

Original Research Article

A SIMULATION MODEL FOR ESTIMATING SOLAR RADIATION OF NASARAWA, NASARAWA STATE – NIGERIA

Abstract

A simulation model to forecast solar radiation of Nasarawa (Latitude of 8° 31' 45" N, Longitude of 7° 43' 27" E) was developed using empirical 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 determining the 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 of Nasarawa, a program in Visual basic .NET was written to this effect and a software was compiled from this program. This software titled "Nas Radd" can be used with confidence on windows based systems to predict the solar radiation of Nasarawa.

KEYWORDS: *Solar Radiation, Sunshine Hours, Simulation, visual basic and Nasarawa, Nigeria*

INTRODUCTION

The rate at which this energy is emitted is 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. Second, 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 which intend 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 is 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. Constant 'a' and 'b' refer to the fraction of the extraterrestrial radiation that is diffused (scattered), and fraction of the extraterrestrial radiation that is direct (beam) respectively. The determination of these constants will enable the determination of the global solar radiation for that location whose solar radiation information is required [7].

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

Nasarawa is located in Nasarawa state at latitude of $8^{\circ} 31' 45''$ N and longitude of $7^{\circ} 43' 27''$ 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 end of the rainy season. Temperatures are generally high at day time especially between the month of March and April. [8].

Visual Basic .NET (VB .NET)

VB .NET is a programming language designed to create applications that work with Microsoft's new .NET Framework. The .NET platform in turn aims at addressing many of the limitations of "classic" COM, Microsoft's Component Object Model, which provided one approach toward application and component interoperability. In contrast to VB, with its reliance on COM, VB .NET offers a number of new features and advantages. Let's take a look at some of these [9].

METHODS AND PROCEDURES

The Angstrom- Prescott regression equation is given as

$$\frac{H_m}{H_0} = a + b \left(\frac{n}{N} \right) \quad (1)$$

Or

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

Where

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

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

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

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

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

Where

H_m = monthly mean of the daily global radiation on a horizontal surface (MJ/m²)

H_0 = extraterrestrial solar radiation on the 15th of month (MJ/m²)

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/m²/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

[10](NRM & E Department, 1998).

Ra is expressed in the above equation in MJ /m²/day. The corresponding equivalent

The latitude, ϕ , expressed in radians is positive for the Northern hemisphere and negative for the Southern hemisphere.

The conversion from decimal degrees to radians is given by:

$$\text{Radians} = \frac{\pi}{180} (\text{decimaldegrees}) \quad (8)$$

Developing the Nasarawa solar radiation software

The program was written using Microsoft Visual studio .NET 2013. The main inputs were date and latitude of Nasarawa or town having similar solar parameter. The day number is calculated based on either the year is a normal year or a leap year. This is decided by judging if the date year is dividable by four (4) or not. Thereafter, the remaining calculations are done based on the

Angstrom equations.

After necessary debugging, the program was later compiled into software for installation purposes.

Analysis Procedures

The estimation of monthly average of daily global solar radiation on horizontal surface was made, employing the Angstrom- Prescott Regression Equation.

The analysis of this equation was made using the following statistical tools: -

- a. Correlation coefficient (r)
- b. Coefficient of determination (r^2)
- c. Significant level at 10%
- d. Root mean square error (RMSE)
- e. Normalized root mean square error (NRMSE)
- f. Nash-Sutcliffe coefficient (E)

RESULTS AND DISCUSSION

Climatological Data of Nasarawa

In order to utilize solar Energy for useful and efficient applications, knowledge of the weather parameters of that locale is important.

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

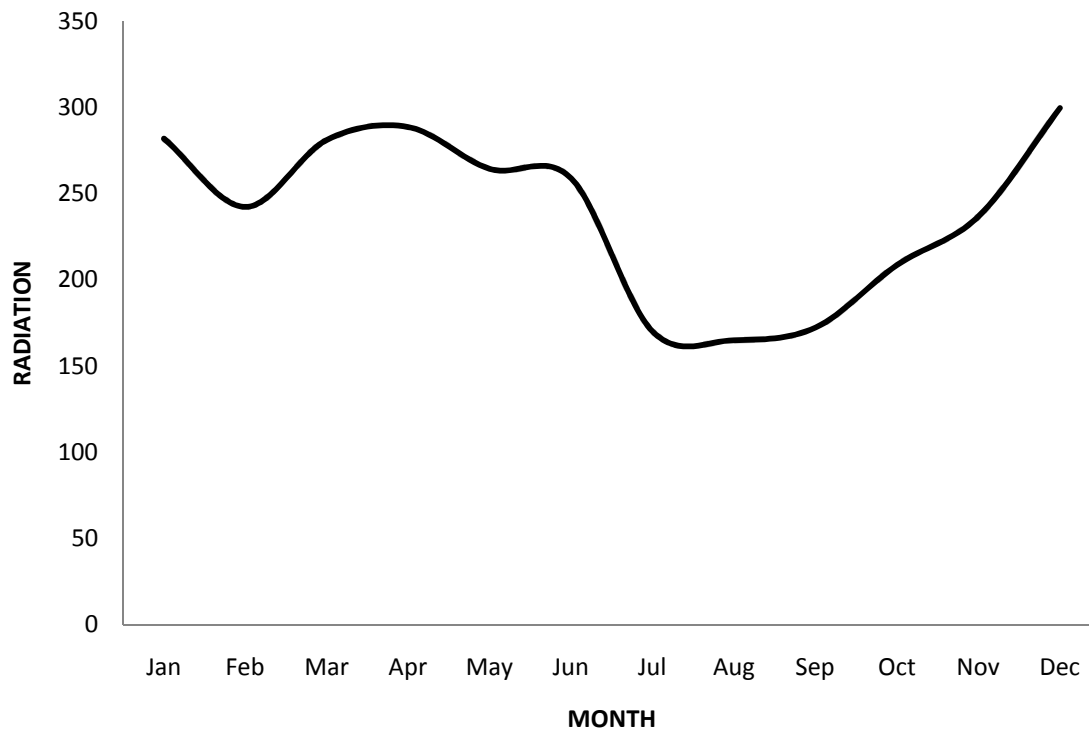


Fig. 1: Summary of the Measured Solar Radiation Parameters from January to December for Nasarawa

Table 1 shows the measured solar radiation for the months of January to December for Nasarawa with the mean being 239.14 W/m². The highest global solar radiation value of 288.64 W/m² was observed in April while the lowest value of 164.95 W/m² was in August.

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

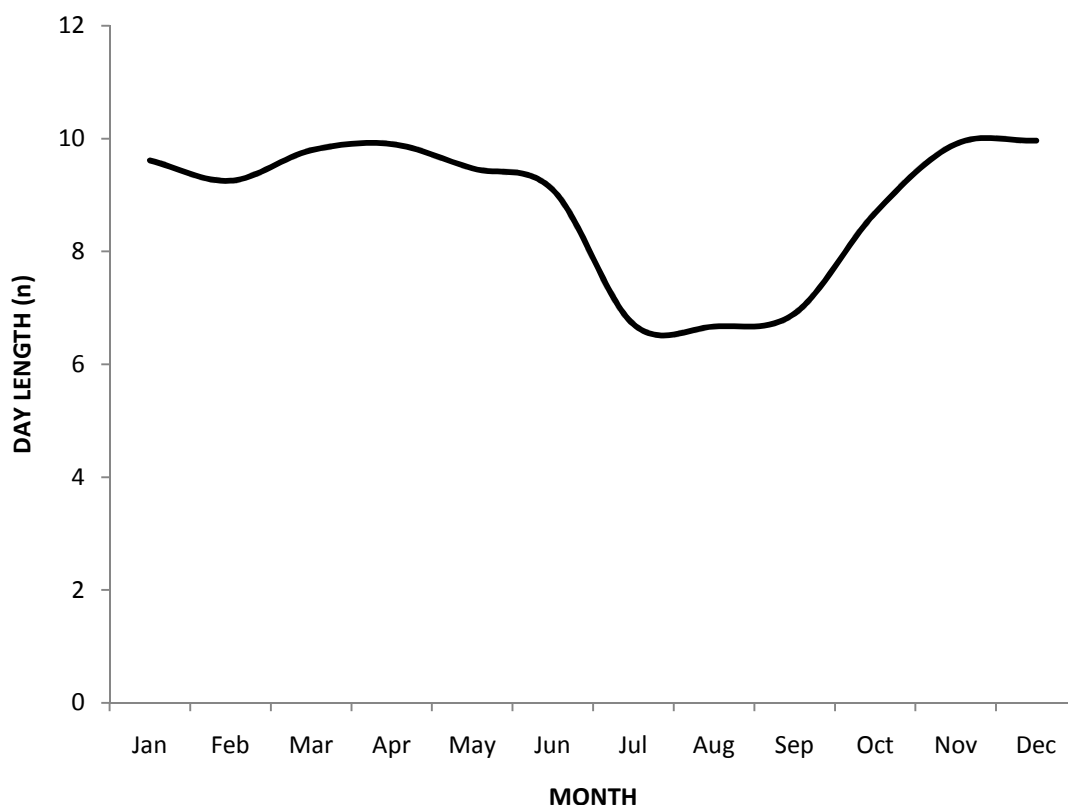


Fig. 2: Monthly Total and Monthly Average Hours of Bright Sunshine per Day for Nasarawa

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 were presented in Table 2 figure 2 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 fetch from the fact that July to October is the wettest period of the rainy season and December to June is generally classified as dry season.

All or parts of the following reasons could have been responsible for these observed values at these periods of the year: -

- i. 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].
- ii. 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 wettest period of

the rainy season. While December to June had good solar radiation distribution and April being the peak of the dry season, hamattan has completely gone and wet season is about to begin.

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 $= \frac{H_m}{H_0}$	$\frac{n}{N}$	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		8.84	11.99	0.56	0.7	228.64

From the above analysis, the model constants of ‘a’ and ‘b’ were 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 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 make is possible to use this model with confidence to predict solar radiation of Nasarawa.

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.

Sky Conditions of Nasarawa

It is to 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 years 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 radiation 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.

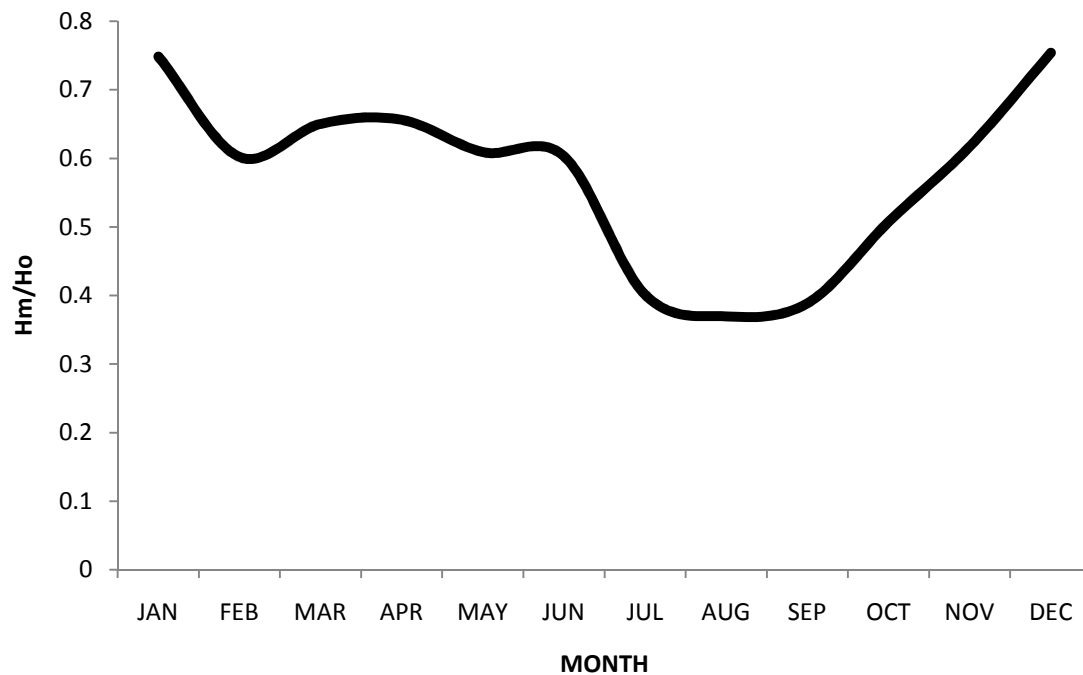


Fig. 3: Sky condition (K_T) of Nasarawa

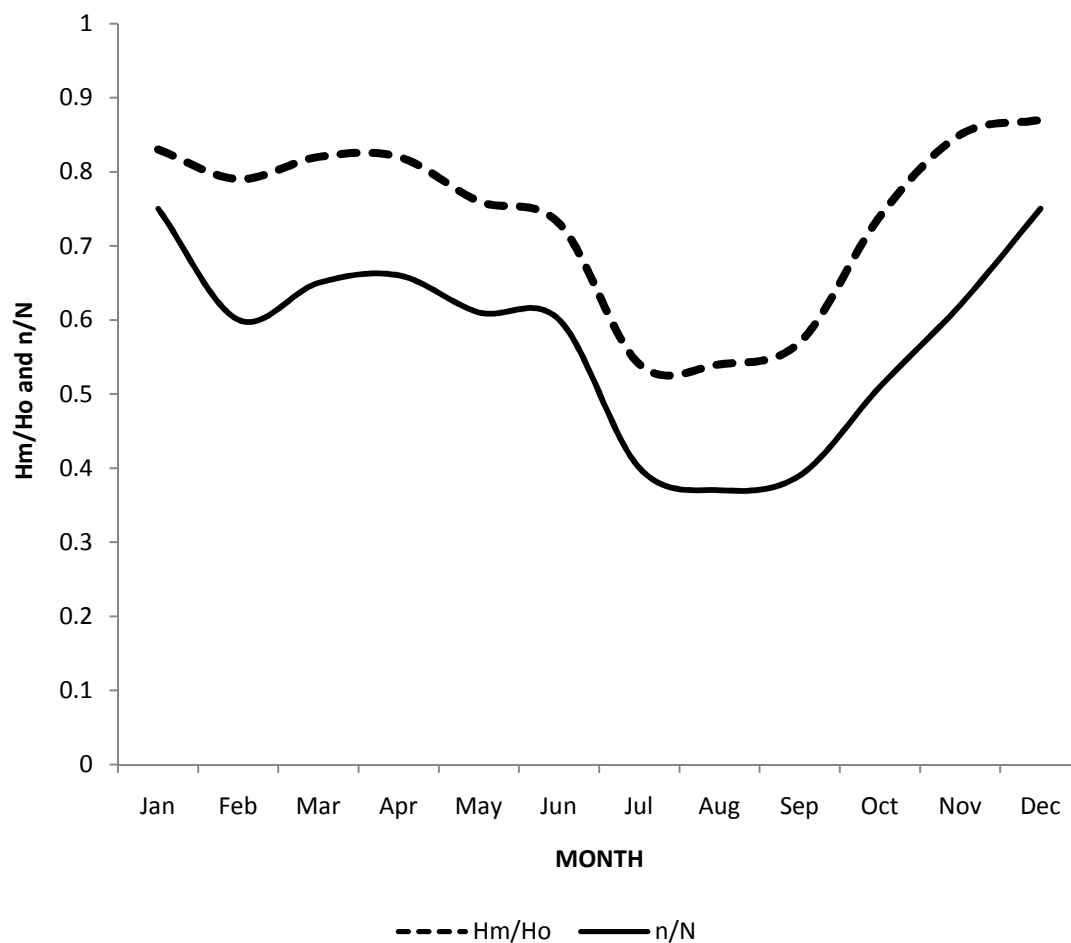


Fig. 4: Comparison of Clearness Index to Relative Sunshine duration of Nasarawa in 2013

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 radiation in table 3 obtained from the developed model equation.

Figure 5 that is the graphical representation of the measured and calculated solar radiation also confirms the strong agreement between the measured and predicted solar radiation of Nasarawa.

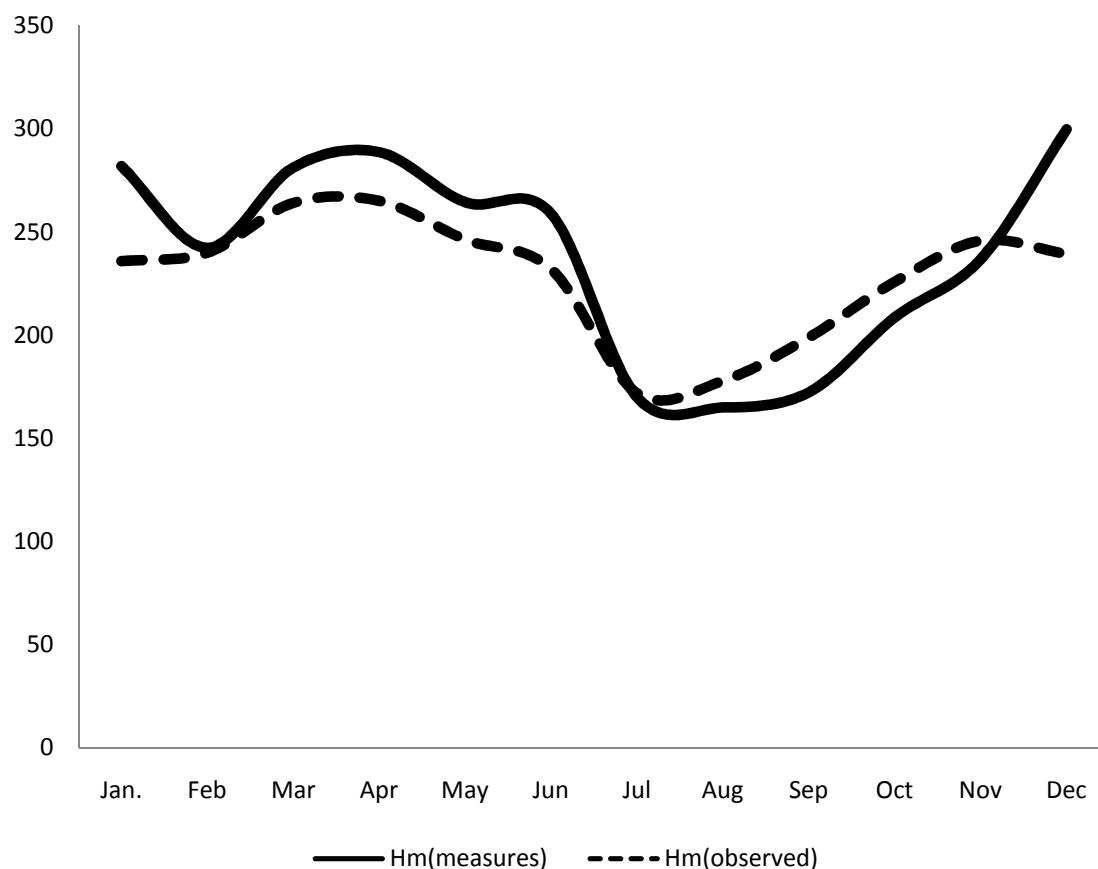


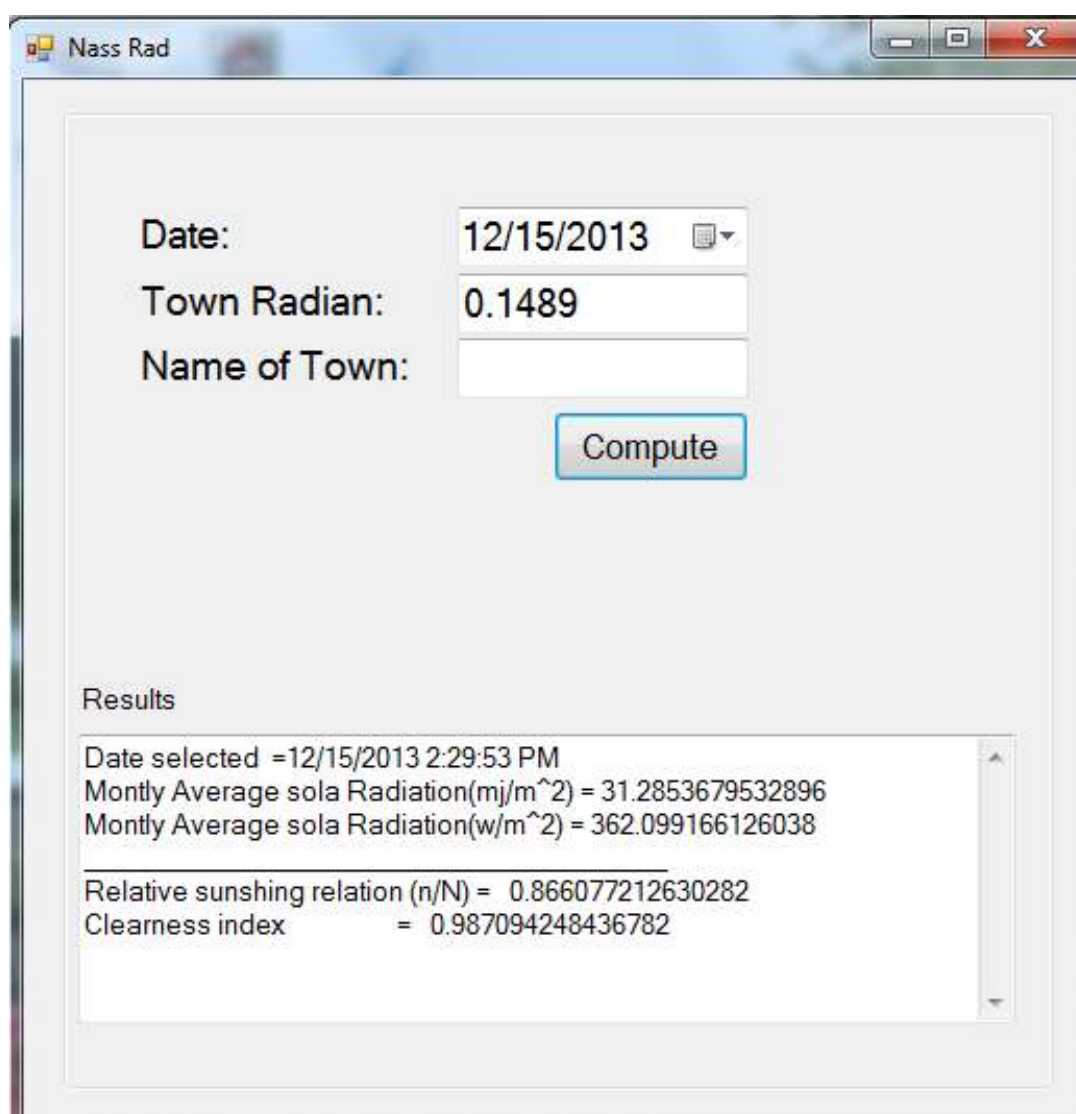
Fig. 5: Comparative Analysis of Measured H_m (Measured) and Predicted H_m (Calculated) Solar Radiation Using the Determined Model

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 plate below.

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THE PROGRAM INTERFACE



The screenshot shows a Windows application window titled "Nass Rad". It contains three input fields: "Date:" with the value "12/15/2013", "Town Radian:" with the value "0.1489", and "Name of Town:" which is empty. Below these fields is a "Compute" button. Underneath the button is a "Results" section containing a text box with the following text:

```
Date selected =12/15/2013 2:29:53 PM
Montly Average sola Radiation(mj/m^2) = 31.2853679532896
Montly Average sola Radiation(w/m^2) = 362.099166126038

Relative sunshing relation (n/N) = 0.866077212630282
Clearness index           = 0.987094248436782
```

237

238

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

241

242 Conclusion

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

247

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

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

250 The highest and lowest global solar radiation values of 288.64 W/m² and 164.95 W/m² were
251 respectively observed in April and August of 2013 in Nasarawa Nigeria.

252 From this study, the prospects of application and efficient utilization of solar energy seems to be
253 very bright. The sun shines for about 3000 hours per year and this abundance of sunshine is an
254 indication of clear sky condition in Nasarawa. This is also confirmed from the high clearness
255 index (K_T) throughout the year.

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