
Multivariable Empirical Equation for Estimation of Global Solar Radiation in Sokoto Nigeria

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ABSTRACT

The global solar radiation is essential in the study, estimation and design of the economic viability of the systems which use solar energy. Correlations are commonly used to estimate average daily global solar radiation for regions where no actual measured values are available using more readily available meteorological, climatological, and geographical parameters. In this study, we proposed a model based on modified Angstrom-PreScott model including multiple climatic parameters for the estimation of global solar radiation (GSR) in Sokoto region. Averaged data of sunshine, wind speed, relative humidity, maximum temperature and cloud cover for a period of five years (2006 - 2010) was used to evaluate GSR of the study location. Result shows an excellent agreement between the measured and estimated values demonstrating good correlation coefficient ($r=0.992165$) and coefficient of determination ($R^2=0.984391$). The values obtained from RMSE, MBE and MPE statistical indicators were all close to zero hence the model is recommended for estimating GSR in the study location.

Keywords: Global Solar Radiation, Angstrom-PreScott, regression, estimation and parameters.

INTRODUCTION

Energy trends signposts that world oil production will reach peak and begin a long downward slide when the fossil fuels and gas will have been drained (Augustine and Nhabuchi, 2009). Studies on the new renewable energy resources have witnessed an encouraging rapid growth in the last few years because resources used today diminishes swiftly and caused environmental pollution. Solar radiation is the largest renewable energy source and it had been studied extensively due to its importance (Ugwu and Ugwanyi, 2011). A precise knowledge of solar radiation distribution at any location is essential in agricultural, ecological, photo thermal and photovoltaic studies as well as development of many solar energy devices (Udounwa *et al*, 2013; Tijjani, 2013). The common practice of measuring the global solar radiation (GSR) in a particular region is to install global solar radiation measuring device at as many locations as possible, consequently requiring daily maintenance that

increases the cost of GSR data collection. With the availability of climatic parameters, it is therefore more economical to ploy means to estimate the GSR using climatic parameters (El-sebaili and Trabea, 2005). Since the solar radiation reaching the earth's surface depends upon climatic conditions of the place, a study of solar radiation under local conditions is essential.

The aim and objectives of this study is to develop an empirical correlation model capable of estimating the mean monthly global solar radiation, compare the estimated monthly average daily GSR with the measured monthly average daily GSR and to also compare the model predictive tendencies with some models reported in literature for Sokoto region located in the North Western part of Nigeria.

MATERIALS AND METHOD

Sokoto state is located in the extreme north western part of Nigeria under latitude 13.060092°N longitude 5.2390213°E and Altitude 513m (Argungu

etal, 2017). The ecological zone of the area is Sudan savannah agro ecological zone of Nigeria. There are two major seasons in the area, namely wet and dry seasons. Sokoto state is boarded with Zamfara state to the east and south by Kebbi state and boarded with Niger republic in the north.

The instrument used in measuring global solar radiation in NIMET Oshodi, Lagos, Nigeria is Pyrometer and measures global solar radiation in w/m². Pyranometers are broadband instrument that measure global solar irradiance incoming from a 2 solid angle from a planar surface. It consists of a white disk for limiting the acceptance angle to 180° and two concentric hemispherical transparent covers made of glass. The two domes shield the sensor from thermal convection, protect it against weather threat (rain, wind and dust) and limit their spectral sensitivity of the instrument in wavelength range 0.29-2.8µm. A cartridge of silica gel inside the dome absorbs water vapour (Kerr and Tabony 2004).

The global monthly average daily solar radiation, Sunshine hours (SS), Wind speed (WS), Relative humidity (RH), Maximum temperature (T_{max}) and Cloud cover (CC) data for the location (Sokoto) and the period under investigation (2006-2010); were

obtained from the Nigerian meteorological agency (NIMET) Oshodi Lagos, Nigeria.

METHODOLOGY

In this study averaged data of parameters such as Sunshine (SS), Wind speed (WS), Relative humidity (RH), Maximum temperature (T_{max}) and Cloud cover (CC) had been used to evaluate the global solar radiation using multiple regression model. The monthly mean of daily global radiation was normalized by dividing with monthly mean of daily extraterrestrial radiation. We can define clearness index (K_T) as the ratio of the observed/measured horizontal terrestrial solar radiation (H_m) to the calculated/predicted horizontal extraterrestrial solar radiation (H₀) (Falayi *et al.*, 2011). Sunshine duration can be easily and reliably measured, and data are widely available at the weather stations. Most of the models for estimating solar radiation uses sunshine ratio (SS_r) for the prediction of monthly average daily global radiation.

Extraterrestrial solar radiation (H₀) and monthly average day length (S₀) were computed for each month using equations 1 and 3 respectively given by Iqbal as cited by (Argungu *et al.*, 2017).

$$H_0 = I_{sc} \frac{24}{\pi} \left[1 + 0.33 \cos \left(\frac{360n}{365} \right) \left(\frac{\pi}{180} \omega_s \sin \phi \sin \delta_s + \cos \phi \cos \delta_s \right) \right] \tag{1}$$

Where

I_{sc} is the solar constant (=1367 W m²), φ is the latitude of the site, δ_s is the solar declination, ω_s is the mean sunrise hour angle for the given month, and n is the number of days of the year starting from the first of January.

Solar declination angle is expressed as:

$$\delta_s = 23.45 \sin \left[\frac{360}{365} (n + 284) \right] \tag{2a}$$

Sunrise hour angle is given by:

$$\omega_s = \cos^{-1} (-\tan \phi \tan \delta_s) \tag{2b}$$

Because the sun travels through 15° in every 1 hour, the average day length S₀ is obtained as:

$$S_0 = \frac{2}{15} \omega_s \tag{3}$$

The analysis of each independent variable and dependent variable was investigated using regression techniques. The independent and dependent variables were supplied into the range value and the coefficients of intercept, sunshine

ratios, maximum temperature, wind speed, relative humidity and cloud cover were computed using SPSS software package. Deviation of the estimated values from the measured values was determined based on the following statistical parameters: the mean bias

error (MBE), root-mean square error (RMSE) and mean percentage error (MPE) given by equations 4-6. The best result is obtained when these statistics are closer to zero (Namrata, *et al*, 2012). Coefficient of determination R^2 is used to describe how well a regression line fits a set of data while coefficient of

correlation r is used to test the linear relationship between estimated and measured values. R^2 and r are given by equations 7-8. T-test statistical tool was used also to test the model equation's null hypothesis.

$$MBE = \frac{1}{n} \sum^n (H_e - H_m) \tag{4}$$

$$RMSE = \left\{ \frac{1}{n} \sum^n (H_e - H_m)^2 \right\}^{1/2} \tag{5}$$

$$MPE(\%) = \frac{1}{n} \sum^n \frac{H_m - H_e}{H_m} \times 100 \tag{6}$$

$$R^2 = 1 - \frac{\sum^n (H_m - H_e)^2}{\sum^n (H_m - H_e)^2} \tag{7}$$

$$r = \frac{n \sum^n H_e H_m - \sum^n H_e \sum^n H_m}{\sqrt{n(\sum^n H_e^2) - (\sum^n H_e)^2} \sqrt{n(\sum^n H_m^2) - (\sum^n H_m)^2}} \tag{8}$$

Where

- n = number of observation
- H_m = measured global solar radiation
- H_e = estimated global solar radiation
- \bar{H}_m = mean measured global solar radiation

RESULTS AND DISCUSSIONS

Regression coefficients for the Angstrom-Prescott (Angstrom, 1924), Swartman-Ogunlade (Swartman and Ogunlade, 1967), Okundamiya (Okundamiya *et al*, 2016), Ogolo (Ogolo, 2014) and study model (Abdullahi-Sharafa) equations were

arranged in table 1 while in table 2 computed statistical indicators values were presented. Monthly average daily measured and predicted clearness indices of the study location were presented in table 3.

- $K_T = a + b \text{ SR}$ Angstrom-Prescott
- $K_T = a + b \text{ SR} + c \text{ RH}$ Swartman-Ogunlade
- $K_T = a + b \text{ SR} + c \text{ TR} + d \text{ Tmax} + e \text{ CC}$ Okundamiya
- $K_T = a + b \text{ SR} + c \text{ T} + d \text{ RH}$ Ogolo
- $K_T = a + b \text{ T}_{\text{max}} + c \text{ RH} + d \text{ CC} + e \text{ WS} + f \text{ SS}_R + g (\text{SS}_R)^2$ Abdullahi-Sharafa

Table 1: Regression Coefficients of the Study and Compared Empirical Models

Models	Model No.	Regression Coefficients						
		a	b	c	d	e	f	g
Angstrom-Prescott	1	0.4785	0.2465	0	0	0	0	0
Swartman-Ogunlade	2	0.7561	-0.0829	-0.0014	0	0	0	0
Okundamiya	3	0.5741	-0.3053	0.1922	0.0097	-0.0577	0	0
Ogolo	4	0.3820	-0.0712	0.00602	0.0157	0	0	0
Abdullahi-Sharafa	5	1.3538	-0.0081	-0.0053	-0.0548	-0.0080	0.5839	-0.3485

Table 2: Validation Results of the Study and Compared Empirical Models

Model No.	Statistical Indicators			
	r	R ²	RMSE	MBE
1	0.7731	0.6702	1.4324	0.2990
2	0.9128	0.8332	1.0715	0.5119
3	0.9377	0.9087	0.9202	0.5192
4	0.7700	0.7231	0.1664	-1.3238
5	0.9922	0.9844	0.01364	9.252x10⁻¹⁸

Table 3: The average measured and estimated values of the Sokoto cleanness index.

Months	K _T Measured	K _T Estimates
January	0.755247	0.748966
February	0.747504	0.769871
March	0.701525	0.710012
April	0.635442	0.634910
May	0.566291	0.546212
June	0.523254	0.536633
July	0.469337	0.477328
August	0.478034	0.490900
September	0.537000	0.517861
October	0.650762	0.654414
November	0.754176	0.752079
December	0.769988	0.749375

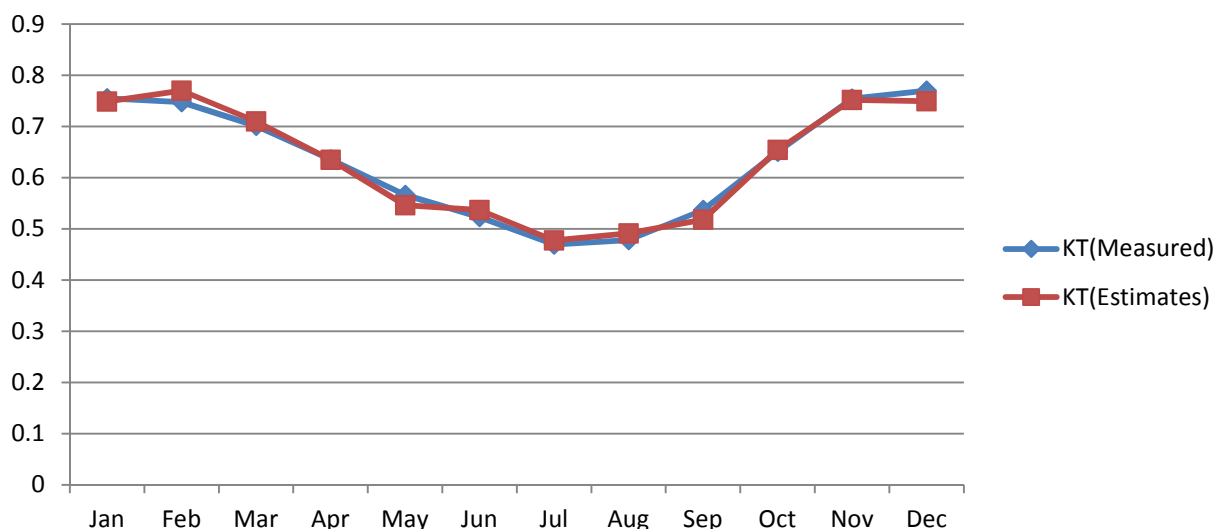


Figure 1: Comparison between measured and estimates of the monthly averages of cleanness indices for Sokoto area (2006-2010).

With reference to the graph in figure 1, the values compared are observed to be nearly equal in

almost all the months of the year showing that a good correlation exists between the measured and

estimated values. Statistical tests used to validate the efficiency of the model shows an R^2 value of 0.9844 which is equivalent to 98% efficiency for the model equation. Also the root mean square error (RMSE) value of 0.01364 makes the proposed model ideal for estimation of global solar radiation in Sokoto region. An MBE value of 9.252×10^{-18} which approaches zero proves that the model is reliable. The correlation coefficient (r) of 0.9922 implies that there is significant relation between the parameters used in the model, this shows that measured and estimated solar radiation are linearly dependent. For the t-Test result, $t_{cal} (0.00) < t_{critical} (2.073873)$ meaning that there is no significance difference between the measured and estimated means at value of 0.05 or at 95% level of significance.

All the statistical indicators considered favorably place the model equation at advantage over the compared models for the estimation of GSR for the study area as shown in table 2. Our proposed model's predictive performance was comparably better and outstanding. This can be attributed to the fact that, the compared models and other models reported in literature does not involve as many climatic parameters as the present model. Wind speed and cloud cover climatic parameters are two important parameters included in our empirical model equation. While cloud cover parameter was considered in few cases (Okundamiya *et al*, 2016; Falayi, 2013), wind speed was not involved in any of the models seen in literature.

CONCLUSION

Knowledge of global solar radiation is indispensable for the proper and effective design and estimation of solar system. Solar radiation models are desirable for designing solar-energy systems and good evaluation for thermal of environmental buildings. However, direct measuring is not available in many places therefore the need for empirical equation to serve as an effective alternative to estimate solar radiation through the observed data. In this study, a prediction model equation was established and evaluated for Sokoto location using

multiple meteorological parameters. The result shows an excellent agreement between the measured and projected values which makes the model's equation suitable for estimating global solar radiation especially in the Sudan savannah agro ecological zone of Nigeria.

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