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A Simulation Model for Estimating Solar Radiation of Nasarawa, Nasarawa State – Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MAA designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author JSI managed the analyses of the study while author HAI managed literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A simulation model for forecasting solar radiation in Nasarawa (Latitude of 8° 31' 45" N, Longitude of 7° 43' 27" E) was developed using empirically established Angstrom equation. The parameters measured were solar radiation intensity (W/m^2) and hours of bright sunshine from 06.00 H to 18.00 H daily for the months of January to December 2013. The regression constants 'a' and 'b' were obtained to be 0.01 and 0.75 respectively. The performance of 'a' and 'b' were tested using Root mean square error (RMSE), Normalized root mean square error (NRMSE) and Nash-Sutcliffe coefficient (E).The developed empirical model for estimating solar radiation for Nasarawa was $H_m = H_0\left[0.01 + 0.75\left(\frac{n}{N}\right)\right]$ with a coefficient of correlation of 0.79. After establishing this model as being accurate for forecasting solar radiation in Nasarawa, a program in Visual basic. NET was written to this effect and a software was compiled using the program. This software titled "NasRadd" can be used with confidence on windows based systems to predict solar radiation in Nasarawa.

Keywords: Solar radiation; sunshine hours; simulation; visual basic; Nasarawa; Nigeria.

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1. INTRODUCTION

The rate at which energy is emitted from the Sunis equivalent to the energy coming from a furnace at a temperature of about 6,000 K. If we could harvest the energy coming from just 101,171 m^2 (10 hectares) of the surface of the Sun, we would have enough to supply the current energy demand of the world [1].

However, there are three important reasons why this cannot be done. First, the earth is displaced from the Sun, and since the Sun's energy spreads out like light from a candle, only a small fraction of the energy leaving an area of the sun reaches an equal area on the earth. Secondly, the earth rotates about its polar axis, so that any collection device located on the earth's surface can receive the Sun's radiant energy for only about one-half of each day. The third and least predictable factor is the condition of the thin shell of atmosphere that surrounds the earth's surface. At best, the earth's atmosphere accounts for another 30 percent reduction in the Sun's energy.

The rate at which solar energy reaches a unit area at the earth is called the "*solar irradiance"* or "*insolation".* The units of measure for irradiance are Watts per square meter (W/m^2). Solar radiation is simply the integration or summation of *solar irradiance* over a time period. The designer of solar energy collection systems is also interested in knowing how much solar energy has fallen on a collector over a period of time such as a day, week or year. This summation is called *solar radiation or irradiation.* The units of measure for solar radiation are Joules per square meter (J/m^2) but often Watt-hours per square meter (Wh/m^2) are used [1].

The limited coverage of radiation measuring networks, and number of solar radiation measuring stations cannot describe the necessary variability. New models and improvements on existing modeling techniques are continually offered in order to improve estimates of solar radiation values with the use of more readily available meteorological variables [2]. These include; estimation of global solar radiation using Angstrom-type models (linear-type) [3,4], estimation of global solar radiation using higher order correlations [5], and estimation of global solar radiation based on ambient temperature [6].

The Angstrom linear type modelis the most widely accepted and used numerical method of determining the monthly average daily global solar radiation in a location. The regression constants of this equation 'a' and 'b' are specific to a particular location. Constants 'a' and 'b' refer to the fractions of the extraterrestrial radiation that is diffused (scattered) and direct (beam) respectively. The determination of these constants enables the determination of the global solar radiation for the location whose solar radiation information is required [7].

Therefore, this study is targeted towards developing the model of the Angstrom-Page equation from measured, computed and simulated parameters based on the regression constants of Nasarawa to determine solar radiation for the latter.

Nasarawa is located in Nasarawa State at latitude of 8° 31' 45" N and longitude of 7° 43' 27" E. The town is characterized by a tropical sub-humid climate with two distinct seasons. The wet season begins around May and ends in October and the dry season is between November and April. Most of the rain falls between May and September, with the wettest month being July and August. Here, the rain comes with thunder storms of high intensity especially at the beginning and at theend of the rainy season. Temperatures are generally high at day time especially between the month of March and April [8,9].

2. MATERIALS AND METHODS

The location for taking readings was carefully selected in Nasarawa town so that there was no obstructions of wind and no sunshine obstruction. The ground was leveled horizontally with a plumb line. A metal cabinet of 1.32 meters height was arranged. The position for each measuring device was marked on the top surface of this cabinet. A Daystar DS-05A solar meter was used to measure solar radiation on hourly basis from January to December of 2013. The meter is digital and has an accuracy of ±3% (0 – 1200 W/m^2) in natural sunlight. The sunshine duration is the sum of all the period during the day when the direct solar radiation measured is equal to or above 120 W/m^2 [10]. This was noted daily for the period of this work.

The maximum and minimum temperatures recorded daily were measured by suspending the thermometer at a height of 1.80 meters above the ground level. Readings of these were taken at 18:00 hour daily from January 1st 2013 to

December 31st 2013. A portable Thompson and Company digital hygrometer was placed in its position beside the solarimeter and used for the corresponding relative humidity readings.

Software for solar radiation for Nasarawa was then developed. The program was written using Microsoft Visual studio .NET 2013. The main inputs were the date to which solar irradiation value has to be estimated and latitude of Nasarawa town. The remaining calculations were done using the Angstrom equations. After necessary debugging, the program was later compiled into software for installation purposes.

The estimation of monthly average of daily global solar radiation on horizontal surface was made employing the Angstrom-Prescott Regression Equation (Basu 2012). The analysis of this equation was carried out using the following statistical tools at 10% significant level:

a. Correlation coefficient (r)
b. Coefficient of determination (r^2)
c. Root mean square error (RMSE)
d. Normalized root mean square error (NRMSE)
e. Nash-Sutcliffe coefficient (E)

The Angstrom- Prescott regression equation is given as

$$\frac{H_m}{\bar{H}_0} = a + b\left(\frac{n}{N}\right) \quad (1)$$

Or

$$H_m = H_0\left[a + b\,\left(\frac{n}{N}\right)\right] \quad (2)$$

Where

$$H_0 = \frac{24(60)G_{sc}d_r}{\pi}(\omega_s sin\varphi sin\delta + cos\varphi cos\delta sin\omega_s) \quad (3)$$

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

$$\delta = 0.409sin\left(\frac{2\pi J}{365} - 1.39\right) \quad (5)$$

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

$$N = \frac{24\omega_s}{\pi} \quad (7)$$

Where

H_m = monthly mean of the daily global radiation on a horizontal surface (MJ/m^2)
H_0 = extraterrestrial solar radiation on the 15th of month (MJ/m^2)
n = number of monthly mean of the daily hours of bright sunshine
N = the maximum daily hours of sunshine (or day length) 'a' and 'b' = regression coefficients
G_{sc} = solar constant = 0.0820 (MJ/m^2/min)
d_r = inverse relative distance earth – sun
δ = solar declination (rad)
φ = latitude of the place (rad)
ω_s = sunset hour angle (rad)
J = day number from January 1st
$\frac{n}{N}$ = fraction of maximum possible numbers of bright sunshine hours
$\frac{H_m}{H_0}$ = atmospheric transmission coefficient, commonly known as clearness index

3. RESULTS AND DISCUSSION

3.1 Climatological Data of Nasarawa

In order to utilize solar energy for useful and efficient applications, knowledge of the localweather parameters is important.

Table 1 shows the measured solar radiation for the months of January to December for Nasarawa with the mean being 239.14 W/m^2. The highest global solar radiation value of 288.64 W/m^2 was observed in April while the lowest value of 164.95 W/m^2 was in August.

Table 1. Summary of the measured solar radiation (H_m) parameters from january to december 2013 for nasarawa nigeria

Month	H_m (W/m^2)
January	281.9
February	242.29
March	281.2
April	288.64
May	264.38
June	258.83
July	169.96
August	164.95
September	172.3
October	208.62
November	236.83
December	299.74
Mean	**239.14**

Source: Data collected

The sunshine data is one of the best parameter to estimate the available solar radiation for a particular place. The numbers of monthly means of the daily hours of bright sunshine for periods of January to December 2013 are presented in

Table 2. Fig. 1 shows the diagrammatical representation of the same data.

Measurement of solar radiation of Nasarawa showed that a total bright sunshine hour of 3,012 from January to December 2013 was recorded. The maximum of 297 hours were recorded for the month of April, whereas a minimum of 183 hours were recorded for the month of July. The reason for these values is not far-fetched from the fact that July to October is the wettest period of the rainy season and December to June is generally classified as thedry season.

The movement of the earth around the sun is such that the sun is in the North hemisphere in the months of April. This brings the earth closer to the sun in this period [11], [12]. This could be responsible for these observations. Also, July to October recorded the lowest values of solar radiation in Nasarawa. The low solar radiation here is directly attributed to this season being the peak of the rainy season. December to June had good solar radiation distribution and April being the peak of the dry season, harmattan has completely gone and wet season is about to begin.

Table 2. Monthly total and monthly average hours of bright sunshine per day for nasarawa

Month	Total bright sunshine hours (hrs)	Day length (n) (hrs)	Range
January	298	9.61	175.93
February	269	9.25	167.61
March	274	9.79	218.07
April	297	9.9	239.54
May	284	9.47	341.84
June	245	9.09	202.84
July	183	6.71	91.23
August	200	6.67	105.69
September	207	6.9	186.69
October	269	8.68	116.30
November	227	9.9	96.53
December	259	9.96	101.30

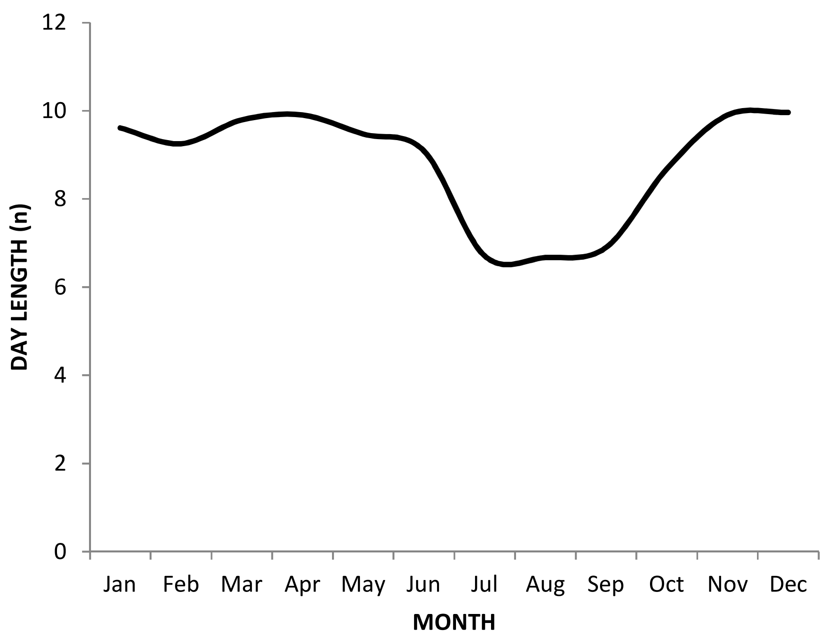

Fig. 1. Monthly total and monthly average hours of bright sunshine per day for Nasarawa

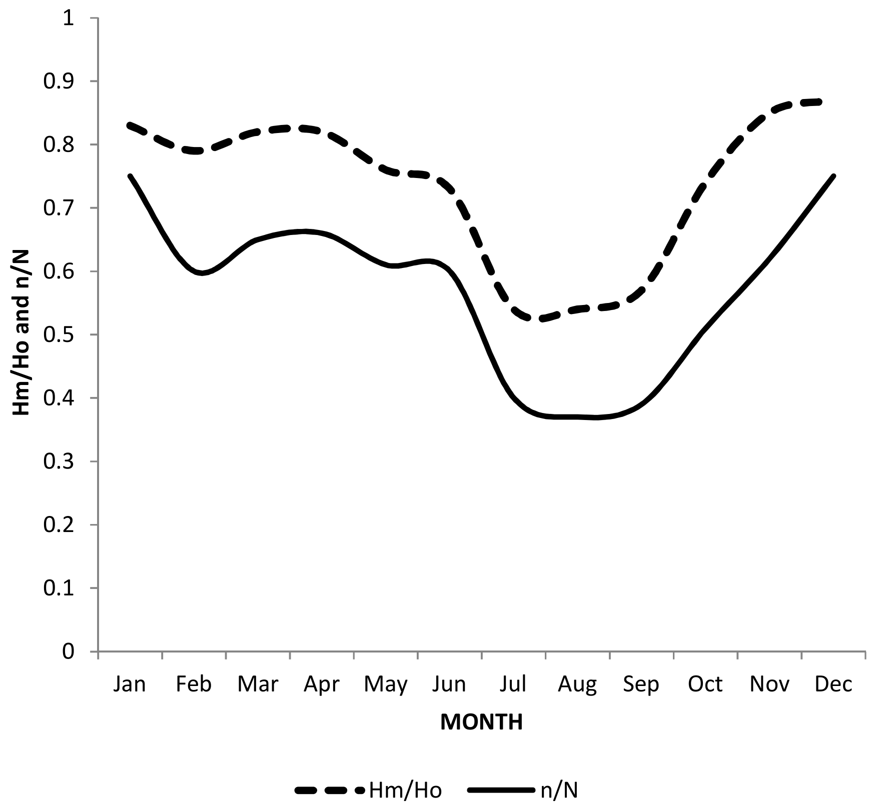

Fig. 2. Comparison of clearness index to relative sunshine duration of Nasarawa in 2013

From the above analysis, the model constants of 'a' and 'b' were 0.01 and 0.75 respectively. The model equation obtained is as stated below:-

$$H_m = H_0 \left[0.01 + 0.75 \left(\frac{n}{N}\right)\right]$$

The Pearson Correlation Coefficient (r) is 0.88, Coefficient of Determination (r^2) is 0.9384, RMSE, NRMSE and E of the determined equation are 9.06%, 0.04% and 0.66 respectively. These indices indicate that the model can be used with a high degree of confidence to predict solar radiation for Nasarawa.

The highest and lowest global solar irradiance values of 288.64 W/m^2 and 164.95 W/m^2 were respectively observed in April and August of 2013 in Nasarawa. These agree with the usual weather pattern of the location with August being in the heart of the rainy season.

It should be noted that the variation of cloudiness is primarily responsible for the day to day variation of the daily total radiation during the whole month [13]. The average clearness index K_T over the year is shown in Fig. 3. The index has a minimum value of 0.37 corresponding to lowest solar radiation value of 164.95 W/m^2 in the month of August, indicating the presence of thick clouds cover.

In the top dry season months, April, the sky is very clear with K_T of 0.66 which corresponds to the highest value of solar irradiance recorded value of 288.64 W/m^2 which allows on the average nearly 60 percent of the extraterrestrial radiation to reach the earth's surface.

3.2 Comparative Analysis of Measured H_m (Measured) and Predicted H_m (Calculated) Solar Radiation Using the Determined Model

Statistical tests conducted to ascertain the degree of accuracy for the measured (H_m) and the predicted (H_{cal}) solar irradiance in Table 3 obtained from the developed model equation. Fig. 3 shows the graphical representation of the measured and calculated solar irradiance also confirms the strong agreement between the measured and predicted solar radiation of Nasarawa.There were some discrepancies between them with the measured data being higher than the calculated ones during the first half of the year with a mean value between 10 - 15%. The opposite was observed in the later part of the year. This implies that there is a possibility of under-prediction and over-prediction in the computation during the respective periods. This could be a strength of the prediction process.

Table 3. Summary of the measured and calculated solar radiation parameters from january to december 2013 for nasarawa nigeria

Month	H_m (W/m^2)	H_0 (W/m^2)	Total bright sunshine hours (hrs)	n (hrs)	N (hrs)	$K_T = \frac{H_m}{H_o}$	$\frac{n}{N}$	H_{cal} (W/m^2)
January	281.9	378.08	298	9.61	11.56	0.75	0.83	235.95
February	242.29	400.95	269	9.25	11.71	0.54	0.71	239.98
March	281.2	428.75	274	9.81	11.95	0.65	0.82	264.16
April	288.64	435.6	297	9.87	12.18	0.66	0.81	265.11
May	264.38	430.29	284	9.45	12.39	0.61	0.76	246.38
June	258.83	421.72	245	9.14	12.46	0.61	0.69	232.08
July	169.96	424.67	183	6.71	12.44	0.40	0.54	171.95
August	164.95	430.14	200	6.74	12.25	0.39	0.55	177.95
September	172.3	427.69	207	6.97	12.03	0.40	0.58	199.00
October	208.62	409.3	269	8.68	11.8	0.51	0.74	225.93
November	236.83	382.64	227	9.87	11.6	0.46	0.63	245.86
December	299.74	367.91	259	9.96	11.51	0.68	0.73	239.33
Mean	**239.14**	**411.48**	**251**	**8.84**	**11.99**	**0.56**	**0.7**	**228.64**
Std. Dev.	**49.04**	**23.52**	**38.65**	**1.28**	**0.353**	**0.123**	**0.103**	**30.42**

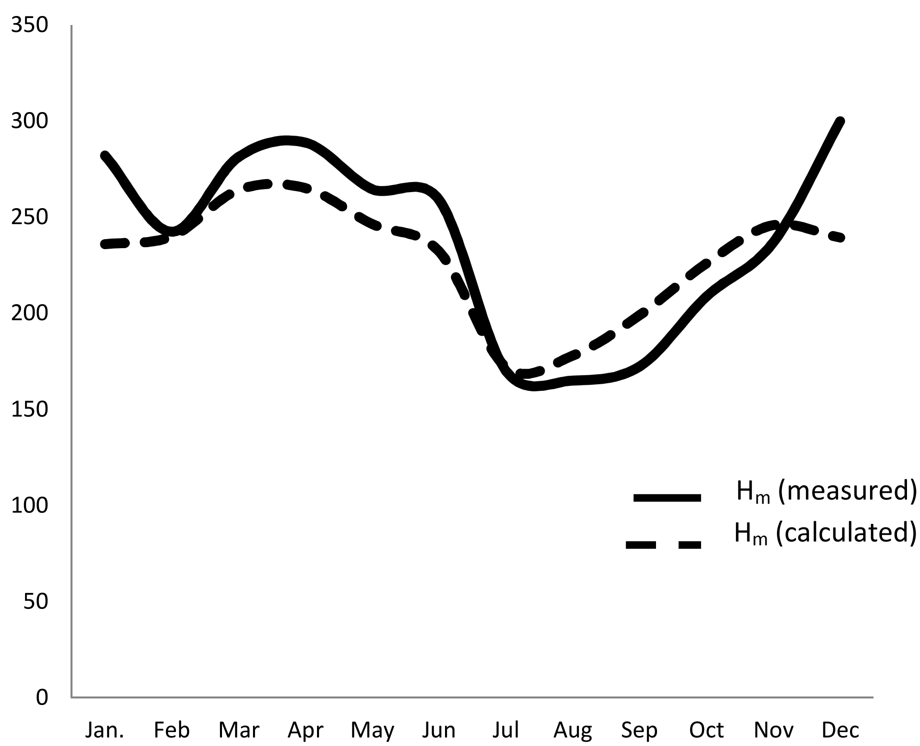

Fig. 3. Comparative analysis of Measured H_m (Measured) and predicted H_m(Calculated) solar radiation using the determined model

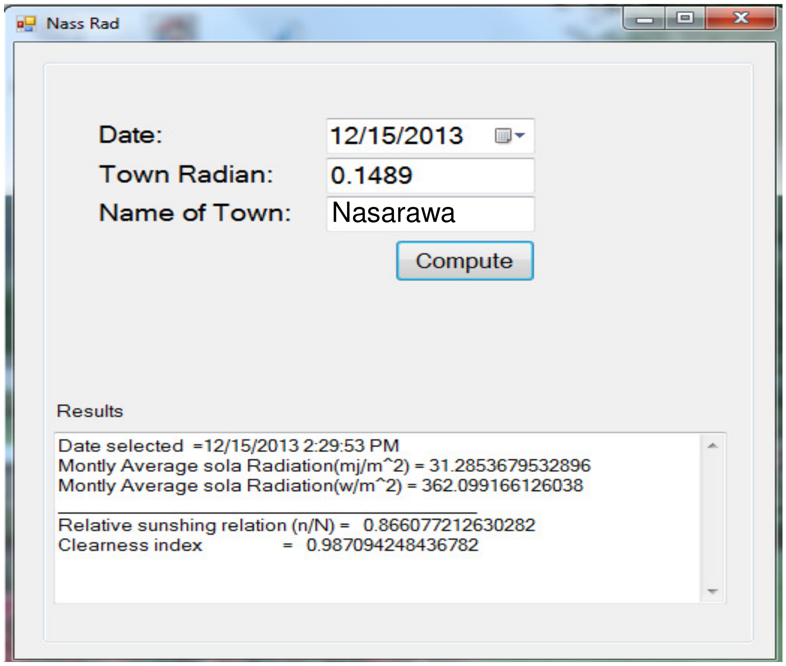

Fig. 4. The programme interface of the developed software

3.3 The Nas Rad Software

Since there is strong agreement between measured and predicted values of the solar radiation of Nasarawa, the program was then written and subsequently software was developed. The program interface of the software is as shown in Fig. 4 (above).

From the interface the monthly average solar radiation is given in MJ/m^{-2} and W/m^{-2}, relative sunshine relation and clearness index (K_T) are being displayed for easy reading.

4. CONCLUSION

Solar radiation of Nasarawa, Nasarawa state Nigeria were collected for a full year (2013) on hourly basis. A model was developed from this data to predict the solar radiation of Nasarawa. From this model, a computer program was written and software that can be installed and run on Windows based computer was created for the prediction of Nasarawa radiation.

The model is developed using Angstrom page linear regression equation type. The constants 'a' and 'b' are 0.01 and 0.75 respectively. The model equation developed is as stated below:

$$H_m = H_0 \left[0.01 + 0.75 \left(\frac{n}{N}\right)\right]$$

The highest and lowest global solar radiation values of 288.64 W/m^2 and 164.95 W/m^2 were respectively observed in April and August of 2013 in Nasarawa (Nigeria).

From this study, the prospects of application and efficient utilization of solar energy seems to be very bright. The sun shines for about 3000 hours per year and this abundance of sunshine is an indication of clear sky condition in Nasarawa. This is also confirmed from the high clearness index (K_T) throughout the year. It is hereby recommended that the software developed should be updated to be capable of predicting solar radiations for other locations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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