IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 6, Issue 6 Ver. I (Nov.-Dec. 2014), PP 19-23
www.iosrjournals.org

Estimation of Global Solar Radiation for Kano State Nigeria Based on Meteorological Data

Auwal Muhammad[1*], T .H. Darma[2]
[1]*Physics Department, Kano University of Science and Technology, Wudil,P. M.B. 3244, Nigeria*
[2]*Physics Department,Bayero University, P. M. B. 3011, Kano - Nigeria*

Abstract:*In this study, a modified Angstrom model for the estimation of global solar radiation in Kano, Nigeria using maximum/minimum temperature and relative humidity based on meteorological data were used. Two new models were developed for estimating the monthly-average daily global solar radiation. Regression coefficients a and b of*$(1.2577,-1.0167)$ *and*$(0.8317,-0.0043)$ *were obtained from the models based on temperature ratios and relative humidity respectively. In order to evaluate the results, three statistical methods have been used namely; Mean bias, root mean square, and mean percentage errors. The temperature based models which has a lower root mean square error is an indication of good agreement between the measured and estimated global solar radiation. Base on the statistical results a new temperature base model is recommended to estimate monthly global solar radiation for Kano state and other locations with similar climate conditions where the radiation data is unavailable.*
Keywords:*clearness index, day length, global solar radiation, extraterrestrial radiation,*

I. Introduction

Solar radiation affects the earth's weather processes which determine the natural environment. Its presence at the earth's surface is necessary for the provision of food for mankind. Thus it is important to be able to understand the physics of solar radiation, and in particular to determine the amount of energy intercepted by the earth's surface at different locations [1].

Meteorological data obtained from direct measurement provide the necessary information of radiation and weather parameters. However, in the developing countries such as Nigeria, sufficient and reliable measuring instruments and poor maintenance culture, has led to poor data records and more often, unreliable solar radiation data. In the absence of these measurements theoretical models have become the desired tools to predict and estimate the global solar radiation of a place using some meteorological parameters such as temperature, sunshine hours and relative humidity.

For country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available almost throughout the year. Solar radiation data are available for most part of the world, but is not available for many countries which cannot afford the measurement equipment and techniques involved.

Global solar radiation in Nigeria is measured in few stations, even in these few stations the use of estimate from theoretical models is important with a view to authenticate and collaborate the measured data.

The estimation of monthly global solar radiation has been reviewed in most of the researches based on the meteorological parameters, identifying the best model and determining different coefficients for several locations. Augustine C. and Nnbuchi M. N. [2], Isukwue et al [3],Namrata K. et al [4],Falayi E. O. et al [5],Medugu D. W. and Yakubu D. [6],Olayinka S. [7],Agbo G. A. et al [8].

In this study, we developed two-model viz temperature-based linear model and relative humidity-based linear model for estimating monthly global solar radiation on horizontal surfaces in Kano state, Nigeria, using monthly mean daily minimum and maximum temperatures and relative humidity.

The aim and objective of this work is to investigate solar radiation characteristics for Kano region using mathematical models and meteorological data, and to develop an equation that estimates global solar radiation on horizontal surface for Kano region, Nigeria.

II. Estimation Method

To estimate the global solar radiation$\overline{H}$, data consisting monthly mean minimum/maximum temperature and relative humidity were taken from Nigerian Meteorological Agency (NIMET), Abuja-Nigeria. The data obtained covered a period of 6 years (2005-2010). The geographical location of Kano, Nigeria is shown in table (1).

Table 1: geographical location of the station

Station	Latitude	Longitude	Altitudes (m)
Kano	12.01	8.30	467

Different modifications to the original Angstrom equation for the determination of monthly mean daily extraterrestrial radiation $\overline{H}_0$have been reported in the literature. In this work, we use equation (1)as reported by [9]. The sunset hour angle ω_{ss} and declination angle δ [10], were calculated using equations (2) and (3) respectively

$$H_0 = \frac{24\times3600}{\pi} I_{SC}(1+0.033\cos(\frac{360n}{365}))[\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega] \quad (1)$$

Sunset angle = ω_{ss}=$\cos^{-1}[-\tan(L)\tan(\delta)]$ (2)

$$\delta = (23.45)^\circ \sin[360^\circ \frac{284+n}{365}] \quad (3)$$

A linear regression analysis of three parameters was employed to estimate the global solar radiation. The parameters are;$\overline{H}/\overline{H_0}$, T_{min}/T_{max}, and RH, where $\overline{H}/\overline{H_0}$ is the clearness index, T_{min}/T_{max} is the ratio of minimum to maximum monthly temperature and RH is the relative humidity. Two equations were developed to estimate the monthly mean global solar radiation$\overline{H}$, temperature based model and relative humidity based model.

$$\overline{H} = \overline{H}_0[a + b\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)] \quad (4)$$

$$\overline{H} = \overline{H}_0[a + bRH] \quad (5)$$

In the regression analysis, starting with one parameter, the equation took the form of [11].

$$y = a + bx \quad (6)$$

Where a and b are regression coefficient

III. Statistical Tests

In order to evaluate the accuracy of the developed models, three statistical tests; mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE) as reported by [12], were employed. Mean bias error is defined as

$$MBE = \{\sum(\overline{H}_{pred} - \overline{H}_{meas})/n\} \quad (7)$$

Root Mean Square Error is defined as

$$RMSE = \{\sum(\overline{H}_{pred} - \overline{H}_{meas})^2/n\}^{1/2} \quad (8)$$

Mean Percentage Error is defined as

$$MPE = \{\sum\left(\frac{\overline{H}meas - \overline{H}pred}{Hmeas} \times 100\right)/n \quad (9)$$

Where $\overline{H}_{pred}$ and $\overline{H}_{meas}$ is the predicted and measured values and n is the total number of observations. In general a low RMSE is desirable, a positive MBE shows over estimation while a negative MBE indicates under estimation

IV. Results and Discussions

Extraterrestrial radiations on horizontal surfaces were calculated using declination angle, latitude, and hour angle at sunset using Equations. (1)-(3).

The regression constants were obtained using Microsoft excel, 2010 and the values substituted in equations (4) and (5) respectively. Using these constants, the modified equations are presented in table (2) for the period 2005 to 2010.

Table 2: Modified linear regression equations based on temperature ratios and relative humidity

Years	Modified Linear Regression Equations	
	Temperature based Models	Relative Humidity based Models
2005	$\frac{\overline{H}}{\overline{H}_0} = 1.1035 - 0.7868\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.7598 - 0.0031RH$
2006	$\frac{\overline{H}}{\overline{H}_0} = 1.1073 - 0.7895\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.763 - 0.0031RH$
2007	$\frac{\overline{H}}{\overline{H}_0} = 1.3288 - 1.15\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.858 - 0.0047RH$
2008	$\frac{\overline{H}}{\overline{H}_0} = 1.387 - 1.2361\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.8581 - 0.005RH$
2009	$\frac{\overline{H}}{\overline{H}_0} = 1.4174 - 1.2472\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.8603 - 0.0045RH$
2010	$\frac{\overline{H}}{\overline{H}_0} = 1.2024 - 0.8904\left(\frac{\overline{T}_{min}}{\overline{T}_{max}}\right)$	$\frac{\overline{H}}{\overline{H}_0} = 0.8907 - 0.0055RH$

Table (1) is a summary of Temperature linear model and Relative humidity based liner model respectively. The graphs for each model were plotted in order to determine the average monthly global solar radiations for the period of study. The measured global solar radiation and predicted global solar radiation for temperature based model and Relative humidity based model were combined in graphs for each year in order to compare and evaluate a better model for prediction of monthly global solar radiation for the location under study.

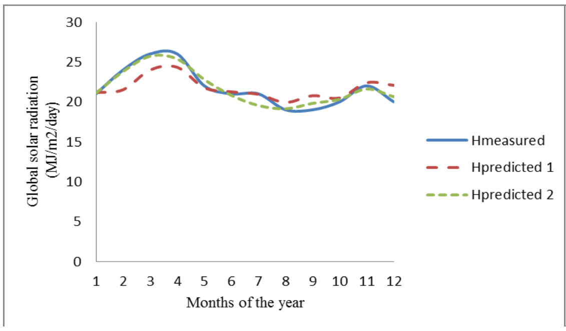

Figure 1: Comparison between measured and predicted Monthly global solar radiation for 2005

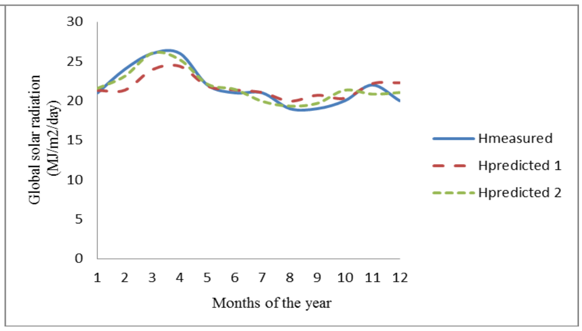

Figure 2: Comparison between measured and predicted monthly global solar radiations for 2006

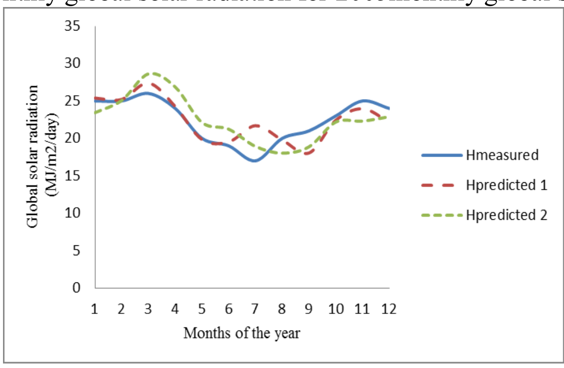

Figure 3: Comparison between measured and predicted Monthly global solar radiation for 2007

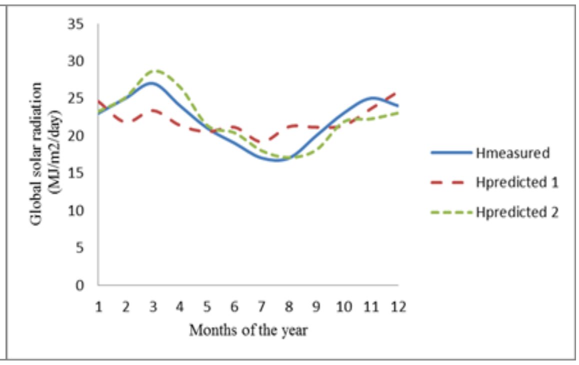

Figure 4: Comparison between measured and predicted monthly global solar radiation for 2008

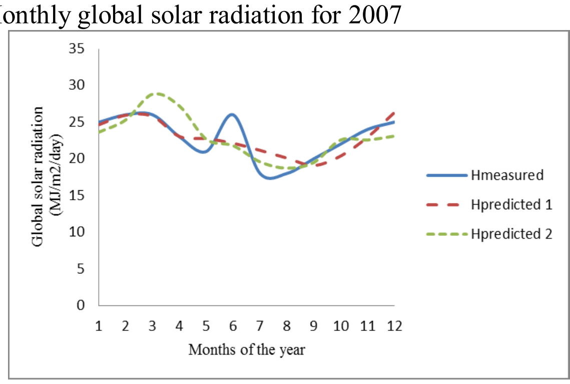

Figure 5:Comparison between measured and Predicted monthly global solar radiation for 2009

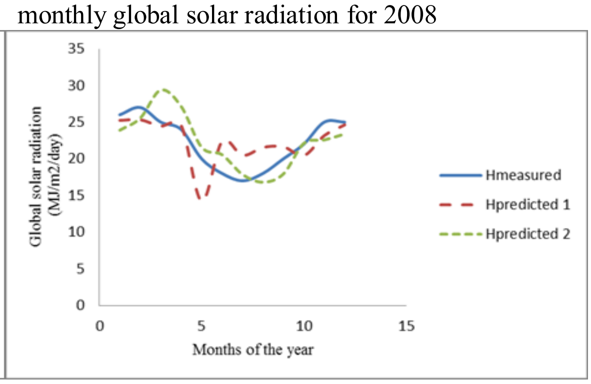

Figure 6: Comparison between measured and predicted monthly global solar radiation for 2010

Figures (1) – (6) are combined graphs for measured and predicted monthly global solar radiations. $H_{predicted\ 1}$, represent monthly global solar radiations based on temperature ratios model and $H_{predicted\ 2}$ is monthly global solar radiation computed from Relative humidity based models. A close examination shows that the monthly global solar radiation on a horizontal surface is maximumin March. The month of Marchis expected in Kano to have highest radiation. Another point to note is that, the lowest value of monthly global solar radiation on a horizontal surface occurs in July and August.Thesemonthswere characterized by heavy rainfall in Kano-Nigeria.It's clearly observed that, the estimated and predicted global solar radiation varies correspondingly. It is also noted that, in comparing the results $_{Hpredicted\ 2}$ match better with $H_{measured}$ than $H_{predicted\ 1}$.

In figure 5, it is observed that global solar radiation peak at the middle of the year for $H_{measured}$. This is attributed to malfunction of the instrument particularly in the months of May and June as recorded in the data retrieved by the instrument. In figure 6, also there is a close agreement between $H_{measured}$ and $H_{predicted}$ respectively.

Figure 7 is the average combined graphs for the period of study in order to validate the performance of the proposed models for estimation of monthly global solar radiation for Kano. Result obtained based on relative humidity models vary correspondingly with measured except in March and April which exhibit monthly global radiation above the measured values. October, November and December exhibit under measured values. This effect could be due to variability in the atmospheric parameters during measurement. However the $H_{predicted\ 2}$gets better correlation in comparison to $H_{predicted\ 1}$.

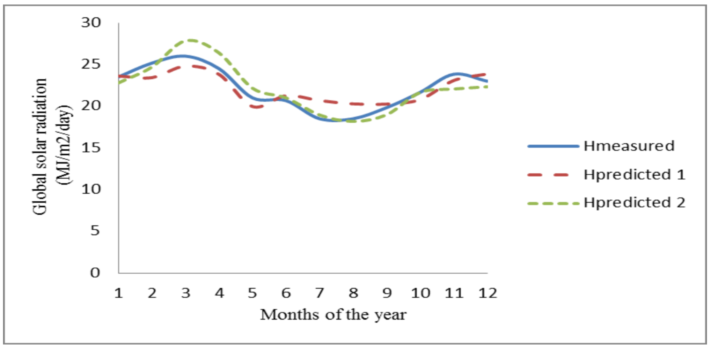

Figure 7: Average graphs for comparison between measured and predicted monthly global radiation for the period of study

V. Comparison Techniques

Comparisons of monthly daily global solar radiation for the two estimation models were done in order to evaluate the accuracy of the modelsusing statistical parameters. Three statistical tests; mean bias (MBE), root mean square (RMSE), and mean percentage errors (MPE) were presented in equation (7) – (9).

The values of regression constants obtained using Table 2 along with the values of the MBE, RMSE and MPE for the location are summarized in Table 3. The relative humidity based model $\bar{H} = 35.290428[\,0.8317 - 0.0043RH]$ is recommended to estimate the monthly global solar radiation for Kano state and other locations with similar climate conditions because the root mean square and mean bias errors are very low, indicating fairly good agreement. The positive values of the MPE indicate that the present correlation slightly overestimate H.

$\bar{H} = 35.290428\left[1.2577 - 1.0167\left(\frac{T_{min}}{T_{max}}\right)\right]$for the second modified Angstrom model base on temperature ratios do not significantly improve the accuracy of estimation of global solar radiation for the location because the values of the MBE, RMSE and the MPE do not increase the accuracy of estimation of global radiation.

Table 3: Summary of statistical test

Models	a	b	MBE	RMSE	MPE
$\frac{\bar{H}}{\bar{H}_0} = a + b\frac{T_{max}}{T_{max}}$	1.2577	−1.0167	0.072042	0.24956	−0.027066
$\frac{\bar{H}}{\bar{H}_0} = a + bRH$	0.8317	−0.0043	−0.024408	0.084553	0.0091703

VI. Conclusions

In this study, solar radiation models for predicting monthly average global solar radiations on horizontal surface were reviewed. Data of global solar radiations, relative humidity, maximum and minimum temperature are analyzed from 2005 to 2010 respectively. The modified Angstrom models were developed to estimate the monthly-average daily global solar radiations on a horizontal surface for Kano, Nigeria. Two new models are developed for estimating the monthly-average daily global solar radiation. Regression coefficients a and b of $(1.2577, -1.0167)$ and $(0.8317, -0.0043)$ were obtained from the models based on temperature ratios and relative humidity respectively. In order to validate the results three statistical methods have been used namely; (MBE), (RMSE), and (MPE) of -0.024408, 0.084553 and 0.0091703. The errors evaluated in the relative humidity based models have lowerRMSE, an indication of the good agreement between the measured and estimated global solar radiation. It can be deduced from the results that, the new developed Relative humidity based linear model is found to be reasonably reliable for estimating or predicting the monthly global solar radiations of location that has the same geographical location information as Kano in the North- west, Nigeria.

References

[1]. Nwokoye A. O. C., Solar energy technology: Other alternative energy resources and environmentalsciences (Rexcharles and Patriclimited, Nigeria, 2006).

[2]. Augustine C. and Nnabuchi M. N.,Correlation between sunshine hour and global solar radiation in Warri, Nigeria, Pacific Journal of Science and Technology,10(2), 2009, 574-579.

[3]. B. C. Isikwue, A. N. Amah, and P. O. Agada,Empirical models for the estimation of global solar radiation in Makurdi, Nigeria,GlobalJournal of Science Frontier Research,12(1):2012, 59-61.

[4]. NamrataK., S. P. Sharma, and S. B. L. Saksena, Estimation of global and diffuse solar radiation for Jamshedpur, India, International Journal of Science and Technology, 2(1): 2012, 44-47.

[5]. E. O. Falayi, J. O. Adepitan, and A. B. Rabiu, Empirical models for the correlation of global solar radiation with meteorological data for Iseyin, Nigeria,Pacific Journal of Science and Technology, 9(2),2008, 583-591.

[6]. Medugu D. W and Yakubu D., Estimation of mean monthly global solar radiation in Yola, NigeriausingAngstrom model, Advances in Applied Science Research, 2(2): 2011, 414-421.

[7]. Olayanka Sunday, Estimation of global and diffuse solar radiation for selected cities in Nigeria, International Journal of Energy and Environmental Engineering, 2(2): 2008, 13-33.

[8]. Agbo G. A. and Baba A.,Empirical models for the correlation of monthly average global solar radiation with sunshine hour, at Mina, Nigeria, Journal of Basic Physical Research, 1(1): 2011, 41-47.

[9]. Duffie A. John and William A.**,** Solar radiation of thermal processes, (Second edition, Wiley-Inter science publication, New York, 1980).

[10]. Firoz Ahmad and IntikhabUlfat, Empirical models for the correlation of monthly average daily global solar radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan, Turkish J. Phys, 28: 2004, 301-307.

[11]. İnci TÜRK TOĞRUL, Estimation of solar radiation from Angrtoms coefficients by using geographical and meteorological data in Bishkek, Kyrgyzstan, J. of Thermal science and Technology, 29(2): 2009, 99-108.

[12]. A. M. Muzathiket. al, Daily global solar radiation estimate based on sunshine hours, International Journal of Mechanical and Materials Engineering, 6(1): 2011, 75-80.