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Research Article

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Correlation of Global Solar Radiation with Meteorological Elements at Umudike, South-eastern Nigeria

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Abstract The aim of this study is to develop empirical models for the correlation of global solar radiation with meteorological parameters at Umudike (latitude 5°29^{1}N, longitude 07° 33^{1}E and altitude 122m) South-eastern Nigeria. A number of regression equations were developed to estimate global solar radiation with the following weather parameters: clearness index, mean daily maximum temperature, relative humidity and relative sunshine duration for Umudike using the Angstrom-Page model. The values of solar radiation estimated by the equations and the measured solar radiation were tested using the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE). The values of correlation coefficient r and the coefficient of determination r^2 were also determined. Maximum temperature and relative humidity showed stronger correlation than the relative sunshine duration. The statistical model performance indicators show that the parameters provided reasonably good correlation with the clearness index and could be used to model the mean daily global solar radiation on horizontal surfaces in the area even though the MPE values confirm underestimation.

Keywords Solar radiation, clearness index, sunshine duration, relative humidity, and maximum temperature

1. Introduction

Global solar radiation is an important parameter necessary for most ecological models and serves as input for different photovoltaic conversion systems. Hence it is of economic importance to renewable energy alternative. The solar radiation reaching the earth's surface depends upon climatic conditions of a location which is essential to the prediction and design of a solar energy system [1]. Although solar radiation data are available in most meteorological stations, many stations in developing countries (including Nigeria) suffer from a shortage of facilities required for solar radiation measurements. As a result, we resort to estimation of the solar radiation to provide the information where measured data are not available. The paper aims to develop regression line equations based on Angstrom-Page model that correlate mean daily global solar radiation on horizontal surface at Umudike, South-eastern Nigeria, using three meteorological parameters: maximum air temperature, relative humidity and relative sunshine hours.

Several researchers have determined the application of the Angstrom type regression model for estimating global solar radiation [2-12]. Bindi and Miglietta [13] proposed a model to estimate daily global radiation on the basis of air temperature and rainfall data. With the use of Angstrom model as a base, Falayi *et al.*, [14] developed a number of multilinear regression equations to predict the global solar radiation using clearness index, mean daily temperature, relative humidity and relative sunshine duration for Iseyin Nigeria. Prieto *et al.*,

[15] developed a correlation model of Austurias, Spain, using air temperature data. In a similar development, Panday and Katiyar [16] developed a temperature base correlation for the extractions of monthly mean daily global distribution of radiation from the ratio of monthly mean maximum to minimum ambient air temperature for five Indian locations. Al-Salihi *et al* [17] estimated the global solar radiation on horizontal surface using sunshine duration and humidity measurements for different cities in Iraq. Augustine and Nnabuchi [18] generated several linear and multilinear regression equations for Owerri, Enugu, Warri and Uyo, using monthly mean daily global solar radiation, sunshine duration hours, maximum temperature, relative humidity data and clearness index.

Okogbue and Adedokun [19] developed modified models for estimating global solar radiation with meteorological data from 24 stations in Nigeria. Chandel *et al.*, [20] developed a new correlation incorporating the latitude and altitude of a site to estimate the monthly average global solar radiation on horizontal surface using the sunshine hours and temperature data at six Indian stations with different geographical locations. Accurate modeling depends on the quality and quantity of the measured data used and is a better tool for estimating the global solar radiation of location where measurements are not available.

In this paper, clearness index values were determined and correlations of global solar radiation received at this station with some meteorological parameters have been determined to help predict the global solar radiation at this location and other locations with similar climatic conditions.

2. Study Area

Umudike is located in the tropical rain-forest belt in South-eastern Nigeria. The average annual rainfall amount is about 2046 mm while the average annual temperature is about 26.9 ^{o}C. The city has two main seasons, namely, the dry and wet seasons. The wet season begins in May and lasts till October while the dry season commences in November and lasts till April. Between December and March, the weather is dominated by winds originating from high-pressure belt off the Tropic of Cancer, locally termed Harmattan. This Harmattan is characterized by severe dry and thick dust haze and early morning fog and mist resulting from radiation cooling during the night under clear sky conditions. The climate of Nigeria is dominated by two air masses: the tropical continental air mass and the tropical maritime air mass. Both air masses converge at a discontinuity called the Inter-Tropical Discontinuity whose North-South oscillation largely dictates the Nigerian weather pattern.

3. Data and Methodology

3.1. Data

The data set used which include mean hourly global solar radiation, maximum air temperature, sunshine duration and relative humidity at Umudike were obtained from the archives of the Agro-meteorological Unit of the National Root Crop Research Institute Umudike for five years (2006-2010).

3.2. Methodology

Among the empirical models, the most popular is the regression equation of the Angstrom-Page type [21-22].

$$\frac{Hm}{Ho} = a + bTm; (Tm = Maximum\ Temperature) \quad (1)$$

$$\frac{H}{Ho} = a + b\left[\frac{S}{Smax}\right]; \left(\frac{S}{Smax} = Relative\ Sunshine\ duration\right) \quad (2)$$

$$\frac{H}{Ho} = a + b\ (RH); \ (RH = Relative\ Humidity) \quad (3)$$

H_m is the monthly mean horizontal daily terrestrial solar radiation and Ho is the monthly mean extra terrestrial solar radiation. $a$and b are regression co-efficient which are model parameters: H_m/H_o is called clearness index K_T. The mean monthly extra terrestrial radiation Ho on the horizontal surface for a period of one day is given by:

$$H_o = 24 \times 3600 Gsc\left(1 + 0.033 Cos\frac{360n}{365}\right)\left(Cos\phi Cos\delta\, Sin Ws + \frac{2\pi Ws}{360} Sin\phi\, Sin\delta\right) \quad (4)$$

$Where\ \mathrm{Gsc} = \ solar\ constant$ = 1367Wm^{-2} = [4.921MJm^{-2}h^{-1}).

∂ = $declination\ angle = 23.45 Sin\left[\frac{360\ (n+284)}{365}\right]$
Φ = latitude
Ws = Sunset hour angle in degrees for the typical day n of month
$= \cos^{-1}(-\tan\Phi\tan\partial)$
$n = is\ day\ number\ (n = 1\ on\ Jan\ 1\ and\ 365\ on\ Dec\ 31).$

$$Smax = \frac{2\cos^{-1}\tan\phi\tan\partial)}{15} \quad (5)$$

The hourly global solar radiation which were obtained using Gun Bellani distillate were converted and standardized after Folayan (1988), using the conversion factor given as:

$$Hgs = (1.35 + 0.176)\ H_{GB}\ in\ MJm^{-2} \quad (6)$$

Where H_{gs} is the hourly solar radiation in MJm^{-2}, H_{GB} is the raw data obtained using Gun Bellani distillate.
Although air temperature is probably the most registered meteorological variable [15] and correlation models based on air temperature are especially interesting to estimate monthly mean values of solar radiation in countries with lack of direct measurements, correlations based on other meteorological elements are beginning to emerge. Regression and correlation analyses were carried out using EXCEL between the clearness index and maximum air temperature, sunshine duration and relative humidity. The accuracy of estimated values was tested by using the widely used statistical indicators, namely, Mean Bias Error (MBE), Root-Mean Square Error (RMSE) and Mean Percentage Error (MPE). RMSE and MBE are commonly used in comparing the model of solar predictions. Low values of RMSE are desirable but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable. Over-estimation of an individual data element will cancel under estimation in a separate observation. It is also possible to have a large RMSE value and at the same time a low MBE value and vice versa [14]. The use of RMSE and MBE statistical indicators is not adequate for evaluation of model performance. The use of MPE in addition to RMSE and MBE gives a more reliable result. Almorox *et al*., [24] and Che *et al*., [25] have recommended that a zero value for MBE is ideal and low RMSE is desirable. The RMSE test provides information on the short term performances of the studied model as it allows a term-by-term comparison of the actual deviation between the estimated values and measured values. The MPE test gives a long term performances of the examined regression equation; a positive MPE value provides the average amount of over estimation while the negative value gives under estimation whereas low values of MPE is desirable [14]. These statistical indicators are expressed in the following equations.

$$MBE = \sum\left(\frac{Hp - Hm}{n}\right) \quad (7)$$

$$RMSE = \sum\left\{\frac{(Hp - Hm)^2}{n}\right\}^{1/2} \quad (8)$$

$$MPE = \frac{1}{n}\left\{\frac{\sum(Hp - Hm)\times 100}{Hm}\right\} \quad (9)$$

$n\ is\ number\ of\ observations.$

4. Results and Discussion

4.1. Results

Table 1 below shows the calculated monthly mean extraterrestrial solar radiation H_o, the measured monthly mean terrestrial global solar radiation, H_m, the clearness index K_T and the meteorological parameters derived from the raw data. Regression and correlation analysis were carried out on the $K_T = \frac{Hm}{Ho}$, RH and T_m using Excel.

Table 1: Values of H_m, H_o, K_T, RH, S, S/S_{max} and T_m

H_m (MJm^{-2})	H_o (MJm^{-2})	$K_T = \frac{H_m}{H_o}$	RH (%)	S_{max} (in hrs)	S (in hrs)	S/S_{max}	T_m (°C)
5.892	33.90	0.1738	62.5	11.68	3.4	0.291	35
5.409	35.88	0.1507	62.5	11.79	5.5	0.873	35
6.945	35.62	0.1949	65.5	11.94	6.3	0.528	34
6.033	37.53	0.1607	69.5	11.85	5.4	0.456	33
5.200	36.42	0.1427	77.0	12.22	4.6	0.376	32
3.42	35.45	0.0963	82.0	12.29	4.6	0.374	30
3.026	35.74	0.0847	81.5	12.26	2.1	0.171	30
2.233	36.83	0.0606	83.0	12.14	2.2	0.818	30
2.802	37.29	0.0751	82.0	12.00	2.8	0.233	33
4.755	36.19	0.1313	82.0	11.84	4.5	0.38	33
5.819	34.29	0.1696	79.5	11.72	5.3	0.452	32
5.872	35.10	0.1673	75.0	11.70	5.1	0.436	33

Table 2 below shows the regression and correlation constants *'a'* and *'b'*, the correlation coefficient *r*, the coefficient of determination, r^2, MBE, MPE and RMSE as they correspond to each of the weather indices. These values were extracted from the scatter plots.

Table 2: Values of regression constants *a* and *b*, correlation co-efficient, *r* and coefficient of determination r^2, MBE, MPE and RSME

Parameter	a	b	r	r^2	MBE	RMSE	MPE (%)
S/S_{max}	0.0800	0.134	0.59	0.348	0.0045	1.2191	-8.70
R.H	0.4315	-0.004	0.75	0.5653	0.0018	1.0087	-5.6958
T_m	-0.4177	0.0169	0.704	0.4953	0.0055	1.1000	-7.2487

The model equations for estimating the global solar radiations with the various meteorological elements are:

$$\frac{H}{Ho} = 0.4315 - 0.004\,R.H. \quad (11)$$

$$\frac{H}{Ho} = 0.0785 + 0.134 S/Smax \quad (12)$$

$$\frac{H}{Ho} = 0.4177 - 0.0169 Tm \quad (13)$$

Table 3 shows the estimated global solar radiation using meteorological parameters of S/S_{max}, RH and T_m.

Table 3: H_m and their corresponding H_p for the various meteorological parameters used in the study as determined by the researchers

Months	H_m(MJm^{-2})	H_p (MJm^{-2})		
		S/S_{max}	RH	T_{max}
1	5.89	5.99	6.15	5.89
2	5.41	6.94	6.51	6.24
3	6.95	5.29	6.04	5.59
4	6.03	5.23	5.76	5.25
5	6.2	4.67	4.5	4.48
6	3.42	4.56	3.67	3.17
7	3.03	3.65	3.77	3.19
8	2.23	3.81	3.66	3.29
9	2.8	4.11	3.86	5.22
10	4.76	4.68	4.75	5.06
11	5.82	4.76	5.89	4.22
12	5.87	5.21	5.78	5.88

4.2. Discussion

In many parts of the world, temperature, sunshine, cloud over, relative humidity, rainfall have been used as parameters for estimating solar radiations, the more commonly used being temperature and sunshine. Even though the rhythms of air temperature reflect the balance between the absorbed solar radiation and effective outgoing radiation, the use of temperature to represent radiation must be cautious because of the tropical location of the study area and the time lag between the distribution of temperature and radiation.

In this study, the temperature base correlation and other climatic indices have different correlation and regression coefficients, the daily maximum temperature and relative humidity showing stronger positive correlation than the relative sunshine duration. However, one should be cautious in temperature base correlation of solar radiation because of the delay between temperature distribution and radiation. Generally, regression line equation with higher correlation coefficient shows stronger correlation and should be used to estimate the terrestrial global solar radiation. The weak positive correlation of relative sunshine hours and the global solar radiation could be as a result of sky conditions in modifying the radiation in the visible range of the spectrum through reflection, scattering and absorption. Nevertheless, attempt should be made to include more years in future to adequately incorporate the climatic nature of the study. Furthermore, future research could use multiple regression of the parameters to produce better model of the global solar radiation.

In this study, relative humidity, mean daily maximum temperature, and relative sunshine hours have proved to be satisfactory in estimating solar radiation at Umudike. The result of the work is in good agreement with other works carried out in places with similar geographical location e.g Amadi [26] and Augustine and Nnabuchi [18].

5. Conclusion

EXCEL Computer software program was used to develop linear regression equations for estimating global solar radiation at Umudike, Southeastern Nigeria, using three meteorological parameters based on Angstrom-Page Model. Based on the values of the correlation coefficient t*r*, coefficient of determination r^2 and the values of MBE, RMSE and MPE statistical indicators, the equations have been found suitable for predicting the monthly mean daily solar radiation in the study area. This prediction can also be extended to other cities the same latitude and within the same geographical location. Relative humidity, maximum daily temperature and relative sunshine duration appear to be good meteorological parameters to estimate terrestrial global solar radiation at Umudike. This is evidenced from table 3 because relative humidity, maximum temperature and relative sunshine duration parameters gave relatively low values of MBE, MPE and RMSE and acceptable values of correlation coefficient, r and coefficient of determination r^2, even though MPE indicator shows underestimation.

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