

The Correlation Functions and Estimation of Global Solar Radiation Studies Using Sunshine Based Model for Kano, Nigeria

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ABSTRACT

The use of empirical models for the comparative study of the correlation functions for the estimation of global solar radiation in Kano, Nigeria has been carried out. The models used are based on relative sunshine duration alongside the measured global solar radiation data, such as: the linear model $H = H_0 (a + b\frac{n}{No})$*, the quadratic model* $H = H_0 [a + b\frac{n}{N_O}+c(\frac{n}{N_O})^2]$*and the cubic model* $H = H_0 [a + b(\frac{n}{N_O}) + c(\frac{n}{N_O})^2 + d(\frac{n}{N_O})^3]$*. The models constants a ,b ,c and d will be used in calculating the estimated value of global solar radiation and also the agreement between the measured and estimated values. The statistical parameters used for the comparative techniques are: the mean bias error (mbe), mean percentage error (mpe) and the root mean square error (rmse), which will be use to determine the efficiency of the estimation. Subsequently, the result obtained for the models constants a and b are 0.045 and 0.051 respectively and the estimated values of global solar radiation are 21.4, 22.6, 22.2, 22.2 and 21.8 for the year 2006, 2007, 2008, 2009 and 2010 respectively. Similarly, the correlation functions obtained for all the three models are above 0.8, which shows that the estimation is good. Consequently, the developed model will be use confidently for Kano and nearby locations which has similar climatic conditions.*

Keywords: solar radiation, sunshine hour, extraterrestrial radiation, Angstrom constants a and b, Kano state Nigeria.

1.1 INTRODUCTION

Energy is the major commodity that enhances the fundamentals of every human needs apart from water, with intention for good life quality.

Solar radiation is the energy that comes from the sun which generate big amount of energy through the process of nuclear fusion. Therefore, it is important to know the logic behind solar radiation for many applications, such as solar energy systems and evapotranspiration [1]

The design of solar energy conversion system needs specific knowledge concerning the availability of global solar radiation and its components at the research area, because the solar radiation reaching the surface of the earth depends on the climatic condition of the study area. Therefore, study of solar radiation within local climate condition is very important [2].

The need for the empirical methods for the prediction and estimation of global solar radiation is essential in the absent and scarcity of reliable solar radiation data, these empirical methods use climatic parameters of the study area. For optimal design and prediction of the system performance, the knowledge of global solar radiation is very important in any solar energy conversion system [3].

Recently, the interest of solar radiation modeling has increased. A large number of empirical models have been developed for prediction and estimation of daily and monthly global solar radiation at the local arrangement. Parameters used for that prediction include extraterrestrial radiation, actual duration of sunshine, sunshine hours, relative humidity, temperatures etc.[4].

2. DATA AND METHODOLOGY

The most widely used correlation in prediction of monthly mean global solar radiation is the linear relationship between the ration of mean daily global solar radiation to the corresponding value on clear sky day and the ratio of mean daily sunshine duration to the maximum possible sunshine duration as proposed by [5]. This empirical equation was modified by [6] who eliminated the problem of computing the clear sky radiation with extraterrestrial radiation [7]. As:

$$H = H_0 \left(a + b\frac{n}{No} \right) \qquad (1)$$

The constants a and b known as Angstrom constants and they are empirical, n is the monthly average daily hour of bright sunshine and N_o is the monthly average of the maximum possible daily hours of bright sunshine [8].

2.1 Solar radiation data

The monthly averaged global solar radiation and the sunshine hours used in this study were obtained from the Nigerian Meteorological Agency (NIMET) measuring station in Kano. The station is located at 12°02'51°N and 008°31'28°E with the elevation of 1,562/476m MSL. A five years record (2007 - 2011) of the monthly averaged data was utilized. The first three years data was used in developing the regression and their analysis, while the models where tested using the last two years records.

2.1.2 Statistical approach

The empirical models employed for the comparative study of the correlation functions, for the estimation of global solar radiation using sunshine based model are given in the table 1 below.

Table1. Regression models for the estimation of global solar radiation

LINEAR	$H = H_0\,(a + b\frac{n}{N_O})$
QUADRATIC	$H = H_0\,(a + b\frac{n}{N_O} + c(\frac{n}{N_O})^2)$
CUBIC	$H = H_0\,(a + b(\frac{n}{N_O}) + c(\frac{n}{N_O})^2 + d(\frac{n}{N_O})^3)$

The correlation coefficients of the models were calculated from the regression analysis between the clearness index (H/H0) and the sunshine duration ratio (n/N). The clearness index is the ratio of the monthly averaged daily global solar radiation H and the extraterrestrial radiation H_o. the clearness index is the ratio between the observed daily sunshine hours n and the day light hours N. the monthly averaged daily extraterrestrial radiation is given by

$$H_0 = \frac{24*60}{\pi} G_{sc} d_r\, [\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s] \quad (2)$$

Where G_{sc} is the solar constant given by

$$G_{sc} = 0.0820 MJ\mathrm{M}^{-2}\mathrm{M}^{-1} \quad (3)$$

And d_r is the relative earth-sun distance given by

$$d_{r=1+0.033\cos\frac{2\pi J}{365}} \quad (4)$$

Here j stand for the day number, a number between 1 and 365 with 1 indicating the 1st of January and 365 representing the 31st of December. The solar sunshine angle N, the solar declination angle δ and the sunset hour angle w_s are given by

$$\omega_s = \cos^{-}1(-\tan\varphi\tan\delta) \quad (5)$$

And $$\delta = 0.409 \sin(\frac{2\pi J}{365} - 1.339) \quad (6)$$

$$\mathrm{N} = 2\pi\omega_s/15 \quad (7)$$

Finally, φ represent the latitude of the station (location of measurement) [9].

2.1.3 Comparison techniques

Among the comparison techniques used for the assessment of the monthly mean global solar radiation, the most popularly used statistical parameters are: the mean bias error (MBE), root mean square error (RMSE) and the mean percentage error (MPE). In this study, to evaluate the accuracy of the estimated data from the model describe above, the following statistical tests were used:

The mean bias error

$$\mathrm{MBE} = \sum_1^n \frac{(Hest - Hmeas)}{n} \quad (8)$$

The root mean square error

$$\mathrm{RMSE} = \sqrt{\sum \frac{(Hest - Hmeas)^2}{n}} \quad (9)$$

Mean percentage error

$$MPE = \frac{1}{n}\sum \frac{(Hest - Hmeas)}{Hmeas} * 100 \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(10)}$$

Where MBE is mean bias error, RMSE is the root mean square error and MPE is the mean percentage error. n stands for the number of observations in all the three relations above, H_{est} and H_{meas} are estimated and measured monthly averaged daily global solar radiation respectively [10].

3. RESULTS AND DISCUSSION

The accuracy among the three models was determined using the data measured between the periods of 2006 to 2010. After analysis, the regression constants a, b, c and d are given in table 2 for the three models.

Table 2. The regression coefficients for 2010.

COEFFICIENT / MODEL TYPE	a	b	c	d	R^2
LINEAR	**0.045**	**0.051**	**-**	**-**	**0.827**
QUADRATIC	**0.010**	**0.058**	**-0.000**	**-**	**0.827**
CUBIC	**1.561**	**-0.365**	**0.037**	**-0.001**	**0.833**

It is clear from Table 2 that, the Angstrom Prescott coefficients a, b, c and d are subjected to a much variability according to type of model. The results of the values of monthly mean daily global solar radiation intensity estimated using the above three models 1 to 3 are compared with the corresponding measured values. The statistical tests of MBE, MPE and RMSE were determined for the year 2009 and 2010. The results are summarized in Table 3 below:

Table3. Validation of the models under different statistical tests

	2009			2010		
MODELS	MBE	RMSE	MPE	MBE	RMSE	MPE
LINEAR	-0.1053	0.5880	-0.1311	-0.35630	0.60036	0.93428
QUADRATIC	4.01001	1.32499	-18.418	1.19831	0.70526	-5.9253
CUBIC	0.06217	0.57262	-0.76595	0.40267	1.34847	-16.010

Subsequently, the estimated and measured values of the monthly mean global solar radiation for the years 2006, 2007, 2008, 2009 and 2010 are given in the Table 4 below:

Table4. Yearly measured and estimated values of global solar radiation.

YEAR	MEASURED H	ESTIMATED H
2006	21.75	21.40858
2007	22.41667	22.61292
2008	22.08333	22.21846
2009	22.33333	22.22796
2010	22.25	21.8937

Similarly, Figures below shows the measured and calculated values of monthly average global solar radiation using model 1 for the study area.

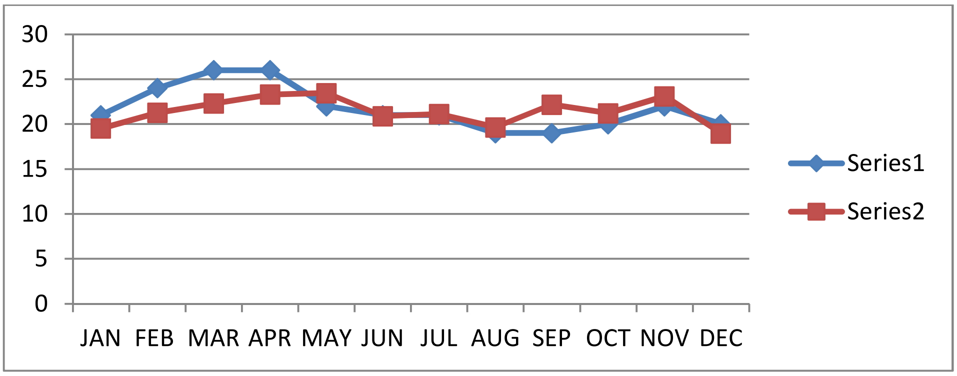

Figure 1 measured versus estimated global solar Radiation for 2006

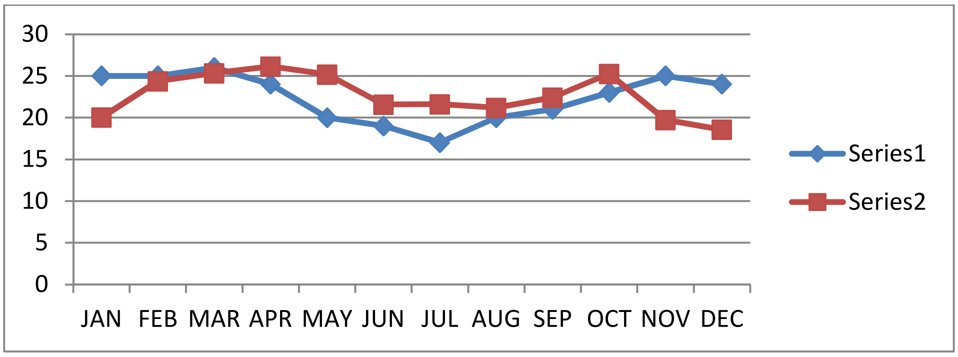

Figure 2 measured versus estimated global solar Radiation for 2007

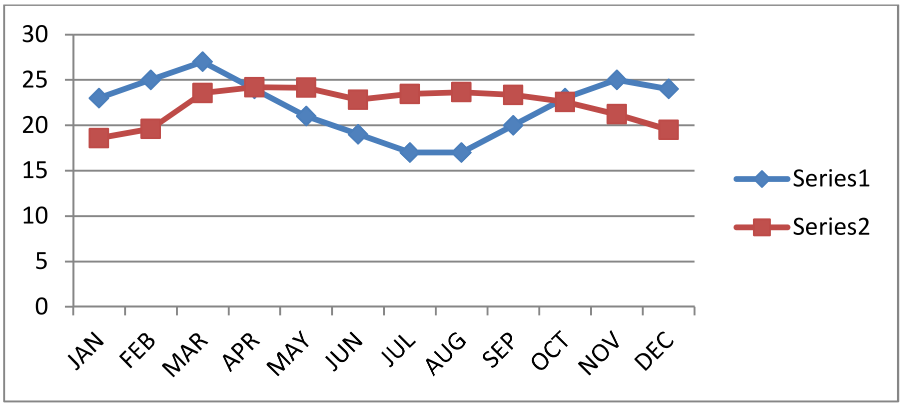

Figure 3 measured versus estimated global solar Radiation for 2008

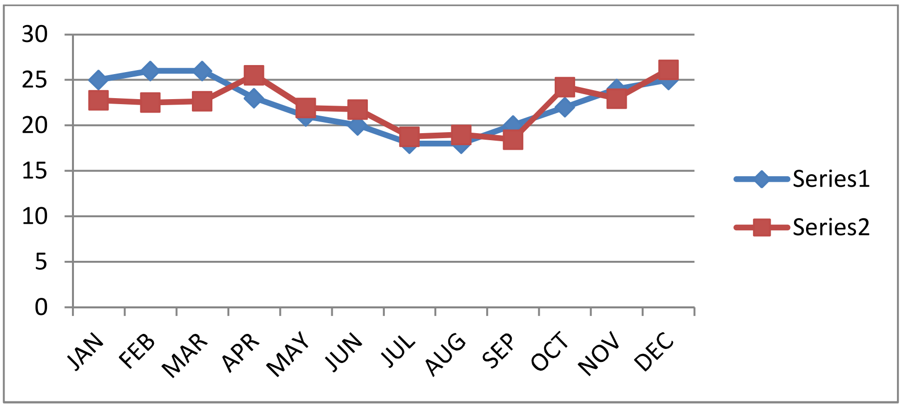

Figure 4 measured versus estimated global solar radiation 2009

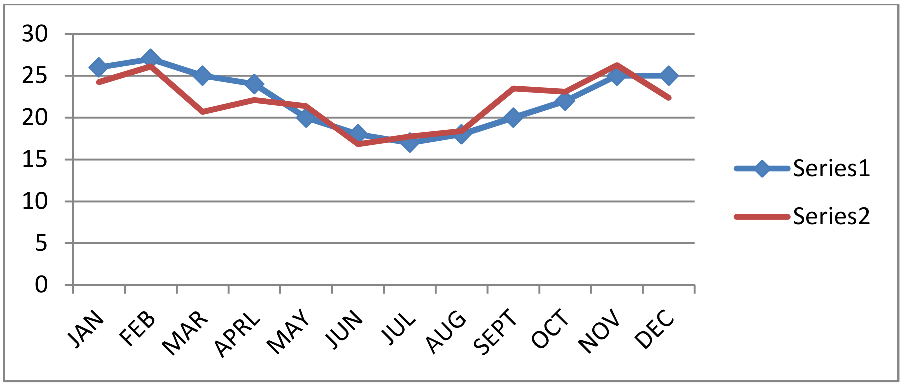

Figure 5 measured versus estimated global solar radiation for 2010

4. DISCUSSION

According to the statistical results, it is clear that the estimated values of monthly mean global solar radiation are in good agreement with the measured values of monthly mean global solar radiation. However, it was found that model 1 shows a good result, because model 1 has lowest values of MBE, RMSE and MPE its ranging from -0.1053 to 0.3563 and MPE from -0.1311 to 0.9342. As seen from Table 2, the statistical test of the correlation coefficient (R), all the models have good results with each (above 0.82) for the location. This directly shows that, the models obtained are reasonable compatible with the measured data. Consequently, it has been concluded that, model 1 was recommended for use to estimate global solar radiation in the study area.

As can be seen from Figures 1 to 5, it shows that there is good agreement between the values obtained for the estimated and measured global solar radiation for all the month of the year. It is also very clear that the deviation between the measured and estimated values using model 1 from all the figures is very small. Therefore, it has been concluded that, model 1 was the best to estimate the global solar radiation among the three models and consequently it is recommended to use in the study area. It has also been shown that, global solar radiation can be estimated using sunshine duration.

Hence, the linear model with the regression coefficient a and b as 0.045 and 0.051 respectively, and it is extremely recommended to estimate monthly average global solar radiation for the study area based on the statistical results and simplicity. With Angstrom Prescott model, one could easily and accurately estimate monthly average global solar radiation for Kano State, Nigeria.

5. CONCLUSION

The objective of this research was to study and compare the three models for the estimation of global solar radiation from bright sunshine hours and to select the most appropriate model for Kano State. The three models were compared on the basis of the statistical parameters such as MBE, MPE, RMSE and R^2.

According to the results, model 1 which is based on Angstrom Prescott model showed the good estimation of the global solar radiation for Kano State. Therefore, based on the statistical results a new simple linear model H/Ho = 0.045+0.051(n/N) based on the modified Angstrom Prescott is highly recommended to estimate global solar radiation for Kano State areas and elsewhere with similar climatic conditions, and also some areas if the radiation data is missing or unavailable. I hope this research will help to advance knowledge of global solar radiation to the level where it has application in the field of estimation of global solar radiation.

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