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ESTIMATION OF GLOBAL SOLAR RADIATION ON HORIZONTAL SURFACE FROM SUNSHINE HOURS AND OTHER METEOROLOGICAL PARAMETERS FOR CALABAR, 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 – 2007) for Calabar, Nigeria (Latitude 5^{o}16’07.6’’N); The parameters include Relative Humidity, Maximum and Minimum temperatures, Rainfall and Wind Speed. The result of the correlations shows that the four variable correlations with the highest value of R gives the best result when considering the error term Root Mean Square Error (RMSE). The model is given as S = -11.049-6.540RF-0.534W+0.142RH+1.127T. Where RH is Relative humidity, T is the Difference in maximum and minimum temperature, RF is Rainfall, and W is wind speed. The developed model can be used in estimating Global solar radiation for Calabar and other locations with similar climatic conditions.

Keywords: Global solar radiation, Sunshine hours

1. INTRODUCTION

Sunshine hours has continued to be one of the most widely measured and applied meteorological parameters. This is so because it plays an important 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. Accurate solar radiation resource data are necessary at various steps of the design, simulation, and performance evaluation of any project involving solar energy (Gueymard, 2008). However, in developing countries such as Nigeria, it has been very difficult measuring global solar radiation due to the availability of equipment or none 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 (Andretta *et al.*, 1982; Bahel *et al.*, 1987; Akpabio *et al.*, 2002; Ahmad and UlFat, 2004; Akpabio *et al.*, 2004; Almorox and Hontoria, 2004; Almorox *et al.*, 2008). The parameter used as input in the calculations include, sunshine duration, Mean temperature, soil temperature, relative humidity, number of rainy days, altitude, latitude, total perceptible 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 certain meteorological parameters for Calabar, Nigeria. However, global solar radiation data are calculated from these correlations. The applicability of the models is also examined.

2. METHODOLOGY

Monthly average Sunshine hours, Relative Humidity, Maximum and Minimum Temperatures, 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). Calabar is located at Latitude 5°16’07.6’’N. Monthly averages (over the eleven year period) of the data in preparation for correlation are presented in table 1.

Table-1. Sunshine hours and relevant meteorological data for Calabar, Nigeria

Month	S, hrs	RH, %	T, °C	RF, mm	W, m/s
Jan.	5.30	56.27	9.68	37.00	4.39
Feb.	4.66	55.27	10.04	47.00	4.72
Mar.	3.75	64.64	8.79	200.00	4.75
Apr.	4.06	69.91	8.39	265.00	4.89
May	4.28	71.63	8.06	304.00	4.85
Jun.	3.57	76.27	7.02	380.00	4.50
Jul.	2.52	82.55	6.34	451.00	4.09
Aug.	1.46	82.09	5.56	443.00	4.10
Sep.	2.31	79.91	6.26	385.00	4.35
Oct.	3.15	74.91	7.17	302.00	4.37
Nov.	4.72	69.91	8.02	156.00	3.95
Dec.	5.74	58.82	8.91	31.00	4.02

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.

3. 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 regressions of four parameters (RH, T, RF, W) were employed to estimate the sunshine hours. Here S is the monthly average daily Sunshine hours, RH is the monthly average daily Relative Humidity in percentage, RF is the monthly average daily rainfall in millimeters, 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 0.899 for RF and lowest value of R as 0.135 for W.

$$S = 5.622 - 7.327RF \ (R = 0.899, \sigma = 0.57910) \quad (1)$$

$$S = 1.524 + 0.513W \ (R = 0.135, \sigma = 0.131285) \quad (2)$$

ii. Two Variable correlation

This correlation gives the highest value of R as 0.918 for T and W and lowest value of R as 0.878 for RH and W.

$$S = 1.147 + 0.890T - 0.985W \ (R = 0.918, \sigma = 0.55231) \quad (3)$$

$$S = 13.635 - 0.117RH - 0.363W \ (R = 0.878, \sigma = 0.66723) \quad (4)$$

iii. Three Variable correlation

This correlation gives the highest value of R as 0.929 for RF, RH and T and lowest value of R as 0.919 for RF, T and W.

$$S = -12.148 - 9.480RF + 0.160RH + 0.899T \ (R = 0.929, \sigma = 0.5857) \quad (5)$$

$$S = 1.265 - 0.267RF + 0.858T - 0.940W \ (R = 0.919, \sigma = 0.5857) \quad (6)$$

iv. Four Variable correlation

$$S = -11.049 - 6.540RF - 0.534W + 0.142RH + 1.127T \ (R = 0.931, \sigma = 0.5775) \quad (7)$$

4. RESULTS AND DISCUSSIONS

Equations (1), (3), (5), (7) have the highest value of correlation coefficient while equations (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 Calabar location used in the analysis. Estimated values of sunshine duration for Calabar along with the measured data are shown in Table2. Inspection of the table shows that the models estimate sunshine hours fairly accurately.

Table-2. Comparison of estimated and measured data for Calabar, Nigeria

Month	S	Eq1	Eq2	Eq3	Eq4	Eq5	Eq6	Eq7
Jan.	5.30	5.35	3.78	5.11	5.46	5.21	5.43	5.26
Feb.	4.66	5.28	3.99	5.43	5.46	5.28	5.43	5.29
Mar.	3.75	4.16	3.96	4.29	4.35	4.20	4.29	4.19
Apr.	4.06	3.68	4.03	3.80	3.68	4.07	3.80	3.99
May	4.28	3.39	4.01	3.54	3.49	3.68	3.54	3.63
Jun.	3.57	2.84	3.83	2.96	3.08	2.76	2.99	2.80
Jul.	2.52	2.32	3.62	2.76	2.49	2.48	2.74	2.68
Aug	1.46	2.38	3.63	2.06	2.54	1.79	2.06	1.79

Sep.	2.31	2.80	3.76	2.43	2.71	2.62	2.44	2.51
Oct.	3.15	3.41	3.77	3.22	3.28	3.42	3.23	3.36
Nov	4.72	4.48	3.55	4.44	4.02	4.81	4.43	4.84
Dec.	5.74	5.39	3.59	5.12	5.29	4.98	5.12	5.00

The following observations can be made from a study of Table 3. 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 equation (1), (2) and (6) is the best while equation (4) is the worst. With respect to MPE, equation (5) offers the best correlation while equation (2) gives the worst.

Table-3. Error calculations

Equations	R	MBE	RMSE	MPE
Eq1	0.899	-0.0033	0.5322	5.1200
Eq2	0.135	-0.0033	1.2041	14.5330
Eq3	0.918	-0.030	0.4837	5.1700
Eq4	0.878	0.0275	0.5796	5.5167
Eq5	0.929	-0.0183	0.4543	1.5675
Eq6	0.919	-0.00167	0.4587	2.8742
Eq7	0.931	0.0150	0.4467	1.6625

Since MPE gives information on 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 gives underestimation (Akpabio *et al.*, 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 *et al.*, 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 (Triola, 1998).

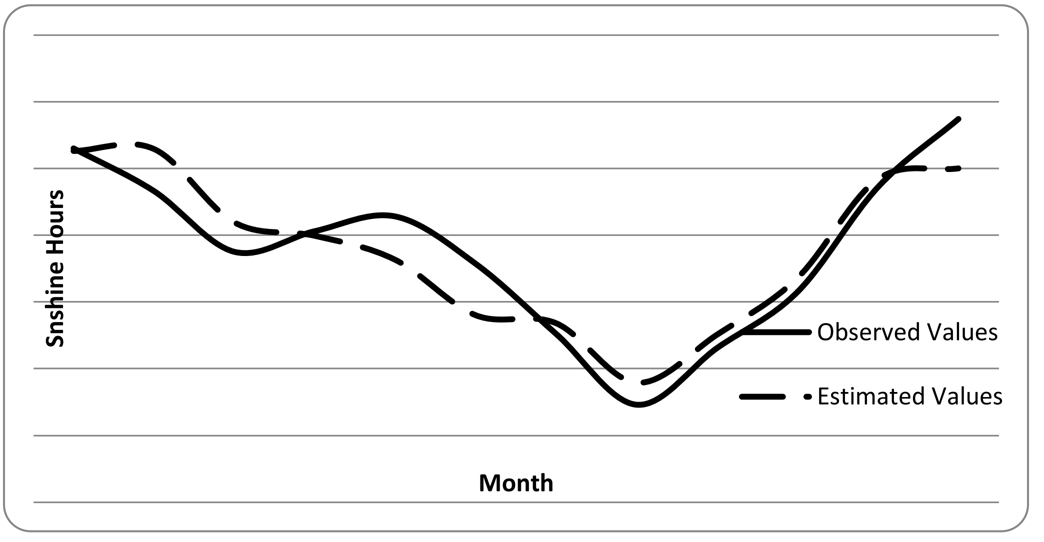
Hence for Calabar,

$$S = -11.049 - 6.540RF - 0.534W + 0.142RH + 1.127T$$

The value of $R^2 = 0.867$ in the equation indicates that 86.7% 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 0.791. This shows that 79.1% of the variation in sunshine hours can be explained by the relative humidity, temperature, rainfall and wind speed.

Figure 1 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.

Figure-1. Comparison of measured and estimated data of monthly average daily sunshine hours for Calabar, Nigeria



Resulting from Equation 7, the values of global solar radiation (H), were computed and presented in table 4.

5. COMPUTATION OF GLOBAL SOLAR RADIATION

The average global solar radiation is such that certain constants are known, thus yielding a value measured in Kilo Joules per meter squared daily.

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

Solar radiation cannot be easily measured at every place. All over the world, attempts are only being made to have solar radiation data computed based on measured meteorological data. The average daily global radiation on horizontal surface H, for a location are now possible if the sunshine hours S are measured and known (Nwokoye, 2006).

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

And

$$W = \text{Cos}^{-1}(-\tan\delta \tan\varphi)$$

$$S_o = (2/15)\ \omega$$

Table-4. Value of Global solar radiation for Calabar, Nigeria

Month	H(MJ/m^2)	H_o(MJ/m^2)	S(hrs)	S_o(hrs)	S/S_o	H/H_o
Jan.	15.36	34.45	5.26	11.73	0.45	0.45
Feb.	16.22	36.37	5.29	11.84	0.45	0.45
Mar.	14.61	38.06	4.19	11.97	0.35	0.38
Apr.	14.58	38.67	3.99	12.12	0.33	0.38
May	13.63	38.25	3.63	12.24	0.30	0.36
Jun.	11.91	37.82	2.80	12.30	0.23	0.31
Jul.	11.71	38.02	2.68	12.27	0.22	0.31

Aug	10.02	38.60	1.79	12.17	0.15	0.26
Sep.	11.57	38.44	2.51	12.03	0.21	0.30
Oct.	12.67	36.98	3.66	11.88	0.28	0.34
Nov.	14.88	34.98	4.84	11.76	0.41	0.43
Dec.	14.62	33.83	5.00	11.70	0.43	0.43

6. 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 Calabar, Nigeria. The result shows that the four variable correlations which is the equation with the highest R give the best result when considering the error term (RMSE). Hence the multiple regression equation can be employed for the purpose of estimating sunshine hours for Calabar and for locations that have the same climate and latitude as Calabar. The equation with the least value of RMSE is:

$$S = -11.049 - 6.540RF - 0.534W + 0.142RH + 1.127T$$

Based on table 4, the greatest amount of global solar radiation was received in February (16.22 MJ/m^2) and the least amount of global solar radiation was received in August (10.02 MJ/m^2).

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