State. These data which include Gunn-Bellani solar radiation, sunshine hour duration, relative humidity, rainfall, wind speed, maximum and minimum temperatures were analyzed using both single-variable and multi-variable regression techniques of the Angstrom type to generate several regression equations (models). The Models were used to estimate the total solar radiation reaching a horizontal surface in Maiduguri. Comparing the estimated model results and the experimental data showed good agreements. Furthermore, statistical methods of Mean Deviation, Average Deviation, Standard Deviation, Variance and coefficient of correlation (R^2) were used to test the performances of these models. Based on the value R^2 and that of standard deviation, the equation that outperformed the rest is the logarithmic equation. This model could be used by designers and engineers to preliminarily assess the potential of the solar energy in Maiduguri and area of similar geographical conditions.

Keywords: Daily global solar radiation, Sunshine hours, Empirical models, Validation, Maiduguri

INTRODUCTION

Solar radiation has been identified as the largest renewable resource on earth. The energy source is more evenly distributed in the World than wind or biomass, allowing for more site locations (Muhammad, Shodiya and Ngala, 2015, Muzathick et. al., 2011, Gungor and Yildirim, 2012, Okonkwwo, 2014). The maximum intensity of solar radiation at the earth's surface is about 1.2 kW/m² but it is encountered only near the equator on clear days at noon. Under these ideal conditions, the total energy received is from 6-8 kWh/m² per day (Gungor and Yildirim, 2012, Okonkwwo, 2014, Garba, Amusat and Ngadda (2015). Solar energy is not available continuously because of the day/night cycle and cloud cover. Its intensity varies according to season, geographical location and

position of the collector (Musa, Zangina and Aminu, 2012).

Studies on solar radiation have become an important issue for renewable energy stemming from oil crises, global warming and other environmental problems, thus increasing the need for reliable measurements of surface solar radiation (Tiwari, 2012).

Also, solar radiation was historically monitored by measuring the sunshine duration with Campbell-Stokes recorders. An estimate of the global solar radiation was then obtained through the well-known Angstrom-Preseott equation (Holman and Gajda, Jr, 1978). Although pyranometers are nowadays available to directly measure the global solar radiation, the sunshine duration is still an essential climatological parameter that is still monitored in

many meteorological stations in order to extend the historical time series.

Furthermore, the global solar radiation on a horizontal surface is the minimum information generally needed as an input parameter for building a solar energy project. The accurate knowledge of the solar radiation intensity at a given location is of importance to the development of solar energy system design. This information is used in the design, cost and effectiveness estimation of a project. Further, monthly mean daily data are needed for the estimation of long-term solar systems performances. The values of the daily global radiation measurements are not available at every location due to the cost of measuring equipment, maintenance, and calibration. In places where no measured values are available, a common application has been to determine this parameter by appropriate correlations, which are empirically established using the measured data (Muhammed, Shodiya and Ngala 2015).

$$\frac{H}{H_0} = a + b \left(\frac{S}{S_0} \right) \quad (1)$$

The monthly average daily extraterrestrial radiation on a horizontal surface (H_0) can be computed from the following equation (Okonkwo, 2014):

$$H_0 = \left(\frac{24}{\pi} \right) I_{sc} \left(1 + 0.033 \cos \frac{360n}{365} \right) x (\cos \phi) \cos \delta \sin w_s + \left(\frac{2\pi w_s}{360} \right) \sin \phi \sin \delta \quad (2)$$

The solar declination (δ) and the mean sunrise hour angle (w_s) can be calculated using Eqs. (3) and (4), respectively (Okonkwo, 2014):

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

For a given month, the monthly average day length (S_0) can be computed by using the following equation (Okonkwo, 2014):

$$S_0 = \frac{2}{15} w_s \quad (4)$$

Therefore, the objective of this study is to develop several regression models for the prediction of monthly average daily global radiation for Maiduguri and to select the most adequate model. The values of the monthly average daily global radiation experimental data used in this present study were taken from Maiduguri Meteorological Service for the periods between 1996 and 2010.

METHODOLOGY

There are several formula that relate global radiation to other climatological parameters such as sunshine hours, relative humidity, and outdoor temperature. The first correlation proposed for estimating the monthly average daily global radiation is based on the method of Angstrom (Musa, Zangina and Aminu 2012). The original Angstrom-PreScott type regression equation-related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hours:

The regression models proposed in the literature and developed in this study are listed in Table 1. The 'a' and 'b' values in the models are determined using regression analysis. Also in this

present study, the predictive efficiencies of the models are tested using the following parameters: correlation coefficient (R^2), mean deviation, average deviation, variance and standard deviation.

Table 1: The Proposed regression models

| Models | Mod. no. | Regression equation | Source |
|-------------|----------|-----------------------------|--------------------------------------|
| Linear | 1 | $H/H_0 = a + b(S/S_0)$ | Angstrom, (1924) and Prescott (1940) |
| Exponential | 2 | $H/H_0 = a + b \exp(S/S_0)$ | Almorox et. al. (2004) |
| Logarithmic | 3 | $H/H_0 = a + b \log(S/S_0)$ | Kadir Bakirci (2009) |
| Power | 4 | $H/H_0 = a(S/S_0)^b$ | Kadir Bakirci (2009) |

RESULTS AND DISCUSSION

By using the data measured at the Maiduguri State Meteorological Service in the periods between 1996 and 2010, the regression constants 'a' and 'b' are reported for the four models in Table 2.

Also from the Table, R^2 for each model were listed. It can be seen from the Table that the model having the highest value of R^2 is the Logarithmic model which is followed by the power model.

Table 2: Regression constants and R^2 values for the proposed models.

| Models | R^2 | $\frac{a}{(SD)^2}$ | $\frac{b}{(SD)^2}$ |
|-------------|--------|--------------------|--------------------|
| Linear | 0.7577 | 0.5380 | 0.0794 |
| Exponential | 0.7453 | 0.1803 | 1.3202 |
| Logarithmic | 0.7928 | 0.3549 | 0.5850 |
| Power | 0.7837 | 0.6242 | 0.8729 |

In further testing of the models, the statistical tools: Mean Deviation, Average Deviation, Standard Deviation and Variance were used as shown

in Table 3. Using the Standard Deviation, the model having the least value of the deviation is the Logarithmic model followed by power model.

Table 3. Statistic for the Validation of the Models

| Models | Mean Deviation | Average Deviation | Standard Deviation | Variance |
|-------------|----------------|-------------------|--------------------|----------|
| Linear | 0.0089 | 0.0089 | 0.0544 | 0.0030 |
| Exponential | 0.0060 | 0.0060 | 0.0578 | 0.0033 |
| Logarithmic | 0.0082 | 0.0082 | 0.0488 | 0.0024 |
| Power | 0.0062 | 0.0062 | 0.0524 | 0.0027 |

Furthermore, each of these models was used to determine the values of the Monthly average daily global radiation. Table 4 shows the comparison between measured values and estimated values for

the monthly average daily global radiation (MJ/m^2) for the 4 Models. From the Table, it can be seen that relatively, Logarithmic model gave the best predictions which is followed by power model.

Table 4: The comparison between measured values and estimated values monthly average daily global radiation (MJ/m^2) for the 4 Models.

| Month | Measured | Models | | | |
|-----------|----------|--------|-------------|-------------|-------|
| | | Linear | Exponential | Logarithmic | power |
| January | 14.30 | 14.80 | 14.84 | 14.83 | 14.88 |
| February | 16.21 | 16.46 | 16.56 | 16.46 | 16.56 |
| March | 17.58 | 16.50 | 16.41 | 16.60 | 16.53 |
| April | 16.82 | 16.03 | 15.88 | 16.14 | 16.00 |
| May | 16.72 | 16.35 | 16.21 | 16.47 | 16.34 |
| June | 14.77 | 15.42 | 15.26 | 15.50 | 15.35 |
| July | 12.69 | 13.50 | 13.46 | 13.27 | 13.26 |
| August | 12.43 | 13.76 | 13.70 | 13.57 | 13.53 |
| September | 14.86 | 14.29 | 14.16 | 14.28 | 14.15 |
| October | 15.81 | 14.60 | 14.45 | 14.70 | 14.56 |
| November | 15.49 | 16.04 | 16.28 | 15.92 | 16.16 |
| December | 13.71 | 14.39 | 14.43 | 14.41 | 14.46 |

CONCLUSION

Several sunshine based models have been developed for estimating global solar radiation for Maiduguri. The differences between the results of the different models when compared with the measured data are negligible. However, the Logarithmic equation is the best overall which is followed by power model, according to R^2 and Standard Deviation. Though, we recommend the use of the logarithmic equation for predicting the global solar radiation for Maiduguri, however, due to the greater simplicity of the power equation when compared with the logarithmic equation, the power equation can be used to estimate the global solar radiation in Maiduguri and area of similar geographical conditions.

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NOMENCLATURE AND SYMBOLS

- H Monthly average daily global radiation ($\text{Wh m}^{-2} / \text{day}$)
- H_c Monthly average clear sky daily global radiation ($\text{Wh m}^{-2} / \text{day}$)
- H_0 Monthly average daily extraterrestrial radiation ($\text{Wh m}^{-2} / \text{day}$)
- k_s Solar constant ($=1367 \text{ W m}^{-2}$)
- S_0 Monthly average maximum daily sunshine duration (hours)
- a, b Empirical constants
- S Monthly average daily bright sunshine duration (hours)
- w_s Mean sunrise hour angle
- Φ Latitude of the site
- δ The sun declination angle