PREDICTION OF CLEARNESS INDEX FOR SOME NIGERIAN STATIONS USING TEMPERATURE DATA

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ABSTRACT
Global solar radiation and mean temperature data for five Nigeria stations have been used to fit the Angstrom model for the clearness index (K_T =H/Ho), the mean temperature (T_{mean}) and maximum temperature (T_{max}). The tests of performance of the model for the five stations have been done in terms of the widely used statistical indicators, Mean Bias Error (MBE) and Root Mean Square Error (RMSE). It was found from statistical model performance indicators that the models provided reasonably high degree of precision in the prediction of average monthly global solar radiation on horizontal surfaces.

Keywords: *Clearness index, Global solar radiation, and Temperature*.

INTRODUCTION

Solar energy is an alternative energy source that can be used to supplement the convectional energy sources in tropical areas. The agriculturists, architects, hydrologists, climatologist, and ventilating engineers depend on availability of information on solar radiation. The technology development of solar energy must start with ensuring of accurate study of radiation data at different status. The global solar irradiance is affected by the atmospheric condition and meteorological parameters such as turbidity, relative humidity, degree of cloudiness, temperature and sunshine duration (Akinbode, 1992; Rietveld, 1978; Soler, 1979; Hargreves *et al.*, 1985; De Jong and Stewart, 1993).

There had been investigation by Angstrom (1924), Arize and Obi (1983), Fagbenle (1990) on the ability of the Angstrom-page model to predict global solar radiation using the temperature and sunshine duration at different locations in Nigerian northern cities. A model was developed using temperature data by Hagreaves *et al.* (1985) to predict the global solar irradiance on horizontal surfaces in Nigeria environment.

The major aim of this paper is to determine the applicability of the Angstrom page regression model for estimating global solar irradiance from surface temperature which includes the maximum temperature and mean temperature data for five stations viz: Ikeja, Ibadan, Port Harcourt, Benin and Ilorin. The performance of the model is also investigated using statistical indicators.

MATERIALS AND METHODS

The data set used which include mean hourly global solar radiation, maximum or minimum temperature, for a solar cycle (1980-1990) for five locations in Nigeria listed on Table 1 and displayed in figure 1, were obtained from the Archives of Nigeria Meteorological Agency, Oshodi, Lagos State.

Table 1:Geographical Location of the Station

Stations	Locations
Ikeja	6.39^0N 3.23^0E
Ilorin	6.50^0N 4.56^0E
Ibadan	7.22^0N 3.58^0E
Port Harcourt	4.43^0N 7.05^0E
Benin	5.25^0N 5.30^0E

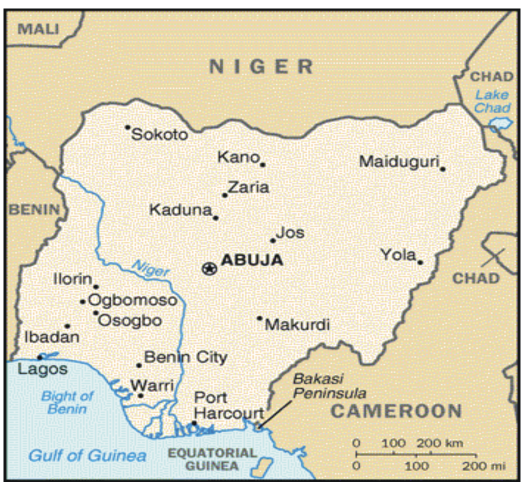


Fig 1: Map of Nigeria showing the stations

The hourly global solar radiation which were obtained using Gun – Bellani distillate were converted and standardized as used by Folayan (1988), using the conversion factor of (1.357± 0.176) H_{GB} MJ/m^2

$$H_{gs} = (1.35 \pm 0.176)\, H_{GB} \quad MJ/m^2 \qquad (1)$$

Where H_{gs} is the hourly global solar radiation in MJ/m^2, H_{GB} is the raw data obtained using Gun –Bellani distillate.

Angstrom (1924) and Page (1964) used an expression in the linear regression model to correlate the measured global solar radiation data (H) with surface temperature (T_s) given by:

$$H = H_0\left[a + b\left(T_s\right)\right] \qquad (2)$$

where H is the monthly mean horizontal daily total terrestrial solar radiation. Ho is the monthly mean horizontal daily total extraterrestrial solar radiation a and b are climatic constants;

T_s is the corresponding value of mean temperature and maximum temperature

The mean monthly extraterrestrial radiation H_0 on the horizontal surface for a period of one day is given by the expression.

$$H_0 = \frac{24x3600}{\pi} Gsc\left(1 + 0.033 Cos\frac{360n}{365}\right)\left(Cos\ \phi Cos\ \delta Sin Ws\ + \frac{2\pi Ws}{360} Sin\ \phi Sin\ \delta\right) \qquad (3)$$

where

Ho = monthly mean daily extraterrestrial radiation KJ/m^2

Gsc = solar constant = 1367 W/m^2

δ = declination angle

ϕ = latitude

Ws = sunset hour angle for the typical day n of each month in degrees

= $\cos^{-1}(-\tan\phi \tan\delta)$

n = mean day of each month

Equation 2 can simplified into

$$\frac{H}{H_0} = a + b(T_{max}) \qquad (4)$$

$$\frac{H}{H_0} = a + b(T_{mean}) \qquad (5)$$

$$T_{mean} = \frac{T_{(max)} + T_{(min)}}{2} \qquad (6)$$

where T_{max} and T_{mean} are maximum temperature and mean temperature respectively. Where a and b are regression constant.

The mean temperature (T_{mean}) and the daily value of extraterrestrial radiation H_0 were estimated using equations 3 and 6 respectively for each location and all days for the period of 1980 -1990. Clearness index K_T is defined as the ratio of the observed/measured horizontal terrestrial solar radiation (H), to the calculated/predicted horizontal extraterrestrial solar radiation (H_0).

$$K_T = \frac{H}{H_0} \qquad (7)$$

The regression and correlation analyses were performed between the clearness index ($K_T = H/H_0$) and the maximum temperature, as well as between the cleanness index and mean temperature.

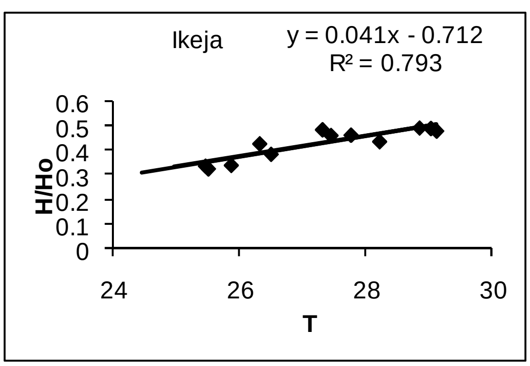
Table 2 and 3 shows the values of regression coefficients(r), coefficients of determination (R^2) and regression constants (a and b). Figure 2 and 3 further illustrate the Angstrom page regression relationship.

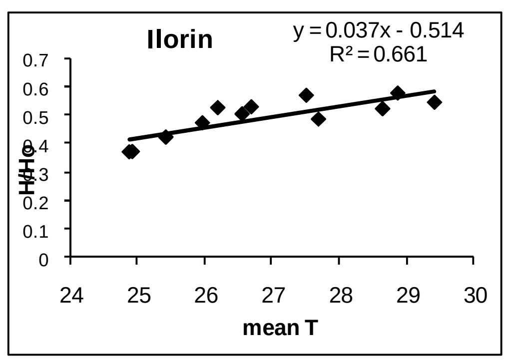
Table 2: Regression and correlation parameters for T_{max}

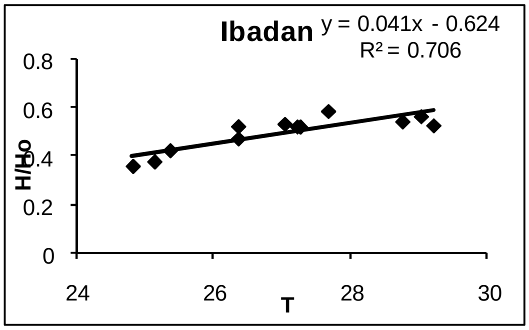
Stations	a	b	r	R^2
Ikeja	-0.5324	0.031	0.923304	0.8525
Ilorin	-0.3703	0.0268	0.938002	0.8798
Ibadan	-0.3753	0.0276	0.860439	0.7404
Port Harcourt	-0.5009	0.0303	0.880028	0.7794
Benin	-0.5270	0.0297	0.927304	0.8599

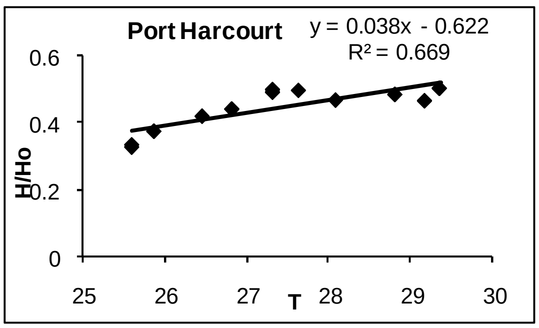
Table 3: Regression and correlation parameters for T_{mean}

Stations	a	b	r	R^2
Ikeja	-0.7125	0.0419	0.890894	0.7935
Ilorin	-0.5145	0.0373	0.813575	0.6619
Ibadan	-0.6246	0.0415	0.840220	0.7060
Port Harcourt	-0.6223	0.0389	0.81875	0.6699
Benin	-0.8424	0.04664	0.893401	0.7982









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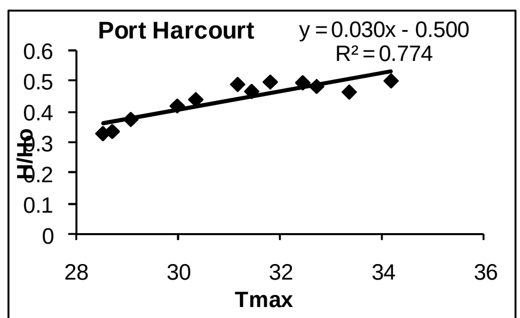

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Figure 3: Monthly Average of Clearness Index and Maximum Temperature for five locations

The monthly mean observed global solar radiation values were compared with predicted values. To assess the predictive accuracy for the monthly predicted solar radiation values, two methods were proposed by Stone (1993). The Mean Bias Error (MBE) and Root Mean Square Error were evaluated using the following equations for the five stations:

$$MBE = \sum \frac{\left(H_{pred} - H_{obs}\right)}{N} \quad (8)$$

$$RMSE = \left[\sum\left(\frac{\left(H_{pred} - H_{obs}\right)^2}{N}\right)\right]^{1/2} \quad (9)$$

H_{pred} is the predicted value from the model. H_{obs} is the measured or observed value and N is the total number of observation. The test of RMSE provides information on the short-term performance of studied model as it allows a term by term comparison of the actual deviation between the calculated value and the measured value. Table 3 presents the RMSE and MBE for the 5 locations. Igbai (1993) and Halouani et al (1993) recommended that a zero value of RMSE is ideal while a low MBE is desirable.

RESULTS AND DISCUSSION

Tables 2 and 3 contains summaries of the results obtained from the application of equation (4) and (6) to the monthly mean global solar radiation values for the 5 stations under study. From table 2 and 3, it is clear that the regression coefficients (a and b), correlation coefficients r and coefficients of determination R^2 vary from one place to another.

Considering clearness index-maximum temperature, the correlation coefficients (0.86 –0.93) are high for all the stations. This implies that, there is statistically significant relationship between the clearness index and the maximum temperature. This is further demonstrated by high values of coefficient of determination R^2 (0.74 – 0.87) across the stations.

The clearness index-mean temperature correlation coefficient (0.81-0.89) is also high for the stations and there are high values of coefficients of determination (0.66-0.79) across the stations.

Mean Temperature

For Ikeja, the coefficient of determination of 0.7937 implies 79.37% of clearness index can be accounted for by mean temperature using Angstrom model equation.

$$\frac{H}{H_0} = -0.7125 + 0.04190\left(T_{mean}\right) \quad (10)$$

Correlation coefficient of 0.8909 exist between the clearness index and T_{mean}

For Ilorin, the coefficient of determination of 0.6619 implies 66.19% of clearness index can be accounted for by mean temperature using Angstrom model equation.

$$\frac{H}{H_0} = -0.5145 + 0.0373\left(T_{mean}\right) \quad (11)$$

Correlation coefficient of 0.8136 exists between the clearness index and mean temperature.

For Ibadan, the coefficient of determination of 0.7060 implies 70.60% of clearness index can be accounted for by the mean temperature which can be expressed as:

$$\frac{H}{H_0} = -0.6226 + 0.0329\left(T_{mean}\right) \quad (12)$$

Correlation coefficient of 0.8402 exists between the clearness index and mean temperature.

For Port Harcourt, the coefficient of determination of 0.6699 implies 66.99% of clearness index can be accounted for by the mean temperature, which can be expressed as,

$$\frac{H}{H_0} = -0.6223 + 0.0389\left(T_{mean}\right) \quad (13)$$

Correlation coefficient of 0.8188 exists between the clearness index and mean temperature.

For Benin, the coefficient of determination of 0.7798 implies 77.98% of clearness index, which can be expressed as

$$\frac{H}{H_0} = -0.8424 + 0.04664\left(T_{mean}\right) \quad (14)$$

Correlation coefficient of 0.8934 exists between the clearness index and mean temperature.

Maximum Temperature
In Ikeja, the coefficient of determination of 0.8525 implies 85.25% of clearness index can be accounted for by maximum temperature using Angstrom model equation.

$$\frac{H}{H_0} = -0.5324 + 0.031\left(T_{max}\right) \quad (15)$$

Correlation coefficient of 0.9233 exists between the clearness index and maximum temperature.

For Ilorin, the coefficient of determination of 0.8798 implies 87.98% of clearness index can be accounted for by maximum temperature using Angstrom model equation.

$$\frac{H}{H_0} = -0.3703 + 0.0268\left(T_{max}\right) \quad (16)$$

Correlation coefficient of 0.9380 exists between the clearness index and maximum temperature.

For Ibadan, the coefficient of determination of 0.7404 implies 74.04% of clearness index can be accounted for by maximum temperature using Angstrom model equation.

$$\frac{H}{H_0} = -0.37534 + 0.0276\left(T_{max}\right) \quad (16)$$

Correlation coefficient of 0.8604 exists between the clearness index and maximum temperature.

For Port Harcourt, the coefficient of determination of 0.744 implies 74.4% of clearness index can be accounted for by maximum temperature using Angstrom model equation.

Correlation coefficient of 0.8800 exists between the clearness index and maximum temperature.

$$\frac{H}{H_0} = -0.5009 + 0.03030\left(T_{max}\right) \quad (17)$$

For Benin, the coefficient of determination of 0.8599 implies 85.99% of clearness index can be accounted for by maximum temperature using Angstrom model equation.

Correlation coefficient of 0.9273 exists between the clearness index and maximum temperature.

$$\frac{H}{H_0} = -0.52270 + 0.0297\left(T_{max}\right) \quad (18)$$

The regression coefficients obtained in this work indicate good performance, with earlier result reported by Iheonu (2001). The low values of the Mean Bias Error and Root Means square Error as evidences on Table 4 and Table 5 are quite remarkable.

Table 4: statistical performance of proposed model for maximum temperature

Stations	MBE	RMSE
Ikeja	-8.643×10^{-4}	0.023468
Ilorin	$- 8.330 \times 10^{-8}$	0.023995
Ibadan	1.393×10^{-3}	0.036014
Port Harcourt	1.608×10^{-5}	0.028941
Benin	8.330×10^{-8}	0.024950

The results show that the Angstrom – page model is effective and useful in predicting global solar radiation in tropical Nigeria.

Table 5: statistical performance of proposed model for mean temperature

Locations	MBE	RMSE
Ikeja	2.283×10^{-3}	0.027754
Ilorin	7.257×10^{-4}	0.029954
Ibadan	8.330×10^{-8}	0.038370
Port Harcourt	-5.000×10^{-6}	0.035805
Benin	-8.333×10^{-10}	0.035012

SUMMARY OF THE RESULTS

The Angstrom – Page linear regression model has been applied to estimates global solar irradiance from maximum and mean temperature data at five tropical stations. The equations of the models together with their coefficients of determination are summarised in the Table below:

Table 6: Summary of the global solar irradiance and mean temperature

Stations	K_T	R^2
Ikeja	$-0.7125+0.0419(T_{mean})$	0.7937
Ilorin	$-0.5145+0.0373(T_{mean})$	0.6619
Ibadan	$-0.6226+0.0329(T_{mean})$	0.7060
Port Harcourt	$-0.6223+0.0389(T_{mean})$	0.6699
Benin	$-0.8424+0.04664(T_{mean})$	0.7798

Table7: Summary of the global solar irradiance and maximum temperature

Stations	K_T	R^2
Ikeja	$-0.5324+0.0310(T_{max})$	0.8525
Ilorin	$-0.3703+0.0268(T_{max})$	0.8798
Ibadan	$-0.6226+0.0276(T_{max})$	0.7404
Port Harcourt	$-0.6223+0.0303(T_{max})$	0.7794
Benin	$-0.8424+0.0297(T_{max})$	0.8599

CONCLUSION

The Angstrom-page coefficient fitting using daily global radiation and Temperature for Nigerian, showed very good result. The tests of performance of the model for the five stations have been done in terms of the widely used statistical indicators, Mean Bias Error (MBE) and Root Mean Square Error (RMSE). It was found from statistical model performance indicators that the models provided reasonably high degree of precision in the prediction of average monthly global solar radiation on horizontal surfaces. Our result indicates that the regression obtained in this paper may be used satisfactorily for the estimation of global radiation in Tropical station in Africa.

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