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Research Article

EMPIRICAL MODEL FOR THE ESTIMATION OF MONTHLY GLOBAL SOLAR RADIATION IN ZARIA, NIGERIA

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ABSTRACT

Angstrom-Prescott empirical model is widely used to estimate global solar radiation because it makes use of the near surface parameter which can be easily obtained. Angstrom Prescott model was used to estimate the monthly mean global solar radiation for Zaria using the latitude 11.1333^0. The Angstrom coefficients **a** and **b** calculated were 0.3325 and 0.4510, respectively. Thus, Angstrom-Prescott model for Zaria is $\overline{H_I} = (0.3325 + 0.4510S_0)$. The estimated monthly global solar radiation was found to be in good agreement with the monthly global solar radiation measured for Zaria.

Keywords: *Angstrom-Prescott, Monthly Mean Solar Radiation, Extraterrestrial Solar Radiation*

INTRODUCTION

The quest for man to attain prosperity through his activities such as the exploration of minerals and natural resources cannot be over emphasized. These activities have a great and adverse effect on the natural environment. Tremendous increase in civilization and standard of man's living had been a function of energy consumption. Energy is used in manufacturing industries, for electricity generation, transportation and also used in our homes and offices. Fossil fuel, natural gas, coal, oil sands are derived from the sun and these fuels are the life blood of industrial civilization, accounting for about 85% of global energy use (Kaufmann, 2008).

This fossil fuel has some effect on our environment and bound to dry-up some day (Julian, 2011). Therefore, there is a great need for other sustainable sources of energy such as solar energy. Almost all of the energy that drives the various systems (climate system, ecosystem, hydrological system, etc) found on earth originates from the sun (Pidwirmy, 2006). Solar energy is sustainable, available and easily accessed compared to other renewable energy sources (Julian, 2011).

Solar radiation is the amount of energy spreading out or emitted to all parts of the planet from the sun. Solar energy reaching the earth is given in kilowatt per meter squared (KW/m^2).

Solar radiation reaching the earth surface depends on the geographical area, latitude of the surface and varies from one place to another (Okonkwo and Nwokoye, 2014). Therefore, we can extrapolate solar radiation reaching the earth surface from other meteorological factors such as temperature, relative humidity, rainfall and sunshine hour (Agbo *et al.,* 2010).

Researchers use regression empirical model such as Angstrom-Prescott model to correlate the mean monthly solar radiation reaching a horizontal surface, using either one of the meteorological factors or more. Solar radiation data have so many applications in photovoltaic, atmospheric energy balance study, building, agricultural studies and meteorological forecasting and should be available and reliable for designers and users, but unfortunately, these data are not readily available in some rural areas due to poor instrument and infrastructure (Innocent *et al.,* 2015). Therefore, there is need to consider methods of estimating the global solar radiation based on available meteorological data.

Hence, this work is aimed at using Angstrom-Prescott a model for the estimation of the mean monthly global solar radiation for Zaria using the available meteorological data. This work will also write a MATLAB program which will estimate the monthly mean global solar radiation using average sunshine hour for the month collected from Nigeria Meteorological Agency Zaria with latitude 11.1333^0.

Angstrom – Type Model

In 1924, Angstrom presented a simple relationship to estimate the monthly-mean daily solar radiation from sunshine duration.

$$H = \left[\alpha + \frac{(1-\alpha)n}{N}\right] H_C \quad (1)$$

Where α is an empirical constant, n is the actual sunshine duration, N is the maximum possible sunshine. The ratio of n/N is the relative sunshine duration.

H_C is the radiation transfer processes, the transfer processes could not be found until recently. Equation (1) could not be applied to sites with no radiation data, which is it disadvantage.

To avoid this disadvantage, in 1940 Prescott then rearranged the correlation in a simpler form as;

$$H = \left[a + b\,\frac{n}{\bar{N}}\right] H_0 \quad (2) \qquad \bar{N} = \left(\frac{2}{15}\right)\cos^{-1}(-\tan\varphi\tan\delta) \quad (3)$$

$$a = -0.110 + 0.235\cos\varphi + 0.323\frac{n}{\bar{N}} \quad (4)$$

$$b = 1.449 - 0.553\varphi - 0.694\frac{n}{\bar{N}} \quad (5)$$

(a and b are the regression coefficient)

Equation (2) is called the revised angstrom approach or the Angstrom-Prescott approach. This approach only involves sunshine duration and thus, it is quite convenient for application. In reality Angstrom–Prescott has been the most popular approach to estimating global radiation from sunshine duration. It is important to emphasis that (a) and (b) which are empirical parameters are sensitive to local latitude, elevation and climate (Kun *et al.*, 2006).

$$H_0 = \frac{24\times3600}{\pi} I_{SC}\left[1 + 0.033\cos\frac{360d}{365}\right]\left(\cos\varphi\cos\delta\sin w_s + \frac{\pi}{180} w_s\sin\varphi\sin\delta\right) \quad (6)$$

H_0 is the extraterrestrial radiation (radiation intensity outside the earth's atmosphere) measured in mega joule per square meter per day (MJm^{-2} day^{-1}), d is the day of the year i.e. the Julian day calculated every 15^{th} of each month.

$$w_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (7)$$

Where Ws is define as the sunset hour angle, φ and δ are the latitude and solar declination angle respectively, where δ is given by the relation

$$\delta = 23.45\sin(360\frac{284+d}{365}) \quad (8)$$

d is given by

$$d = INT\left(\frac{275\times M}{9}\right) - 1\times INT\left(\frac{M+9}{12}\right) + D - 30 \quad (9)$$

The expression for the Mean Bias Error (MBE) and Root Mean Square Error (RMSE) as stated by El-Sebail and Trabea, (2005) are;

$$RMSE = \left[\frac{\sum\left(\bar{H}_{i,cal} - H_{i,measured}\right)^2}{n}\right]^{1/2} \quad (10)$$

$$MBE = \left[\frac{\sum(\bar{H}_{i,cal} - H_{i,measured})}{n}\right] \quad (11)$$

MATERIALS AND METHODS

Methodology

This research would estimate the monthly the mean global solar radiation through routine meteorological data collected from Nigeria Meteorological Agency (NIMET) located at Nigeria College of Aviation Technology (NCAT) Zaria, Kaduna State Nigeria, with latitude 11.1333^0N and longitude 7.6800^0E. The mean monthly solar radiation and sunshine hour data was obtained for the period of 6years (2009-2014).

The average of the solar radiation and the sunshine duration data recorded using the Gunn-Bellani and Campbell-Stocks sunshine recorder respectively would be taken and used to develop Angstrom-Prescott model for estimating global solar radiation for Zaria.

Matlab Program

A MATLAB program which estimates the mean global solar radiation in Zaria was written and simulated using MATLAB (R2008 version). The program inputs the latitude of the area (φ), K which is one (1) for a common year and two (2) for a leap year, the month M(1-12), and the mean sunshine duration for the month (n). The program outputs the estimated mean solar radiation for the month (M) imputed.

```
[H_bar] = solar(phi,k,M,n)
% phi = [11.1333]; represent the latitude of the location.
% k = 1; where k is 1 for common year and 2 for leap year.
% M = 2; M represent the month in a year, example February is 2.
% n = 9.1; represent the sunshine duration in a day.
Isc = 1366;
pi_solar = 3.1416;
D = 15
d = floor((275*M)/9) - 1*floor((M+9)/12) + D - 30;
delta = 23.45*(sind(360*((284+d)/365)));
W = acosd(-(tand(phi))*tand(delta));
A = ((24*3600)/pi_solar)*Isc;
B = (360*d)/365;
C = (1 + (0.033*(cosd(B))));
E = (cosd(phi))*(cosd(delta))*(sind(W));
G=(pi_solar/180)*W*(sind(phi))*(sind(delt));
I = (E+G);
H_nut = ((A)* (C)* (I))/1000000;
N_bar = (2/15)*W;
S_bar = n/(N_bar);
H_bar = (0.3326+0.4510*(S_bar)*(H_nut)
```

RESULTS AND DISCUSSION

Table of Result

Table 1 shows the value of extraterrestrial solar radiation (H_0) and the corresponding mean monthly global solar radiation calculated.

Table 1: Calculated and Measured Values

Month	H_0	S_0	$\overline{H_I}, calculated$	$\overline{H_I}, measured$	Error	Error^2
January	31.2845	0.7885	21.5272	22.4000	-0.8728	0.7618
February	34.0650	0.7815	23.3325	24.2000	-0.8665	0.7508
March	36.6796	0.6116	22.3128	24.9000	-2.5872	6.6936
April	37.9643	0.5873	22.6790	24.0000	-1.3210	1.7450
May	37.7538	0.6151	23.0258	22.7000	0.3258	0.1061
June	37.2550	0.6008	22.4818	20.9000	1.5818	2.5020
July	37.3471	0.5322	21.3827	18.7000	2.6827	7.1969
August	37.6819	0.4045	19.3819	18.2000	1.1819	1.3969
September	36.8953	0.5810	21.9358	21.2000	0.7358	0.5414
October	34.6482	0.6902	22.3058	23.0000	-0.6942	0.4819
November	31.8080	0.8543	22.8320	24.2000	-1.3369	1.7873
December	30.3778	0.8282	21.4477	22.7000	-1.2523	1.5683

Root Mean Square Error (RMSE) and Mean Bias Error (MBE) were obtained as;

$$RMSE = \left[\frac{\sum_1^{12}(\overline{H}_{i,cal} - H_{i,measured})^2}{n}\right]^{1/2} = \frac{25.5320}{12}^{1/2} = 1.4542$$

$$MBE = \frac{\sum_1^{12}(\overline{H}_{i,cal} - H_{i,measured})}{n} = \frac{-2.4229}{12} = -0.2019$$

The parameters for analysis of this work are presented in the table 2

Table 2: Parameters for Analysis

Month	H_0	$\overline{H}_I$,	$K_T = \frac{\overline{H\iota}}{H_0}$	$S_0 = \frac{\overline{n}}{\overline{N}}$
January	31.2845	21.5272	0.6881	0.7885
February	34.0650	23.3325	0.6849	0.7815
March	36.6796	22.3128	0.6083	0.6116
April	37.9643	22.6790	0.5974	0.5873
May	37.7538	23.0258	0.6099	0.6151
June	37.2550	22.4818	0.6035	0.6008
July	37.3471	21.3827	0.5725	0.5322
August	37.6819	19.3819	0.5144	0.4045
September	36.8953	21.9358	0.5945	0.5810
October	34.6482	22.3058	0.6438	0.6902
November	31.8080	22.8320	0.7178	0.8543
December	30.3778	21.4477	0.7060	0.8282

Plot of Results

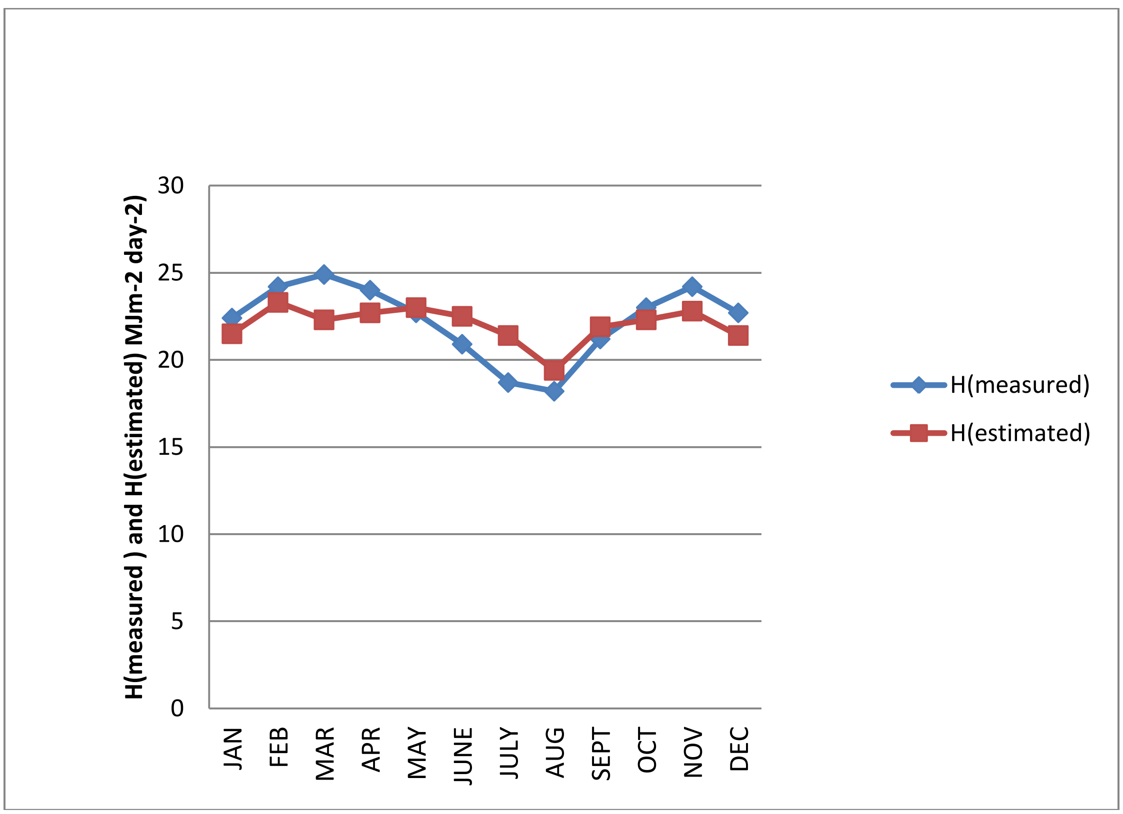

Figure 1: Relationship between the Measured and Estimated Monthly Mean Global Solar Radiation for Zaria, Nigeria

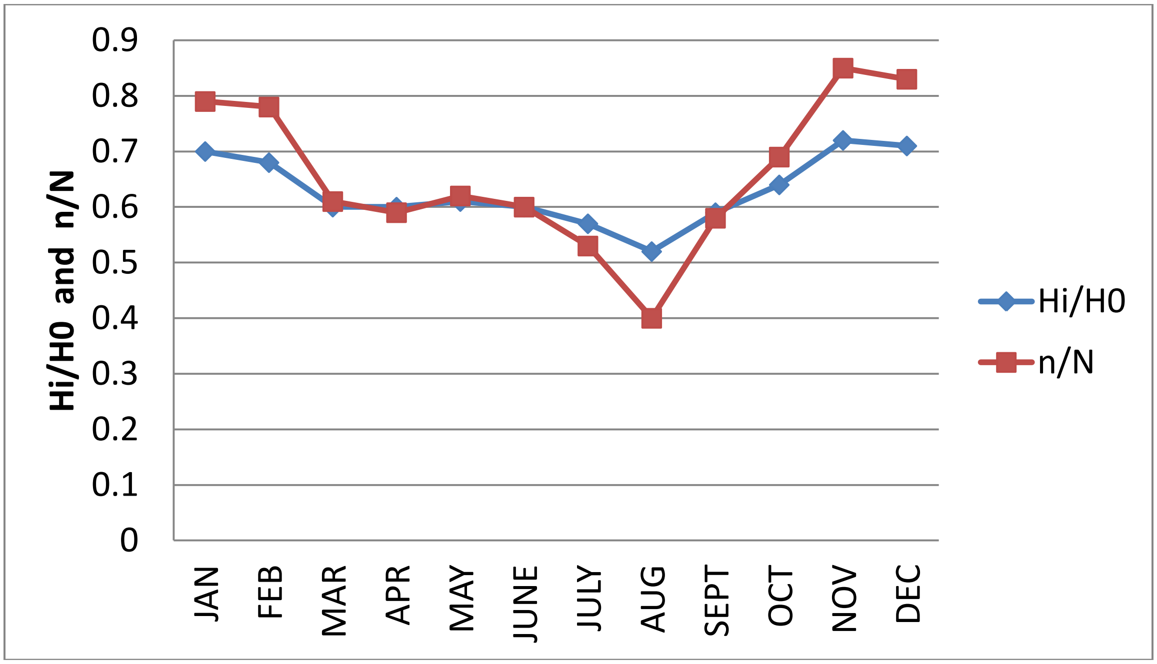

Figure 2: Shows the Relationship between the Clearness Index and the Relative Sunshine Duration in Zaria, Nigeria

Discussion

This research developed Angstrom Prescott model that estimate the monthly mean global solar radiation in Zaria using data obtained from Nigerian Meteorological Agency office located at Nigerian College of Aviation Technology Zaria with latitude 11.1333 ^{0}. The latitude, monthly mean sunshine duration, were used as input parameters. The angstrom Prescott model developed for Zaria was found as;

$$\overline{H_I} = (0.3325 + 0.4510S_0)H_0$$

Where 0.3325 and 0.4510 are the coefficient of correlation **a** and **b** respectively.

It can be seen from table 2, that the highest value of the clear sky index (k_T=0.7178) corresponds to the highest value of the relative sunshine duration (0.8543) while the lowest value of the clear sky index (K_T=0.5144 in August) corresponds to the lowest value of the relative sunshine duration (0.4045). This further shows that in August there is lower sunshine and lower solar radiation which is as a result of the raining season between June to September.

Figure 2 shows the relationship between the estimated and measure solar radiation. The root mean standard error (RMSE) between the estimated and measured monthly mean solar radiation was found to be 1.4542 which shows a good agreement between the estimated and measured values. Figure 2 shows that both the estimated and measured solar radiation vary correspondingly, except for March and April where the measured is more than the estimated. This could be as a result of variability in atmospheric condition during measurement. January and December shows a slight decline in both the estimated and measured monthly mean global solar radiation which is as a result of the harmattan dust which diffuses the solar radiation.

Conclusion

The objectives of this study was to estimate mean global solar radiation in Zaria using Angstrom Prescott model, write a MATLAB program that simulates the monthly mean global solar radiation and estimate the Angstrom regression constants for Zaria. The results obtained in this research clearly show that am empirical model for estimation of monthly global solar radiation is $\overline{H_I} = (0.3325 + 0.4510S_0)H_0$ for Zaria with a regression coefficient **a** and **b** as 0.3325 and 0.4510 respectively, the results and the plotted graphs show that the Angstrom-Prescott model is suited to estimate the global solar radiation in Zaria as a result of the MBE and the RMSE which fall within acceptable ranges. The MATLAB program written was simulated and found to estimate the monthly mean solar radiation correctly. This work is useful to solar energy researcher and engineers

REFERENCES

Agbo GA, Baba A and Obiekezie TN (2010). Model for the Correlation of Monthly Average Global Solar Radiation with Sunshine Hour at Minna Niger State, Nigeria. *Journal of Basic Physical Research* **1**(1) 41-47.

El-Sebail AA and Trabea AA (2005). Estimation of Global Solar Radiation on Horizontal Surface over Egypt. *Egyptian Journal of Solids* **28** 166.

Innocent AJ, Jacob OE, Chibuzo GC, James L and Odeh DO (2015). Estimation of Global Solar Radiation in Gusau Nigeria. *International Journal of Research in Engineering and Technology* **3**(2) 27-32.

Julian C (2011). *Physics of Solar Energy*, (John Wiley and Sons, New Jersey, USA) chapters 1, 2, 4 and 5.

Kaufmann C (2008). *Fundamental Principles of Energy*. Available: WWW.EOEARTH.ORG/VIEW/ARTICLE/5893.

Okonkwo GN and Nwokoye AOC (2014). Estimating Global Solar Radiation from Temperature Data in Minna. *European Scientific Journal* **10**(15) 255-264.

Pidwirmy M (2006). *Fundamentals of Physical Geography*, (University of British Columbia, Okanagan, Canada) Chapters 1 and 2.

Yang K, Koike T, Huang G and Tamail N (2006). *Recent Development in Solar Energy*, (Nover Science Publisher, Tokyo, Japan) Chapter 1.