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ESTIMATING GLOBAL SOLAR RADIATION FROM SUNSHINE HOURS FOR UYO, NIGERIA

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ABSTRACT

Multiple linear regression models were developed to estimate the monthly from daily sunshine hours using four meteorological parameters for a period of eleven years (1997 to 2007) for Uyo, Nigeria (Latitude of 5°18'53.7''N). The parameters include Relative Humidity (RH), Maximum and Minimum Temperature (T), Rainfall (RF) and Wind Speed (W). The result of the four variable correlations gives the highest value of correlation coefficient R. This gives the best result when considering the error term, Root Mean Square Error (RMSE). The correlation is given as

$$S = -16.876 – 2.065RF + 0.237W + 1.278T + 0.129RH$$

The developed correlation is a veritable tool which can be used for estimating Sunshine hours for other locations with similar climatic conditions.

Keywords: Global solar radiation, sunshine hours, meteorological parameters, multiple linear regression.

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, atmospheric 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 four meteorological parameters for Uyo in southern Nigeria. The applicability of the models is also examined.

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MATERIALS AND METHODS

METHODS

Monthly average Sunshine hours, Relative Humidity, Maximum and Minimum Temperature, Rainfall data and Wind Speed data were obtained from the Nigerian Meteorological Agency (NIMET) in Oshodi, Lagos, Nigeria. 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 table 1.

Multiple linear regression equation for estimating S with four parameters is as follows

$$Y = a + bx_i + cx_2 + dx_3 + ex_4$$

Where a, b, c, d and 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 table 1 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

Table 1. Sunshine hours and relevant meteorological data for Uyo.

Month	S(hrs)	RH%	Tmax°C	Tmin°C	T°C	RF(mm)	W(m/s)
JAN	3.10	51.00	33.21	22.79	10.42	35.00	2.83
FEB	3.61	50.36	34.31	24.13	10.18	56.00	3.43
MARCH	2.92	62.73	33.03	24.06	8.97	164.00	3.70
APRIL	3.15	70.27	32.37	24.05	8.32	217.00	3.98
MAY	3.40	74.09	31.35	23.61	7.74	264.00	3.64
JUNE	2.56	78.09	30.40	23.37	7.03	321.00	3.14
JULY	1.47	81.86	29.17	22.96	6.21	326.00	3.11
AUG	1.24	82.09	29.17	23.00	6.15	300.00	3.29
SEP	1.99	80.63	29.15	23.25	6.70	329.00	3.34
OCT	2.75	75.00	30.84	23.45	7.39	207.00	2.97
NOV	3.35	63.64	32.18	23.14	9.04	73.00	2.99
DEC	2.84	56.82	32.15	23.12	9.03	11.00	2.69

Table 2. Comparison of estimated and measured data for Uyo.

Month	**S**	Eq.1	Eq.2	Eq.3	Eq.4	Eq.5	Eq.6	Eq.7
JAN	3.10	3.68	2.65	3.73	3.58	3.71	3.21	3.62
FEB	3.61	3.58	2.75	3.33	3.64	3.27	3.65	3.33
MAR	2.92	3.07	2.84	3.17	3.05	3.13	3.27	3.22
APRIL	3.15	2.79	2.92	3.20	2.67	3.18	3.17	3.32
MAY	3.40	2.55	2.82	2.87	2.51	2.84	2.66	2.89
JUNE	2.56	2.25	2.66	2.38	2.34	2.33	1.99	2.26
JULY	1.47	1.90	2.65	1.65	2.16	1.61	1.88	1.62
AUG	1.24	1.88	2.71	1.66	2.08	1.65	2.09	1.73
SEPT	1.99	2.11	2.72	2.23	2.20	2.20	2.07	2.20
OCT	2.75	2.40	2.61	2.50	2.38	2.53	2.28	2.52
NOV	3.35	3.10	2.61	3.38	2.89	3.44	2.94	3.44
DEC	2.84	3.09	2.52	2.53	3.21	2.57	3.06	2.61

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.

One variable correlation:
This correlation gives the highest value of R as 0.811 for T and lowest value of R as 0.157 for W.

$S = -0.725 + 0.423T$ ($R = 0.811, \sigma = 0.46536$) Eq. 1

$S = 1.677 + 0.313W$ ($R = 0.157, \sigma = 0.78644$) Eq. 2

Two variables correlation
The highest value of R is 0.893 for T and RH and lowest value of R is 0.723 for RF and RH

$S = - 16.815 + 0.122RH + 1.375T$
($R = 0.893, \sigma = 0.37797$) Eq. 3

$S = 6.497 – 0.058RH + 1.162RF$
($R = 0.723, \sigma = 0.57959$) Eq. 4

Three variables correlation
The highest value of R is 0.894 for T, RF and T and lowest value of R is 0.795 for RH, RF and W

$S = -17.760 – 0.991RF + 0.135RH + 1.403T$
($R = 0.894, \sigma = 0.39838$) Eq. 5

$S = 2.094 – 3.190RF – 0.021RH + 0.814W$
($R = 0.795, \sigma = 0.53996$) Eq. 6

Four Variables Correlation

$S = -16.876 – 2.065RF + 0.237W + 1.278T + 0.129RH$
($R = 0.898, \sigma = 0.41835$) Eq. 7

RESULTS AND DISCUSSION

Eqs. 1, 3, 5 and 7 have the highest value of correlation coefficient while Eqs. 2, 4 and 6 have the lowest values of R. However, the applicability of the proposed correlations is tested by estimating the sunshine duration values for Uyo location used in the analysis. Estimated values of

Table 3. Error calculations.

Equations	R	MBE	RMSE	MPE
Eq.1	0.811	0.00170	0.4861	4.165
Eq.2	0.157	-0.000833	0.7183	11.052
Eq.3	0.893	0.0208	0.3266	3.2783
Eq.4	0.723	0.0225	0.5047	6.8192
Eq.5	0.894	0.0067	0.3242	0.9817
Eq.6	0.795	-0.0092	0.4420	4.3442
Eq.7	0.898	0.0317	0.3186	3.7125

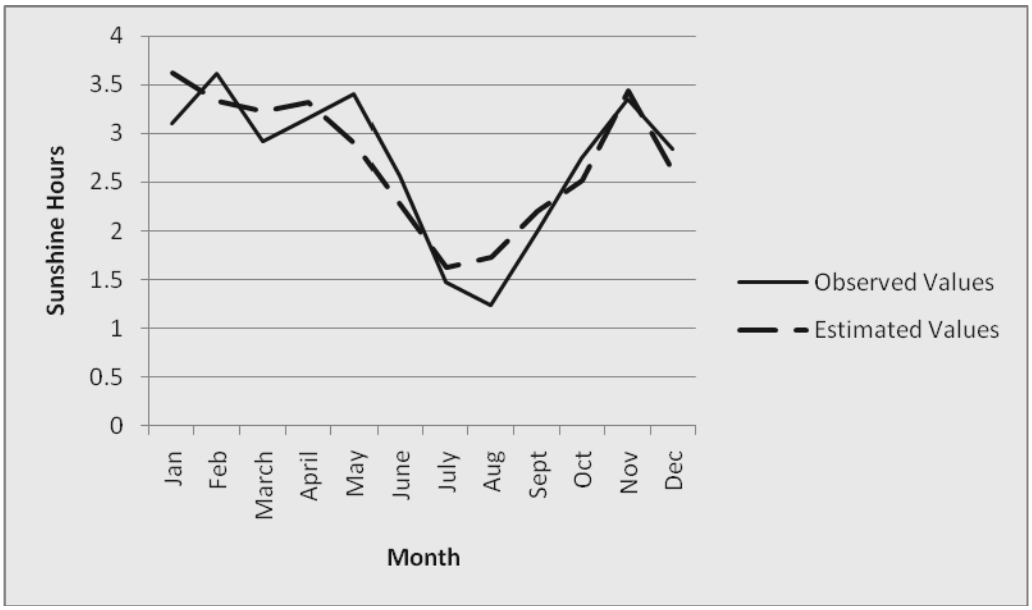

Fig. 1. Comparison of measured data with estimated data for monthly average daily sunshine hours for Uyo.

sunshine duration for Uyo along with the measured data are shown in table 2. Inspection of the table shows that the models estimate sunshine hours fairly accurately.

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

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 enables 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 supposed 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.

$$S = -16.876 - 2.065RF + 0.237W + 1.278T + 0.129RH$$

The value of $R^2 = 0.807$ in the equation indicates that 81% 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 0.697. This shows

Table 4. Values of Global solar radiation for Uyo.

Month	H(MJ/m^2)	Ho(MJ/m^2)	S(hrs)	So(hrs)	S/So	H/Ho
JAN	12.79	34.45	3.62	11.73	0.31	0.37
FEB	12.64	36.37	3.33	11.84	0.28	0.34
MARCH	12.91	38.02	3.22	11.97	0.27	0.34
APRIL	13.45	38.71	3.32	12.12	0.27	0.35
MAY	12.08	38.25	2.89	12.24	0.24	0.32
JUNE	10.75	37.82	2.26	12.30	0.18	0.28
JULY	9.31	38.02	1.62	12.28	0.13	0.24
AUG	9.75	38.60	1.73	12.17	0.14	0.25
SEP	10.62	38.44	2.20	12.03	0.18	0.28
OCT	11.10	36.98	2.52	11.88	0.21	0.30
NOV	12.43	34.98	3.44	11.76	0.29	0.36
DEC	10.42	33.83	2.61	11.70	0.22	0.31

that 69.7% of the variation in sunshine hours can be explained by the relative humidity, temperature, rainfall and wind speed.

Figure 1 shows plots of Eq. 7 with the least value of RMSE together with the monthly average daily sunshine hours measured for eleven years. Eq. 7 shows almost exact fit to the sunshine hours data.

Based on Eq.7 the values of global solar radiation (H), were computed and presented in table 4.

Computation of Global solar radiation

The linear regression model used in computing Global solar radiation data is given after Angstrom (1924)

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

H is the monthly mean horizontal daily total terrestrial solar radiation.

H_o is the monthly mean horizontal daily total extraterrestrial solar radiation given by

$H_o = 24/\pi * I_{sc} [1 + 0.033 Cos (360/365)*dn]*[(\omega Sin\Phi Sin\delta) + (Cos\Phi Cos\delta Sin\omega)]$ where

I_{sc} = solar constant

δ= declination angle

Φ= latitude of the location of study

ω= sunset hour angle given by

$\omega = Cos^{-1}(-tan\delta tan\Phi)$

dn= mean day of month

S = the monthly mean of daily hours of sunshine

S_o= number of hours of insolation given by

$S_o = (2/15)\omega$

CONCLUSION

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 Uyo location. The result shows that the four variables 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 Uyo, 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 table 2, the greatest amount of global solar radiation was received in April (13.45MJ/m^2) and the least amount of Global solar radiation was received in July (9.31MJ/m^2).

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