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Testing the Predictive Efficiencies of Four Angstrom-Type Models for estimating Solar Radiation in Bida Nigeria

Nwokoye A.O.C.[1] And Okonkwo G.N.[2]
[1]*Department of Physics and Industrial Physics, NnamdiAzikiwe University, Awka.*
[2]*Department of Science Laboratory Technology, The Federal Polytechnic, Bida. Niger State.*

Abstract: *This paper measures the predictive efficiencies of four empirical models developed for estimating global solar radiation in Bida (9.1°N, 6.02°E). A set of constants for Angstrom-type correlation of the linear, quadratic, cubic, and power form, were determined from sunshine-hours data measured over the period (2000 – 2012). The predictive efficiencies of the models were also compared with the actual efficiency. The results show that the models have equal efficiencies and therefore can be used separately, for calculating solar radiation in Bida.*
Keywords:*Predictive efficiencies, empirical models, linear, quadratic, cubic, power.*

I. Introduction

The performance of any solar energy system in a particular location largely depends on the amount of solar radiation received on a horizontal surface at that location. It is therefore imperative to obtain information on the available solar radiation at a place in order to select and design suitable solar energy systems for that location. However, due to the obvious reality that data on solar radiation are not readily available everywhere, researchers around the world, have over time, adopted regression equations (empirical models) as tool for estimating the total solar radiation (global solar radiation) reaching a horizontal surface, from meteorological parameters measured at the location of interest [1 – 5].

The first model which was based on sunshine hours was developed by [6] and later modified by [7] to a more convenient form. Many researchers have employed the Angstrom-Prescott model for estimating the global solar radiation in several locations around the globe using sunshine data [1, 2, 4, 5, 8 – 16].

The objective of this work is to test the predictive efficiencies of four sunshine-based Angstrom-type regression equations (models) developed in this study for estimating global solar radiation in Bida. These are the linear, quadratic, cubic and power models.

II. Materials And Methods

The Gunn-Bellani radiation and sunshine hour data of thirteen years (2000 – 2012) measured in Bida were obtained from the Nigerian Meteorolgical Agency, Bida, Niger State. The Gunn-Bellani radiation data in millimetre (mm) were converted to $MJm^{-2}day^{-1}$ according to [17].

The monthly average daily values of the converted Gunn-Bellani data was correlated with the monthly average daily values of the relative sunshine hours using Angstrom- Prescott correlation, to generate four models (linear, quadratic, cubic and power equations) which were used to estimate the global solar radiation in Bida. A computer statistical software program (IBM SPSS 20) was used in obtaining the regression constants. The accuracy of the estimated values was tested by calculating the mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE). Again, the clearness indices of the measured and predicted values of the global solar radiation were calculated and the results plotted to determine the predictive efficiency of each model.

The Angstrom-Prescott model was given by [7] as:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) \quad (1)$$

where $\overline{H}_M$ is the measured monthly average daily global solar radiation, $\overline{H}_O$ is the monthly average daily extraterrestrial solar radiation on a horizontal surface, a and b are regression constants, $\overline{n}$ is the monthly average daily bright sunshine hours, $\overline{N}$ is the maximum possible monthly average daily bright sunshine hours (or the day length), $\frac{\overline{H}_M}{\overline{H}_O}$ (= K_T) is the clearness index, which is a measure of the deflection of the incoming global solar radiation by the sky and it indicates both the level of the availability of solar radiation and changes in atmospheric conditions in a given locality, $\frac{\overline{n}}{\overline{N}}$ is relative sunshine and it is a measure of the cloud cover [12].

$\overline{H}_O$ is given by [18] as:

$$\overline{H}_O = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180}\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s\right) \quad (2)$$

where I_{sc} is the solar constant,, E_o is the eccentricity correction factor, φ is the latitude angle, δ is the solar declination and w_s is the hour angle. The expressions for I_{sc}, E_o, δ and ω_s are also given by [18] as:

$$I_{sc} = \frac{1367 * 3600}{1000000}\,\mathrm{MJm^{-2}day^{-1}} \quad (3)$$

$$E_o = 1 + 0.033\cos\left(\frac{360N}{365}\right) \quad (4)$$

$$\delta = 23.45\sin\left(360\left(\frac{N+284}{365}\right)\right) \quad (5)$$

where: N is the characteristic day number for each month.

$$w_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (6)$$

The mean day length $\overline{N}$ is expressed as:

$$\overline{N} = \frac{2}{15}w_s \quad (7)$$

The expressions for the error test indicators, MBE (MJm^{-2}day^{-1}), RMSE (MJm^{-2}day^{-1}), and MPE (%) as stated by [19] are:

$$MBE = \frac{[\Sigma(\overline{H}_{i,cal} - \overline{H}_{i,meas})]}{n} \quad (8)$$

$$RMSE = \left[\frac{\Sigma(\overline{H}_{i,cal} - \overline{H}_{i,meas})^2}{n}\right]^{1/2} \quad (9)$$

$$MPE = \frac{\left[\Sigma\left(\frac{\overline{H}_{i,meas} - \overline{H}_{i,cal}}{\overline{H}_{i,meas}} \times 100\right)\right]}{n} \quad (10)$$

where $\overline{H}_{i,cal}$ and $\overline{H}_{i,meas}$ are the ith calculated and measured values of solar radiation respectively, n is the total number of observations.

The Angstrom-Prescott type regression equation of the linear, quadratic, cubic and power form are shown in equations (11) – (14).

Linear model:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) \quad (11)$$

Quadratic model:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) + c\left(\frac{\overline{n}}{\overline{N}}\right)^2 \quad (12)$$

Cubic model:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) + c\left(\frac{\overline{n}}{\overline{N}}\right)^2 + d\left(\frac{\overline{n}}{\overline{N}}\right)^3 \quad (13)$$

Power model:

$$\frac{\overline{H}_M}{\overline{H}_O} = a\left(\frac{\overline{n}}{\overline{N}}\right)^b \quad (14)$$

III. Results And Discussion

The following were the models obtained for Bida using equations (11) – (14), respectively.

Linear model:

$$\frac{\overline{H}_1}{\overline{H}_O} = 0.11 + 0.79\left(\frac{\overline{n}}{\overline{N}}\right) \quad (15)$$

Quadratic model:

$$\frac{\overline{H}_2}{\overline{H}_O} = 0.025 + 1.125\left(\frac{\overline{n}}{\overline{N}}\right) - 0.308\left(\frac{\overline{n}}{\overline{N}}\right)^2 \quad (16)$$

Cubic model:

$$\frac{\overline{H}_3}{\overline{H}_O} = 0.050 + 0.971\left(\frac{\overline{n}}{\overline{N}}\right) - 0.200\left(\frac{\overline{n}}{\overline{N}}\right)^3 \quad (17)$$

Power model:

$$\frac{\overline{H}_4}{\overline{H}_O} = 0.880\left(\frac{\overline{n}}{\overline{N}}\right)^{0.79} \quad (18)$$

Table 1. Measured and predicted values of clearness indices in Bida

Month	$\frac{\overline{n}}{\overline{N}}$	$\overline{H}_M$ (MJm^{-2}day^{-1})	$\overline{H}_O$ (MJm^{-2}day^{-1})	Measured $\overline{K}_T = \frac{\overline{H}_M}{\overline{H}_O}$	Model 1 $\overline{K}_T = \frac{\overline{H}_1}{\overline{H}_O}$	Model 2 $\overline{K}_T = \frac{\overline{H}_2}{\overline{H}_O}$	Model 3 $\overline{K}_T = \frac{\overline{H}_3}{\overline{H}_O}$	Model 4 $\overline{K}_T = \frac{\overline{H}_4}{\overline{H}_O}$
Jan.	0.6012	18.6	32.3	0.5744	0.5883	0.5900	0.5903	0.5887
Feb.	0.5971	21.0	34.7	0.6044	0.5851	0.5869	0.5872	0.5855
Mar.	0.5757	21.7	37.2	0.5840	0.5681	0.5706	0.5709	0.5689
Apr.	0.5543	20.4	38.0	0.5370	0.5511	0.5540	0.5542	0.5522
May	0.4935	19.3	37.6	0.5135	0.5028	0.5052	0.5051	0.5037
Jun.	0.4695	18.2	36.7	0.4944	0.4838	0.4853	0.4852	0.4843
Jul.	0.4392	16.0	36.9	0.4330	0.4597	0.4597	0.4595	0.4594
Aug.	0.3630	15.0	37.6	0.3993	0.3992	0.3928	0.3929	0.3952
Sep.	0.4254	16.9	37.1	0.4551	0.4487	0.4478	0.4476	0.4479
Oct.	0.5988	19.7	35.3	0.5599	0.5864	0.5882	0.5885	0.5869
Nov.	0.7242	21.9	32.7	0.6703	0.6860	0.6782	0.6772	0.6820
Dec.	0.6290	20.3	31.4	0.6456	0.6104	0.6108	0.6110	0.6101

Table 2. Statistical error indicator of the models

Models	R	R²	MBE	RMSE	MPE
1	0.973	0.946	0.003	0.645	-0.113
2	0.973	0.947	0.003	0.636	-0.086
3	0.974	0.948	0.004	0.635	-0.090
4	0.976	0.952	-0.012	0.639	-0.020

In "Table" 1, it was shown that the clearness indices of the models are closely related and each attained the highest and lowest values in November and August, respectively. This means that the global solar radiation received in Bida is highest in the month of November and lowest in the month August. It was also observed that the relative sunshine hour value was highest for the month of November and lowest in the month of August. This means less cloud cover in the month of November due to onset of dry season and overcast sky in the month of August due to rain bearing cloud that is characteristic of the rainy season.It was also evident from "Table" 2, that the values of correlation coefficient R, coefficient of determination R^2, MBE, RMSE and MPE for the models were similar. This means that their accuracy figure is closely related.

Fig."1" shows the comparison between measured and predicted values of monthly average daily clearness indices of the global solar radiations. It is observed that the performance of the models (linear, quadratic, cubic and power) is effectively the same. The models show a slight underestimation for the months of February and December, and slight overestimation for the months of July and October. For the rest months (January, March, April, May, June, August, September and November), the models gave 100% of the measured clearness index.

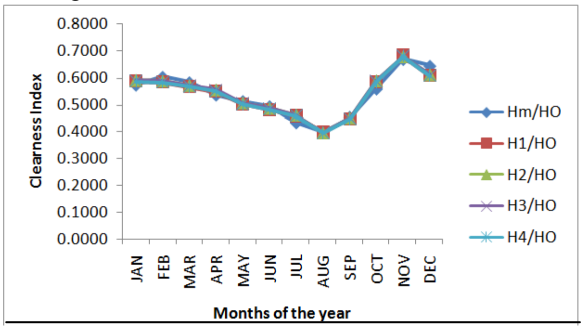

Figure 1. Comparison between the measured and predicted values of monthly average daily clearness indices of the global solar radiations

IV. Conclusion

The monthly mean daily global solar radiation and fraction of sunshine hours (relative sunshine hours) have been used to develop linear, quadratic, cubic and power correlation models for predicting the amount of global solar radiation received on a horizontal surface in Bida. It was observed from the performance tests, that the predictive efficiencies of the models are the same.

It was also shown that the highest and lowest values of global solar radiation as well as relative sunshine hours were obtained in the months of November and August, respectively. Therefore, we recommend these models to designers of solar energy equipment and agricultural experts in Bida and its environs.

References

[1]. S.O. Udo, Contribution to the Relationship between Solar Radiation and Sunshine Duration of the Tropics, A case Study of Experimental data at Ilorin Nigeria, Turks J. Phys.,26, 2002, 229 – 236.
[2]. L.E. Akpabio andS.E. Etuk, Relationship between Global Solar Radiationand Sunshine Duration for Onne, Nigeria, Turks J. Phys.,27, 2003, 161 – 167.
[3]. I.T. Togrul, Estimation of Solar Radiation from Angstroms Coefficients By Using Geographical And Meteorological Data in Bishkek, Kyrgyzstan, J. Therm. Sc. Tech., 29 (2), 2009,99 – 108.
[4]. C. Augustine and M.N. Nnabuchi, Analysis of some meteorological data for some selected Cities in theEastern and Southern zone of Nigeria, African J. Environ. Sc. Tech., 4 (2), 2010, 92 -99.
[5]. V. Sivamadhavi and R.S. Selvaraj,Robust regression technique to estimate the global radiation. Indian J. Radio Space Phys., 41, 2012, 17 – 25.
[6]. A.S. Angstrom, Solar Terr. Radiat.,Meteorol. Soc., 50, 1924, 121 – 126.
[7]. J.A. Prescott, Evaporation from a water Surface in relation to Solar Radiation, Tran. R. Soc. S. Austr., 64, 1940, 114 – 118.
[8]. A.G. Aliu andA.S. Sambo, Development of a Model for Computing the Total Component of Solar Radiation in Sokoto, Nig. J. Ren. Energy, 2 (2), 1991, 10 – 17.
[9]. F.O. Akinbode, Solar Radiation in Minna: Correlation with Meteorological Data, Nig. J. Ren.Energy, 3 (1&2), 1992, 9 – 17.
[10]. F.W. Burari and A.S. Sambo andE.D. Mshelia, Estimation of Global Solar Radiation in Bauchi, Nig. J. Ren. Energy, 9 (1 & 2), 2001, 34 – 36.
[11]. Y.A. Sanusi, Ranking of the Performance of Some Climatological Parameters in Estimation of Solar Radiation in the Minna Environment, Central Nigeria. Nig.J. Ren. Energy, 12 (1 & 2), 2004, 27 – 37.
[12]. L.E. Akpabio, Udo S.O. andS.E. Etuk,Modeling Global Solar Radiation for a Tropical Location:Onne,Nigeria, Turk J. Phys., 29, 2005, 63 – 68.
[13]. E.O.Falayi,J.O. Adepitan andA.B. Rabiu, Empirical model for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria. Inter. J. Phys. Sc., 3 (9), 2008, 210 – 216.
[14]. A. Chukwuemeka andM.N. Nnabuchi, Solar Radiation in Port Harcourt: Correlation with Sunshine Duration, Pacific J. Sc. Tech., 10 (1), 2009, 681 – 685.
[15]. B.I. Tijjani, Comparison Between First and Second Order Angstrom Type Models For Sunshine Hours of Katsina, Nigeria, Bayero J. Pur. Appl. Sc., 4 (2), 2011, 24 – 27.
[16]. D.W. Medugu,A.B. Adisa,F.W. Burari andM.A. Abdul'Azeez, Solar Radiation: Correlation between measured and predicted values in Mubi, Nigeria. Int. J. Sc. Tech. Ed. Res., 4 (1), 2013, 11 – 17.
[17]. J.C. Ododo, In OAU/STRC Conference Proceedings: 2nd OAU/STRC Conference on New, Renewable and Solar Energies, at Bamako Mali, 1994.
[18]. M. Igbal, An Introduction to Solar Radiation, Academy Press: New York, 1983.
[19]. A.A. El-Sebaii andA.A. Trabea, Estimation of Global Solar Radiation on Horizontal Surfaces over Egypt, Egypt J. Solids, 2005, 28 – 166.