# Prediction of Solar Radiation in Potiskum – Nigeria

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***Abstract***
*Solar energy will remain the most environmentally clean and abundant renewable energy ever on earth surface. Hence, a handy process for predicting the solar radiation is very vital. Meteorological parameters namely; sunshine duration, maximum air temperature and relative humidity have been used to develop two model equations (12) and (13) for predicting solar radiation for Potiskum. For these model equations (12) and (13) respectively, the coefficients of determination* $\mathbf{R^2}$ *are 97.8 and 98.6, the maximum percentage error* ***MPE*** *are 0.3135 and 0.1177; and the root mean square errors* ***RMSE*** *are 0.8921 and 0.7109. These statistical validation values show that the model equations can be used at the said geographical location for predicting solar radiation.*

## Introduction

Renewable energies like geothermal energy, tidal energy and cosmic radiation constitute not more than one percent of all the energy received on earth compared to solar energy (Nordell and Garvet, 2009). Hence, solar energy remains the most abundant and viable source of energy. Therefore, solar serves as the most appropriate substitute for fossil fuels, and in turn utilizing it minimizes the threat of green-house effect.

Empirical solar radiation models employ relationships between solar radiation and other meteorological variables which include sunshine hours, cloud cover, air temperature, precipitation, relative humidity, etc.

The angstrom model equation (1924) was the first to investigate empirical linear correlation later modified by Prescott (1940) and Page (1964) in the form $H/H_0 = a + b(S/S_0)$ … (1)

Scholars later developed more models by evaluating the constants a and b appropriate for a location, while others brought in more terms as can be seen in the following literature

Rietveld (1978) proposed Angstrom – Prescot model for most locations $\frac{H}{H_0} = 0.18 + 0.62\left(\frac{S}{S_0}\right)$ … (2)

Sambo (1986) formed an empirical model for northern Nigeria

$$\frac{H}{H_0} = 0.621 - 0.294\left(\frac{S}{S_0}\right) + 0.178\left(\frac{S}{S_0} - R - \theta\right) + 0.1491\left(\frac{S}{S_0}.\theta\right) \quad \ldots (3)$$

Burari (2004) developed a correlation equation for Bauchi as

$$\frac{H}{H_0} = 0.136\left(\frac{S}{S_0}\right)^{0.374} (T_a)^{0.00584}(R)^{0.000451} \quad \ldots (4)$$

Burari *et al* (2010) married a model pyranometer and Angstrom – Prescot model for Bauchi Sambo (1986) formed an empirical model for northern Nigeria

$$\frac{H}{H_0} = 0.449 - 0.139\left(\frac{S}{S_0}\right) + 0.185\left(\frac{S}{S_0}.\theta\right) - 0.00022(\theta.R) \quad \ldots (5)$$

Isikwe *et al* (2012a) Angstrom – Prescot model for Makurdi $\frac{H}{H_0} = 0.138 + 0.488\left(\frac{S}{S_0}\right)$ … (6)

**Methods**

Meteorological data of ten years (2003-2013) for Potiskum, Yobe state, acquired from Nigeria Meteorological Agency (NIMET), Ushodi, Lagos were used. These data are the mean monthly ratio of solar radiation $\frac{H}{H_0}$, the mean monthly ratio of sunshine hours $\frac{S}{S_0}$, air temperature $T_a$ and relative humidity $R$. Equation (1) below was used in coding these data. The coding is simply transforming the data to be in the range $-1\ to + 1$.

$$X_i = \frac{Y - \frac{Y_{max} - Y_{min}}{2}}{\frac{Y_{max} - Y_{min}}{2}} \quad \ldots (7)$$

Where $Y$ stands for the actual value.

The response (independent variable) is $\frac{H}{H_0}$, while the dependent variables are $\frac{S}{S_0}$, $T_a$ and $R$, such that

$$\frac{H}{H_0} = f\left(\frac{S}{S_0}, T_a, R\right) \quad \ldots (8)$$

2.2 Definitions

Monthly Mean of Extraterrestrial Radiation

$$H_0 = \frac{24X3600}{\pi} G_{sc}\left\{1 + 0.033\left(\frac{360.n}{365}\right)\right\}.\left(cos\emptyset cos\delta sin\omega_s + \frac{\pi\omega_s}{180} sin\emptyset sin\delta\right) \quad \ldots (9)$$

Monthly mean of the maximum possible hours of day $n$

Sunrise hour angle $\omega_s = Cos^{-1}(-tan\varphi tan\delta)$ … (10)

Angle of declination $\delta = 23.45 Sin\{\frac{360(284+n)}{365}\}$ … (11)

Where $n$ is the day of the year, $L$ is the latitude, $I_{sc}$ is the solar constant as $1367\ W/m^2$.

The following model equations are proposed for this work upon which statistical tools will be applied for validation:

$$H/H_0 = a_0 + a_1(S/S_0) + a_2T + a_3R + a_4(S/S_0)T + a_5(S/S_0)R + a_6(TR) + a_7(S/S_0)^2 \quad \ldots (12)$$

$$H/H_0 = a_0 + a_1(S/S_0) + a_2T + a_3R + a_4(S/S_0)T + a_5(S/S_0)R + a_6(TR) + a_7(S/S_0)^2 + a_8T^2 \quad \ldots (13)$$

**Statistical tools**

The following statistical tools were used to validate the developed models, thus:

The maximum percentage error MPE= $\frac{100\%}{N}\sum_{k=1}^{N}\frac{\left|H_i - H_j\right|}{H_i}$ … (14)

The root mean square error RMSE= $\frac{1}{N}\sum_{k=1}^{N}\sqrt{H_i - H_j}$ … (15)

The coefficient of determination $R^2 = 1 - \frac{\sum_{k=1}^{N}\left|H_i - H_j\right|}{\sum_{k=1}^{N}\left|H_i - \overline{H}_i\right|}$ … (16)

Where $H_i$ is the measured solar radiation, $H_j$ is the predicted solar radiation and N is the total sample size.

**Results**

Table (1) below is the raw meteorological data for Potiskum. Equation (7) is used to code table (1), and the following results were obtained:

Table 1: Values of $H/H_0$, $S/S_0$, $T_m(^0C)$ and R for Potiskum (2003-2013)

| Months | $H/H_0$ | $S/S_0$ | $T_m(^0C)$ | R |
|---|---|---|---|---|
| Jan | 0.7133 | 0.7337 | 31.5 | 0.1522 |
| Feb | 0.6786 | 0.7616 | 33.2 | 0.1200 |
| Mar | 0.6891 | 0.6711 | 38.0 | 0.1000 |
| Apr | 0.6440 | 0.5546 | 40.4 | 0.2125 |
| May | 0.6125 | 0.6419 | 39.2 | 0.3600 |
| Jun | 0.5876 | 0.6501 | 36.2 | 0.4786 |
| Jul | 0.5330 | 0.5344 | 32.5 | 0.6325 |
| Aug | 0.4807 | 0.4600 | 30.7 | 0.7350 |
| Sep | 0.5583 | 0.5531 | 32.4 | 0.6519 |
| Oct | 0.6389 | 0.6991 | 34.9 | 0.4586 |
| Nov | 0.7316 | 0.8035 | 34.7 | 0.2186 |
| Dec | 0.7045 | 0.7472 | 31.9 | 0.2093 |

Table 2: Coded values of $H_0$, $H/H_0$, $S/S_0$, $T_m(^0C)$ and R for Potiskum

| MONTHS | $H_0$ | $H/H_0$ | $S/S_0$ | $T_m(^0C)$ | R |
|---|---|---|---|---|---|
| Jan | 0.1495 | 0.8541 | 0.5936 | -0.8351 | -0.8356 |
| Feb | 0.3868 | 0.5775 | 0.7560 | -0.4845 | -0.9370 |
| Mar | 1.0000 | 0.6612 | 0.2291 | 0.5052 | -1.0000 |
| Apr | 0.7889 | 0.3017 | -0.4492 | 1.0000 | -0.6457 |
| May | 0.4401 | 0.0506 | 0.0591 | 0.7526 | -0.1811 |
| Jun | 0.1038 | -0.1479 | 0.1068 | 0.1340 | 0.1924 |
| Jul | -0.4704 | -0.5831 | -0.5668 | -0.6289 | 0.6772 |
| Aug | -1.0000 | -1.0000 | -1.0000 | -1.0000 | 1.0000 |
| Sep | -0.3022 | -0.3814 | -0.4580 | -0.6495 | 0.7383 |
| Oct | 0.1156 | 0.2611 | 0.3921 | -0.1340 | 0.1295 |
| Nov | 0.4281 | 1.0000 | 1.0000 | -0.1753 | -0.6265 |
| Dec | -0.1175 | 0.7840 | 0.6722 | -0.7526 | -0.6558 |

Table 3: Predicted values of $(H/H_0)$ Potiskum Station

| Model Eqns. | 12 | 13 |
|---|---|---|
| Jan | 0.7426 | 0.7381 |
| Feb | 0.6972 | 0.6931 |
| Mar | 0.6417 | 0.6432 |
| Apr | 0.3113 | 0.3097 |
| May | 0.0444 | 0.0466 |
| Jun | -0.1407 | -0.1421 |
| Jul | -0.6397 | -0.6304 |
| Aug | -0.9440 | -0.9462 |
| Sep | -0.4394 | -0.4446 |
| Oct | 0.3505 | 0.3468 |
| Nov | 0.8979 | 0.8991 |
| Dec | 0.8561 | 0.8646 |

Table4: Regression constants for Potiskum models

| Model Eqns. | 12 | 13 |
|---|---|---|
| $a_0$ | 0.027 | -0.143 |
| $a_1$ | 0.654 | 1.150 |
| $a_2$ | -0.351 | -0.339 |
| $a_3$ | -0.587 | -0.363 |
| $a_4$ | -0.121 | -0.201 |
| $a_5$ | 0.642 | 0.474 |
| $a_6$ | -0.426 | -0.719 |
| $a_7$ | 0.225 | -0.068 |
| $a_8$ | | 0.397 |

Table 5: RMSE, MPE and $R^2$ for Potiskum

| **Model Equations** | **12** | **13** |
|---|---|---|
| **RMSE** | 0.8921 | 0.7109 |
| **MPE** | 0.3135 | 0.1177 |
| $\boldsymbol{R^2}$ | 97.8 | 98.6 |

**Discussion**

The table (4) shows the values of the regression constants for the model equation (12) and (13) where as table (5) shows the values of the statistical parameters **RMSE, MPE** and $\boldsymbol{R^2}$ respectivelys. The value for **MPE** show that the model equation (12) could be applied for long term to data from Potiskum MPE(0.3135), $R^2$(97.8%). Similarly, the model equation (13) could be applied for long term to data from Potiskum MPE(0.1177), $R^2$(98.6%).
The Plots for the measured and the predicted solar radiation are shown in fig(1) and fig(2)

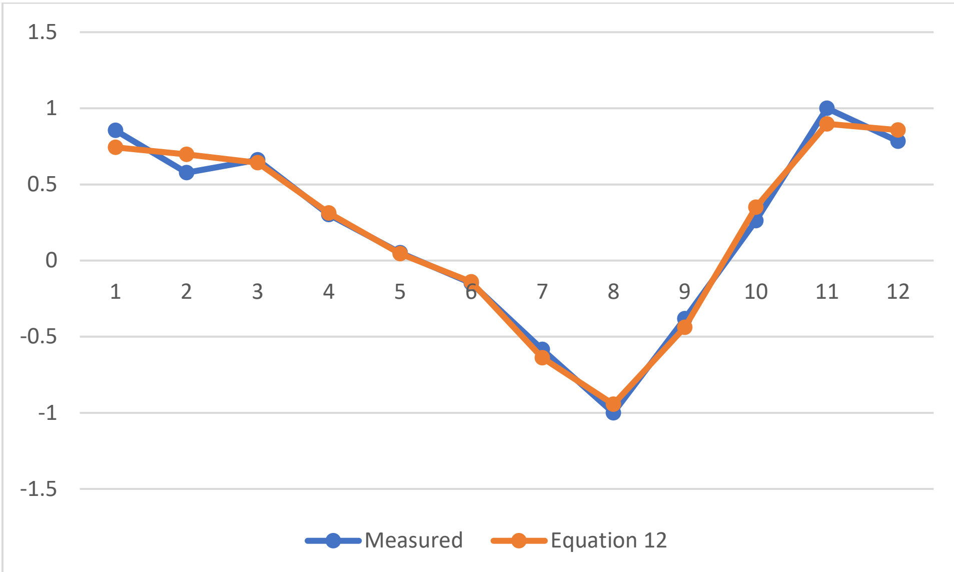


Fig 1: Measured and the Predicted Solar Radiation (Eqn 12)

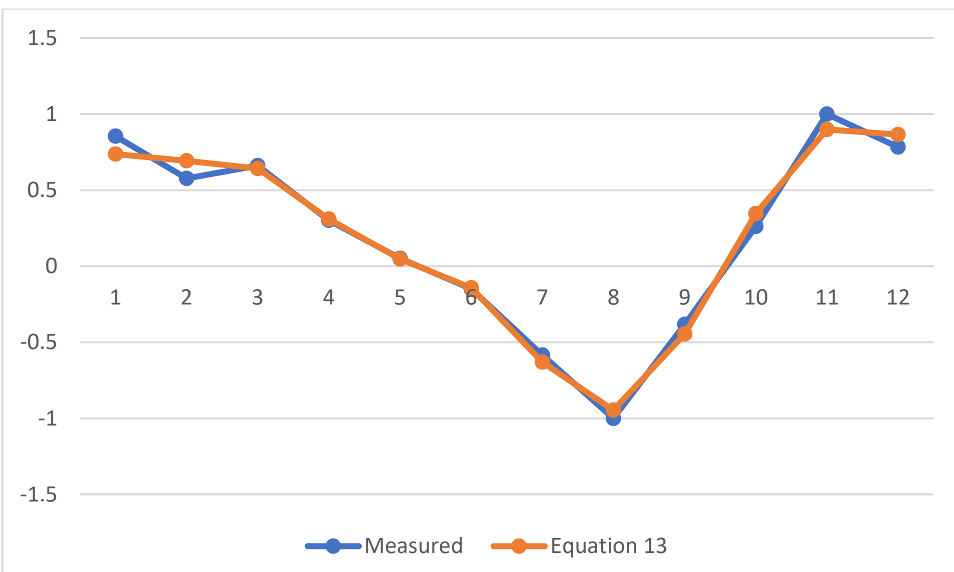


Fig 2: Measured and the Predicted Solar Radiation(Eqn 13)

## Conclusion

The results from both the statistical values and the graphs show that there is a good correlation between the measured and the predicted values of global solar radiation for Potiskum given the metrological parameter

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