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Estimating global solar radiation on horizontal surface from sunshine hours over Port Harcourt, Nigeria

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A model for estimating sunshine hours from some meteorological parameters was developed. An eleven year (1997 to 2007) period of relative humidity, maximum and minimum temperatures, rainfall and wind speed measured at Port Harcourt, Nigeria (Latitude 4°56’26.2’’N) was analyzed. The results of the correlations show 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 developed model can be used in estimating global solar radiation for Port Harcourt and other locations with similar climatic conditions.

Key words: Global solar radiation, sunshine hours.

INTRODUCTION

Development of a solar energy research programme must always start with a study of solar radiation data at the site or region of interest. Long term measurements of solar radiation on a horizontal surface exist for only relatively few meteorological stations (Akpabio, 2002). To this effect, the development of emperical models for the estimation of solar radiation in a developing country such as Nigeria has become imperative. Sunshine hours has been the best alternative way of estimating global solar radiation. This is because sunshine hours is easy to use and is reliable. It is also easily measured and readily available. Several empirical models have been developed to calculate global solar radiation using various parameters (Umoh and Udoh, 2010, Umoh and Akpan, 2011a, b; Khan and Ahmad, 2012; Hussein and Ahmed 2012; Jakhrani et al., 2013; Kaya, 2012; Al-Dulaimy, 2010). 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 main objective of the study is to develop an equation that correlate monthly average daily sunshine hours with certain meteorological parameters for Port Harcourt, Nigeria. Global solar radiation is then computed from this equation.

METHODOLOGY

In order to obtain the set of equations necessary for this research, measured data of monthly average sunshine hours, relative humidity, difference in maximum and minimum temperatures, rainfall data and wind speed of Port Harcourt corresponding to the period 1997 to 2007 was obtained from the Nigerian Meteorological Agency (NIMET) in Oshodi, Lagos. Port Harcourt is located at Latitude 4°56’26.2’’N (Figure 1). Monthly averages (over the eleven

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Figure 1. Map of Port Harcourt. Source: Google Map.

Table 1. Sunshine hours and relevant meteorological data for Port Harcourt.

Month	January	February	March	April	May	June	July	August	September	October	November	December
S (h)	4.30	4.24	3.84	4.41	4.85	3.74	2.28	2.36	3.30	4.07	5.08	5.37
RH (%)	53.55	56.64	64.82	70.36	75.73	78.09	81.64	81.18	79.36	74.91	63.55	53.91
T (°C)	11.60	10.96	9.81	8.95	8.04	7.32	6.51	6.44	6.90	8.04	9.46	11.26
RF (mm)	34.00	69.00	107.00	157.00	284.00	308.00	341.00	263.00	389.00	226.00	79.00	20.00
W (m/s)	2.95	3.18	3.40	3.36	2.19	3.18	3.09	3.43	2.97	2.36	2.23	2.15

year period) of the data in preparation for correlations are presented in Table 1. 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 (Akpabio et al., 2004).

Correlations

Table 1 presents the various meteorological parameters. These parameters are all linked to sunshine hours in various degrees. In order not to overlook any particular parameter or group of parameters, multiple linear regressions of four parameters (RH, T, RF, and 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

One variable correlation

This correlation gives the highest value of R as 0.717 for T and lowest value of R as 0.547 for W.

$S = 0.699 + 0.375T$ ($R = 0.717$, $\sigma = 0.70775$) (1)

$S = 7.422 – 1.162W$ ($R = 0.547$, $\sigma = 0.85003$) (2)

Two variable correlation

This correlation gives the highest value of R as 0.737 for T and W and lowest value of R as 0.689 for RH and RF.

$S = 3.436 + 0.315T – 0.749W$ ($R = 0.791$, $\sigma = 0.65459$) (3)

$S = 8.109 – 0.058RH – 0.3396RF$ ($R = 0.689$, $\sigma = 0.77560$) (4)

Three variable correlation

This correlation gives the highest value of R as 0.797 for T, RF and W and lowest value of R as 0.737 for RH, T and RF.

$S = 1.917 + 0.453T + 2.167RF - 0.783W$ ($R = 0.797$, $\sigma = 0.6854$) (5)

$S = -13.674 + 0.123RH + 1.050T – 0.334RF$ ($R = 0.737$, $\sigma = 0.76735$) (6)

Four variable correlation

$S = -27.306 – 0.272RH + 1.806T – 0.281RH – 1.114W$ ($R = 0.863$, $\sigma = 0.6258$) (7)

RESULTS AND DISCUSSION

MPE gives information on long term performance of the examined regression equation; a positive MPE value

Table 2. Comparison of estimated and measured sunshine Hours data for Port Harcourt.

Month	S	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6	Equation 7
January	4.30	5.05	3.99	4.88	4.99	4.94	5.08	3.83
February	4.24	4.81	3.73	4.51	4.80	4.54	4.78	4.22
March	3.84	4.38	3.47	3.98	4.31	3.93	4.56	4.09
April	4.41	4.06	3.52	3.74	3.97	3.68	4.33	4.07
May	4.85	3.71	3.72	3.58	3.60	3.68	3.99	4.03
June	3.74	3.44	3.73	3.36	3.46	3.41	3.51	3.37
July	2.28	3.14	3.83	3.17	3.20	3.19	3.09	2.96
August	2.36	3.11	3.44	2.90	3.30	2.72	2.99	2.35
September	3.30	3.29	3.97	3.38	3.35	3.56	3.20	3.16
October	4.07	3.71	4.68	4.20	3.67	4.20	3.91	4.75
November	5.08	4.25	4.83	4.75	4.39	4.63	4.05	4.43
December	5.37	4.92	4.92	5.37	4.97	5.38	4.77	5.18

Table 3. Error calculations.

Equations	R	MBE	RMSE	MPE
S = 0.699 + 0.375T	0.717	0.0525	0.6464	4.7617
S= 7.422 – 1.162W	0.547	-0.00083	0.7755	5.4808
S = 3.436 + 0.315T – 0.749W	0.791	-0.00167	0.5665	2.7483
S = 8.109 – 0.058RH – 0.3396RF	0.689	0.0175	0.6892	4.2380
S = 1.917 + 0.453T + 2.167RF - 0.783W	0.797	0.00167	0.5601	2.6975
S = -13.674 + 0.123RH + 1.050T – 0.334RF	0.737	0.0350	0.6272	3.9792
S = -27.306 – 0.272RH + 1.806T – 0.281RH – 1.114W	0.863	-0.1107	0.4665	-1.1560

provides the average amount of over estimation in the calculated values while a negative MPE gives under estimation (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. However, the R^2 has serious flaws, which 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).

Equations (1), (3), (5) and (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 Port Harcourt location used in the analysis. Estimated values of sunshine duration for Port Harcourt along with the measured data are shown in Table 2. Inspection of the table shows that the models estimate sunshine hours fairly accurately.

A study of Table 3 indicates that 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 (2) is the best while Equation (7) is the worst. With respect to MPE, Equation (7) offers the best correlation while Equation (2) gives the worst.

Hence for Port Harcourt,

$$S = -27.306 – 0.272RH + 1.806T – 0.281RH – 1.114W$$

The value of $R^2 = 0.745$ in the equation indicates that 74.5% 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 0.600. This shows that 60% of the variation in sunshine hours can be explained by the relative humidity, temperature, rainfall and wind speed.

Figure 2 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)

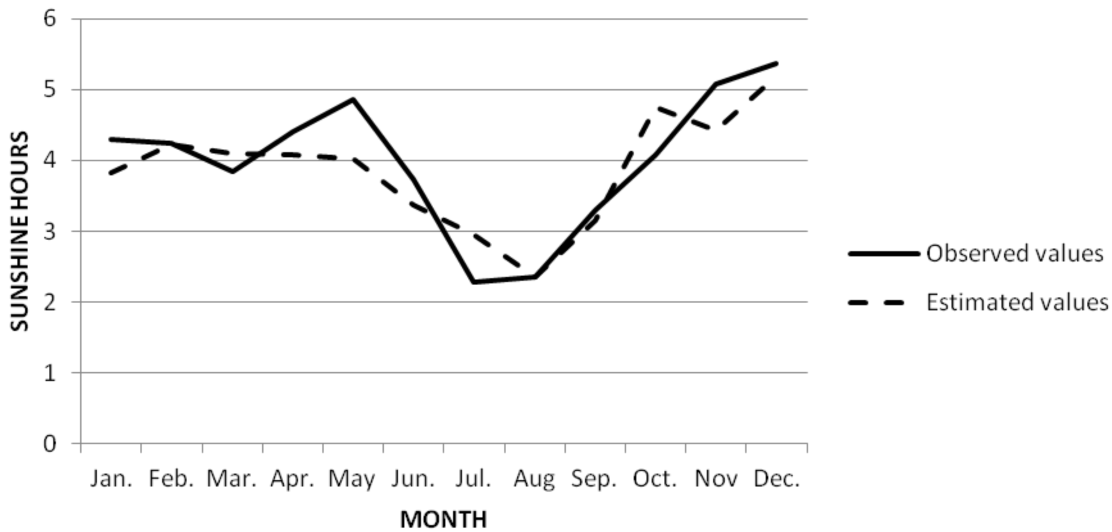

Figure 2. Comparison of measured and estimated data of monthly average daily sunshine hours for Port Harcourt, Nigeria.

shows almost exact fit to the sunshine hours data. Based on Equation 7, the values of global solar radiation (H) were computed and presented in Table 2.

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.

$H = H_o \{a + b[S/S_o]\}$ (Nwokoye, 2006).

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 is 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

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

$S_o = (2/15)\ \omega$ (Nwokoye, 2006).

Conclusion

Multiple regressions was employed in this study to develop several correlation equations used to describe the dependence of sunshine hours on other meteorological data for Port Harcourt, 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 Port Harcourt and for locations that have the same climate and latitude as Port Harcourt. The equation with the least value of RMSE is

S = -27.306 – 0.272RH + 1.806T – 0.281RH – 1.114W

Based on Table 4, the greatest amount of global solar radiation was received in October (15.79 MJ/m^2) and the least amount of global solar radiation was received in August (11.21 MJ/m^2).

Definition of terms

RH = Relative humidity
T = Difference in maximum and minimum temperature
RF = Rainfall
W = Wind speed
MBE = Mean bias error
MPE = Mean percentage error
RMSE = Root mean square error
H = Global solar radiation
H_O = Daily extraterrestrial radiation
H/H_O = Clearness index
S = Maximum sunshine duration or day length
S_O = Daily sunshine duration
S/S_O = Measure of cloud cover
I_{SC} = Solar constant
dn = Day number

Table 4. Value of global solar radiation for Port Harcourt, Nigeria.

Month	H (MJ/m^2)	H_o (MJ/m^2)	S (h)	S_o (h)	S/S_o	H/H_o
January	12.99	34.56	3.83	11.75	0.33	0.38
February	14.47	36.44	4.22	11.85	0.36	0.40
March	14.85	38.06	4.09	11.97	0.34	0.39
April	14.80	38.63	4.07	12.11	0.34	0.38
May	14.62	38.17	4.03	12.23	0.33	0.38
June	13.10	37.71	3.37	12.28	0.27	0.35
July	12.36	37.90	2.96	12.26	0.24	0.33
August	11.21	38.56	2.35	12.16	0.19	0.29
September	13.08	38.44	3.16	12.03	0.26	0.34
October	15.79	37.10	4.75	11.89	0.40	0.43
November	14.44	35.10	4.43	11.77	0.38	0.41
December	15.45	34.02	5.18	11.72	0.44	0.45

ω = Sunset hour angle
δ = declination
φ = Latitude of research location.

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Conflict of Interests

The author(s) have not declared any conflict of interests.

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