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ESTIMATION OF GLOBAL SOLAR RADIATION FROM SUNSHINE HOURS FOR WARRI, NIGERIA

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ABSTRACT

Multiple linear regression models were developed to estimate the monthly daily sunshine hours using four parameters during a period of eleven years (1997 to 2007) for Warri, Nigeria (Latitude of 5^o 34' 21.0''); the parameters include, Relative Humidity, Maximum and Minimum Temperature, Rainfall and Wind Speed. The result of the correlations showed that four Variable correlations with the highest value of correlation coefficient R gives the best result when considering the error term Root Mean Square Error (RMSE). The correlation is given as

$S = - 22.424 + 0.272RH + 1.388T – 9.791RF – 0.623W$

Where RH is the Relative Humidity, T is the difference of the Maximum and Minimum Temperature, RF is the average rainfall and W is the Wind Speed. The developed correlation can be used for estimating Sunshine hours for Warri and other locations with similar climatic conditions.

Key words: Sunshine hours, Relative humidity, rainfall, wind speed.

INTRODUCTION

Sunshine duration is one of the most widely measured and applied meteorological parameters. This is because it plays a very major role in the determination of global solar radiation data. It is also the parameter with the best correlation with global solar radiation, air temperature, relative humidity and other climatic factors.

In developing countries such as Nigeria, it has been very difficult measuring global solar radiation due to unavailability of equipment or non functioning of these equipments. Duration of sunshine has thus been used as an alternative way of estimating this parameter.

Sunshine duration is not only easy to use at networks of stations, it is relatively reliable. It enables spatial interpolation thus filling in gaps left by missing or unavailable data. One of the earliest correlations was proposed as far back as 1924 by Angstrom and relates global solar radiation to hours of bright sunshine.

Several empirical models have been developed to calculate global solar radiation using various parameters(Ahmad and Ulfat 2004; Akpabio et al 2004; Akpabio and Etuk 2002 ; Almorox et al 2008; Almorox and Hontoria 2004; Andretta et al 1982; Bahel et al 1987) . The parameter used as input in the calculations include, sunshine duration, mean temperature, soil temperature, relative humidity, number of rainy days, altitude, latitude, total precipitable water, albedo, atmostpheric pressure, cloudiness and evaporation. The most commonly used parameter for estimating global solar radiation is sunshine hours which can be easily and reliably measured, and data are widely available.

In this article, we develop equations that correlate monthly average daily sunshine hours with certain meteorological parameters for Warri in southern Nigeria. The applicability of the models is also examined.

METHODOLOGY

Monthly average sunshine hours, Relative Humidity, Maximum and Minimum

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Temperature, Rainfall data and Wind Speed data were obtained from the Nigerian meteorological Agency (NIMET) in Oshodi, Lagos. The data covered a period of Eleven Years (1997 to 2007). Uyo is located at a Lattitude of 5°18'53.7''N. Monthly averages (over the eleven year period) of the data in preparation for Correlation are presented in Table1.

Table1. Sunshine hours and relevant meteorological data for Warri.

MONTH	S	RH%	Tmax	Tmin	T°C	RF(mm)	W(m/s)
JAN	4.81	58.45	33.25	23.21	10.04	0.028	3.02
FEB	4.60	60.09	33.65	24.18	9.47	0.061	3.02
MARCH	4.60	66.73	33.52	24.53	8.99	0.187	3.15
APRIL	4.92	72.18	32.84	24.27	8.57	0.237	3.54
MAY	4.90	75.00	31.97	23.68	8.29	0.291	2.82
JUNE	3.72	79.27	30.61	23.47	7.14	0.392	3.23
JULY	2.27	83.91	28.91	22.95	5.96	0.423	3.19
AUG	2.45	82.00	29.02	23.32	5.70	0.312	3.48
SEP	2.48	82.18	30.05	23.34	6.71	0.451	3.50
OCT	4.25	76.36	31.45	23.39	8.06	0.281	3.06
NOV	5.68	69.27	32.70	24.44	8.26	0.105	2.79
DEC	5.24	62.55	32.87	23.62	9.25	0.021	2.95

Multiple linear regression equation for estimating S with four parameters is as follows
$Y = a + bx_1 + cx_2 + dx_3 + ex_4$
Where a …e, are the regression coefficients and x_i is the correlated parameter. The estimated values were compared to measured values in each regression equation through correlation coefficient R and standard error of estimate σ.

CORRELATIONS

The Various meteorological parameters shown in Table1 are all related to sunshine hours in varying degrees. In order not to overlook any particular parameter or group of parameters multiple linear regression of four parameters (RH, T, RF, W) were employed to estimate the sunshine hours. Here S is the monthly average daily sunshine hour, RH is the monthly average relative humidity in percentage, RF is the monthly average daily rainfall in meters, W is the monthly average daily wind speed in m/s.
The various linear regression analyses are as follows.

i. **One variable correlation**:

This correlation gives the highest value of R as 0.851 for T and lowest value of R as 0.652 for W.

$S = - 1.584 + 0.715T$ ($R = 0.851$, $\sigma = 0.64112$) (1)

$S = 13.548 – 2.984W$ ($R = 0.652$, $\sigma = 0.92702$) (2)

ii. **Two variable correlation**

The incorporation of one extra parameter to the sets of correlation equations for one variable yield the highest value of R for T and W and lowest value of R for RH and RF.

$S = 3.488 + 0.590T – 1.294W$ ($R = 0.885$, $\sigma = 0.60060$) (3)

$S = 7.417 – 0.031RH – 4.243RF$ ($R = 0.788$, $\sigma = 0.79360$) (4)

Iii **Three variable correlation**

The highest value of R is 0.943 for T, RH and RF and lowest value of R is 0.831 for RH, RF and W

$S = -26.758 + 0.297RH + 1.489T – 11.016RF$ ($R = 0.943$, $\sigma = 0.45280$) (5)

$S = 12.155 – 0.039RH – 2.449RF – 1.458W$ ($R = 0.831$, $\sigma = 0.76091$) (6)

Iv **Four Variable Correlation**

$S = -22.424 + 0.272RH + 1.388T – 9.791RF – 0.623W$ ($R = 0.950$, $\sigma = 0.45812$) (7)

RESULTS AND DISCUSSIONS

Equations (1), (3), (5), (7) have the highest value of correlation coefficient while equations (2), (4), (6) have the lowest values of R. however, the applicability of the proposed correlations is tested by estimating the sunshine duration values for Warri location used in the analysis. Estimated values of sunshine duration for Warri along with the measured data are shown in table2. Inspection of the table shows that the models estimate sunshine hours fairly accurately.

Table2 comparison of estimated and measured data for Warri

MONTH	**S**	**Eq1**	**Eq2**	**Eq3**	**Eq4**	**Eq5**	**Eq6**	**Eq7**
JAN	4.81	5.59	4.54	5.50	5.49	5.24	5.39	5.25
FEB	4.60	5.19	4.54	5.17	5.30	4.52	5.26	4.59
MAR	4.60	4.84	4.15	4.72	4.55	4.39	4.50	4.41
APRIL	4.92	4.54	2.98	3.96	4.17	4.83	3.60	4.58
MAY	4.90	4.34	5.13	4.73	3.86	4.61	4.41	4.88
JUNE	3.72	3.52	3.91	3.52	3.30	3.10	4.48	3.20
JULY	2.27	2.68	4.03	2.88	3.02	2.38	3.20	2.54
AUG	2.45	2.49	3.16	2.35	3.55	2.65	3.12	2.57
SEPT	2.48	3.21	3.10	2.92	2.96	2.76	2.74	2.65
OCT	4.25	4.18	4.42	4.28	3.86	4.83	4.03	4.88
NOV	5.68	4.32	5.22	4.75	4.82	4.96	5.13	5.12
DEC	5.24	5.03	4.75	5.13	5.39	5.36	5.36	5.39

The following observations can be made from a study of table3. based on the RMSE, equation (7) produces the best correlation while equation (2) gives the worst with larger value of RMSE. For MBE, the result shows that equations (1) and (3) is the best while equation (6) is the worst. With respect to MPE, equation (5) offers the best correlation while equation (2) gives the worst.

Table3 error calculations

Equations	**R**	**MBE**	**RMSE**	**MPE**
Eq1	0.851	0.00083	0.5855	3.3350
Eq 2	0.652	0.00170	0.8467	6.2083
Eq 3	0.885	-0.000833	0.5209	1.9800
Eq 4	0.788	0.02917	0.6851	4.6958
Eq 5	0.945	-0.02417	0.3761	0.4783
Eq 6	0.831	0.10833	0.6512	6.1725
Eq 7	0.950	0.01167	0.3495	1.2467

Since the MPE gives information on the long term performance of the examined regression equation, a positive MPE value provides the average amount of overestimation in the calculated values while a negative MPE value gives underestimation(Akpabio and Etuk 2002). On the whole, a low MPE is desirable. The test on RMSE conveys information on the short-term performance of the different equations since it enebles a term – by – term comparison of the actual variations between the estimated and measured values. For more accurate estimation, lower values of RMSE should be obtained(Akpabio and Etuk 2002)

R^2 denotes the multiple coefficient of determination, which is a measure of how well the multiple regression equation fits the sample data. A perfect fit would result in $R^2 = 1$. a very good fit results in a value near 1. a very poor fit results in a value of R^2 close to 0. The R^2 has serious flaws however; this is because, as more variables are included R^2 increases. This is not suppose to be so. Consequently, it is better to use the adjusted R^2 when comparing different multiple regression equations because it adjusts the R^2 value based on the number of variables and the sample size(Triola 1998)

For Warri location

$$S = - 22.424 + 0.272RH + 1.388T – 9.791RF – 0.623W$$

The value of R^2 = 0.902 in the equation indicates that 90.2% of the variation in sunshine hours can be explained by the relative humidity, temperature, rainfall and wind speed. Hence the adjusted R^2 value is 0.845. This shows that 84.5% of the variation in sunshine hours can be explained by the relative humidity, temperature, rainfall and wind speed.

Figure shows plots of equation (7) with the least value of RMSE together with the monthly average daily sunshine hours measured for eleven years.
Equation (7) shows almost exact fit to the sunshine hours data.

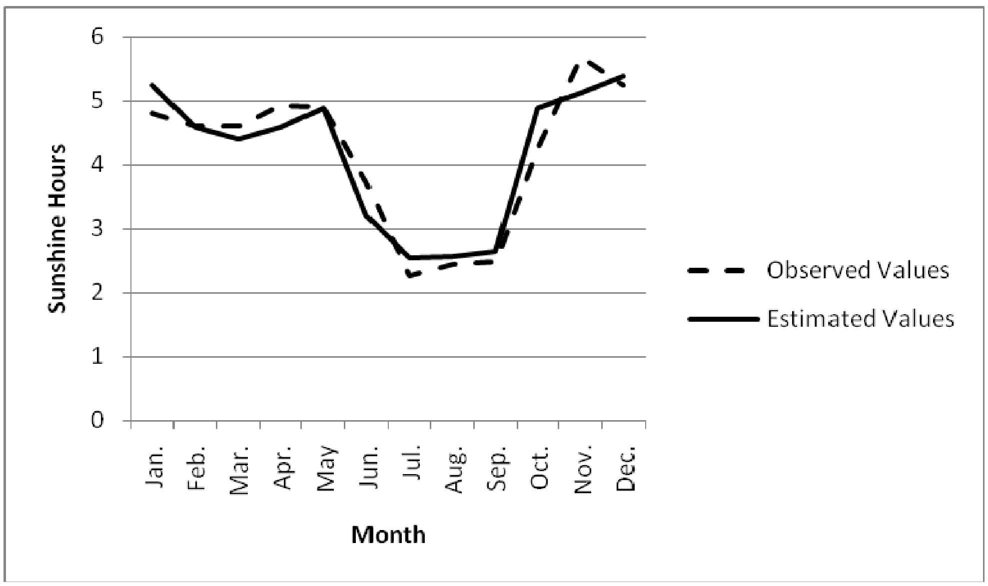

Figure1. Comparison of measured and estimated data of monthly average daily sunshine hours for Warri location.

Based on eq7 the values of global solar radiation (H), were computed and presented in table2.

Computation of Global solar radiation

The linear regression model used in computing Global solar radiation data is given after Angstrom (1924) and later modified by Page (1964);

$$H = H_o \{ a + b[S/S_o] \}$$

Where,
H is the monthly mean horizontal daily total terrestrial solar radiation.
H_o is the monthly mean horizontal daily total extraterrestrial solar radiation

$H_o = 24/\pi * I_{sc} [1 + 0.033Cos (360/365)*dn]*[(\boldsymbol{\omega} Sin\Phi\ Sin\delta) + (Cos\Phi Cos\delta Sin\boldsymbol{\omega})]$
I_{sc} = solar constant
δ= declination angle
Φ= latitude of the location of study
$\boldsymbol{\omega}$**=** sunset hour angle

And

$\omega = \text{Cos}^{-1}(-\tan\delta\tan\Phi)$
dn= mean day of month
S = the monthly mean of daily hours of sunshine
S_o= number of hours of insolation
$S_o = (2/15)\omega$

Table2: values of Global solar radiation for Warri.

Month	**H(MJ/m^2)**	**H_o(MJ/m^2)**	**S(hrs)**	**S_o(hrs)**	**S/S_o**	**H/Ho**
Jan.	15.10	34.33	5.25	11.71	0.45	0.44
Feb.	14.77	36.25	4.59	11.83	0.39	0.41
Mar.	14.98	37.98	4.41	11.97	0.37	0.39
Apr.	15.52	38.71	4.58	12.12	0.38	0.40
May	15.88	38.36	4.88	12.25	0.40	0.41
Jun.	12.50	37.94	3.20	12.32	0.26	0.33
Jul.	11.56	38.10	2.54	12.29	0.21	0.30
Aug.	11.72	38.63	2.57	12.18	0.21	0.30
Sep.	11.92	38.44	2.65	12.03	0.22	0.31
Oct.	15.53	36.94	4.88	11.87	0.41	0.42
Nov.	15.12	34.87	5.12	11.74	0.44	0.43
Dec.	15.06	33.72	5.39	11.68	0.46	0.45

CONCLUSIONS

Multiple regressions have been employed in this study to develop several correlation equations used to describe the dependence of sunshine hours on other meteorological data for Warri locaton. The result shows that the four variable correlation which is the equations with the highest R gives the best result when considering the error term (RMSE). Hence the multiple regression equation that could be employed for the purpose estimating sunshine hours of locations that have the same climate and latitude as Warri, Nigeria is correlation equation with the least value of RMSE, that is:

$S = -22.424 + 0.272RH + 1.388T - 9.791RF - 0.623W$

Based on table2, the greatest amount of global solar radiation was received in May (15.88MJ/m^2) and the least amount of Global solar radiation was received in July (11.56MJ/m^2).

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