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Estimation of Global Solar Radiation using Sunshine and Temperature based Models in Makurdi, North-Central, Nigeria

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Abstract

Precise knowledge of solar radiation distribution at a particular geographical location is of great significance for the development of solar thermal and photovoltaic energy devices. The monthly mean daily data for global solar radiation and sunshine hours for a period of ten years for Makurdi (Latitude 7.7322°N, 8.5391°E) were obtained from the Nigerian Meteorological Agency, and used to develop a number of first order Angstrom-type correlations. The regression constants of 'a' and 'b' in Angstrom-page equation were found to be 0.273 and 0.558 respectively. Maximum and minimum measured monthly mean global solar radiations were 20.09 and 13.25MJ/m^2/day which occurs in the months of November and August respectively. Estimated monthly clearness index and monthly sunshine duration were used in modeling four temperature-based and two sunshine-based models. Estimated values of global solar radiation by the various models and the measured solar radiation were tested using statistical tools of mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), relative root mean square error (RRMSE), coefficient of residual mass (CRM), and Nash–Sutcliffe Coefficient (NS). The values of coefficient of determination (R^2) were also determined for each developed equation. Comparing these models, it was observed that the Louche model equation performed better in terms of coefficient of determination (R^2) and least values of MBE, RMSE, MPE, and CRM while, Hargreaves-Samani model have the least R^2.

Keywords: *Solar Radiation, clearness index, sunshine hours, regression constants and statistical tools*

Introduction

Solar energy is original renewable energy source on the earth's surface, and global solar radiation (R_s) plays an important role in a wide range of applications in areas such as meteorology, hydrology, chemical, physical and biological activities (Almorox *et al.,* 2013). Changes in the value of R_s greatly influence the hydrological cycle, terrestrial ecological systems, and the climate (Mehdizadeh *et al.,* 2016). Though, not all solar irradiance successfully reach terrestrial surface as interacting with atmospheric components causes reflection, diffusion and absorption action. According to Ometto (1981), about 51% of the extraterrestrial solar irradiance is fully available and utilized in the processes of biological and physical environment. Global solar of global solar radiation values are necessary in the forecast, study and design of solar thermal, and photovoltaic systems including estimating its economic viability. Global solar radiation values collected at sites over a given period is not only vital to the locality where the radiation data is collected but also for the wider neighborhood (Massaquoi, 1988). A study of the nation's distribution of global solar radiation requires knowledge of the radiation data in various regions, states and towns for the purpose of designing, marketing, and manufacturing of solar equipment that will meet the average global solar radiation available in different and specific regions and states of the country (Ibrahim, 1985).

Dependable measurement of R_s data is comparatively scarce in many developing countries of the world owing to the expensive nature of instruments, technical equipment, and maintenance requirements. Different R_s models are known to have been developed for estimating daily or monthly R_s by means of diverse techniques such as geostationary satellite images, neural networks, time series methods, physically radiative transfer models, and stochastic weather methods, which are generally based on different types of data including meteorological and geographical data (Piri and Kisi, 2015; Hassan *et al.,*

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2016). Quite a lot of effort has been put in collating, developing and analyzing solar radiation in Nigeria with the aim of developing and integrating renewable energy solar devices into the economy. Arinze and Obi, (1983) in their work used sunshine model to developed a correlation with solar radiation in Northern Nigeria with regression coefficients of a=0.2 and b=0.74. Sambo (1985) developed correlation with solar radiation using sunshine hours for Kano with the regression coefficients a=0.413 and b=0.241 using data between 1980-1984. Similarly, Burari *et al.,* (2001) developed a model for estimating global solar radiation in Bauchi with empirical regression coefficients of a=0.24 and b=0.46. Louis and Sunday (2003) used measurements of global solar radiation and sunshine duration data within the rainforest climatic zone of southern Nigeria (Onne) to establish an Angstrom-type correlation equation. The linear regression analysis of the global solar radiation and sunshine duration data by means of the least-squares technique gives our model to be the best correlation for the location of Onne with coefficients of a=0.23, b=0.38. Isikwue *et al*., (2012) proposed the coefficients for Angstrom-Prescott type of model for the estimation of global solar radiation in Makurdi-Nigeria using relative sunshine duration. The model constants of 'a' and 'b' obtained in their investigation were 0.138 and 0.488 respectively. Kaltiya *et al*., (2014) used the Angstrom-Page model to predict the global solar radiation for Makurdi. This was done by measuring, solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloudiness and bright sun-shine at the interval of one hour from 060:0 hrs to 18: 00 hrs daily for a period of six months (February to July, 2011).

The result obtained showed that the mean solar radiation, relative humidity, dry and wet bulb temperatures, hours of cloudiness and bright sun-shine for the location were; 191.64w/m^2, 60.10%, 30.24°C, 28.25°C, 7.72hrs and 5.28hrs respectively. The regression constants 'a' and 'b' in Angstrom-page equation were found to be 0.24 and 0.57 respectively. The performance of the variance between measured and calculated radiation were analyzed statistically using mean bias error (MBE) and root mean square error (RMSE) and found that there was a strong correlation between calculated and actual global solar radiation. Audu *et al.,* (2014) carried out studies using meteorological parameters to assess the feasibility of solar energy utilization in Makurdi. Measured solar radiation, relative sunshine hours, air temperature and relative humidity data for Makurdi covering a period of 10 years (2000 - 2010) were used to establish Angstrom type correlation equations. Among the models formulated, the model equation with R^2 of 84.3%, MBE of 1.079 x 10^{-1} and RMSE of 2.466 x 10^{-2}, which can best be used to estimate the global solar radiation, was obtained. From the formulated equation, the highest global solar radiation of 15.702 MJm^{-2}day^{-1} was estimated in the dry season against the measured value of 15.690 MJm^{-2}day^{-1} for the same period, while the lowest radiation of 11.805 MJm^{-2}day^{-1} was obtained for rainy season as against 11.354 MJm^{-2}day^{-1} of measured value. Adesina *et al.,* (2015) in an attempt to establish a model for predicting solar radiation of Nasarawa-Nigeria (Latitude of 8° 31' 45" N, Longitude of 7° 43' 27" E), measured solar radiation intensity and hours of bright sunshine from 06.00 hours to 18.00 hours on a daily basis for the months of January to December, 2013 for evaluation. The regression constants 'a' and 'b' were obtained to be 0.01 and 0.75 respectively and their performance were tested using Root mean square error (RMSE), Normalized root mean square error (NRMSE) and Nash-Sutcliffe coefficient (E). Measured solar radiation was compared to the predicted by the model and indicated no significant difference. Low Normalized Root Mean Square Error (NRMSE) of 0.04 % and Coefficient of Determination (R^2) 93.84 % showed a good agreement between the measured and predicted global solar radiation. Innocent *et al.,* (2015) used daily sunshine hours measured for a period of 6 years (1995-2000) to estimate mean global solar radiation in Gusau, a town in North-West Nigeria. Angstrom-Prescott model was then used to estimate the global solar radiation based on the monthly mean sunshine hours. The values of global solar radiation for Gusau ranged from 16.1676 - 21.6536 MJ/m^2/day under the period of study with mean value of 18.8015 MJ/m^2/day. Gajere and Abdullahi (2017) estimated global solar radiation with the data of maximum and minimum temperature for the month of February, 2017 which was obtained from the archive of weather online limited. The analysis shows the average global solar radiation of 25.551 MJ/m^2/day (7.1kwh/m^2/day), while the maximum and minimum global solar radiation of the location for the month under studies are 27.374 MJ/m^2/day and 24.119 MJ/m^2/day in that order. Salisu (2017) developed adaptive neuro fuzzy inference system (ANFIS) model for predicting the monthly average solar radiation in Nigeria. Air temperature of monthly mean minimum temperature, maximum temperature and relative humidity obtained from Nigerian Meteorological Agency (NIMET) were used as inputs to the ANFIS model and monthly mean global solar radiation was used as output of the model.

Statistical evaluation of the model was done based on root mean square error (RMSE) and correlation coefficient (R) to examine the accuracy of the developed model. The obtained result showed a good correlation between the predicted and measured solar radiation which proves ANFIS to be a good model for solar radiation prediction. Abdullahi *et al.,* (2017) utilized maximum and minimum temperature for February 2017 obtained from the website of weather online limited to estimate the global solar radiation of Makurdi using the Hagreaves–Sammani model. It was discovered from the result that the study location (Makurdi) has the maximum global solar radiation for February 2017 as 30.486 MJ/m^2/day, minimum global solar radiation of 23.871 MJ/m^2/day, and an average global solar radiation of 28.425 MJ/m^2/day respectively. Salihu and Chifu (2019) obtained data for a period of three years (2016-2018) to generate linear single variable temperature based model, linear single variable relative humidity based model and linear double variable temperature and relative humidity based model for Jos North, Plateau State. The peak values of the estimated solar radiation were April (46.02 MJ/m^2/day) and August (38.45 MJ/m^2/day) for the single variable temperature based model, March (47.88 MJ/m^2/day) and August (34.14 MJ/m^2/day) for the single variable relative humidity based model and March (47.88 MJ/m^2/day) and August (34.14 MJ/m^2/day) for the double variable temperature-relative humidity based model, based on maximum and minimum values respectively. The estimated solar radiations were tested using the mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) statistical techniques for each model and found that the double variable model with least values of MBE, RMSE and MPE is most suitable for predicting global solar radiation in the area under study. Studies have shown that the regression coefficients are not universal but depend on the climatic conditions. Nigeria is a country within the tropics having substantial amount of solar radiation which could be utilize for the operation of solar thermal and solar photovoltaic applications such as solar powered pumps, solar irrigation systems lift irrigated projects, solar photovoltaic electricity, solar water heating, solar drying, solar refrigeration etc. This paper analysis's the accuracy and applicability of 4 sunshine-based models and 2 temperature-based models to estimate R_s.

2.Materials and Methods

2.1 Study Area and Experimental Data.

The location of the study is Makurdi which is the capital of Benue state located on latitude 6.5ºN-8.5ºN and longitude 7.5ºE-10ºE in the North-Central region of Nigeria. The state occupies a land area of about 33,955 square kilometers. The land is made up of undulating plains at elevations ranging from 150-300m above sea level. The town enjoys a tropical climate with two distinct seasons. The rainy season spans from April to October, while the dry season is from November to March. The state experiences annual rainfall which varies from 1,750mm in the southern part to 1,250mm in the north with average annual temperature variation of 32-38ºC. The global solar radiation and sunshine hour data used in this study was obtained from the Gunn-Bellani radiation integrator at the Nigerian Air force Base Makurdi-Nigeria situated at an altitude of about 106.4 m above the sea level.

*2.2. Models for Estimation of Solar Radiation***.**

A number of empirical correlations which determine the relation between R_s and various meteorological parameters have been developed to estimate daily or monthly R_s in literature, such as sunshine-based models, cloud-based models, temperature based models, and other meteorological parameter-based models (Almorox *et al.*, 2011; Besharat *et al.,* 2013). The sunshine and temperature based models are the most frequently used around the global (Abraha and Savage; Besharat *et al.*, 2013). In this paper, 6 representative models are chosen to forecast R_s, including 4 sunshine-based models and 2 temperature based models

2.2.1. Sunshine-Based Models

Model 1

Angstrom-Prescott model, (AP). Angstrom (1924) derived a simple linear relationship between the ratio of average daily R_s and the corresponding value on a completely clear day at a given location and the ratio of average daily sunshine duration to the maximum possible sunshine duration, which is the most widely, used correlation for estimating daily R_s. Prescott (Prescott, 1940) modified the method and proposed the following equation:

$$R_s = \left[a + b\left(\frac{n}{N}\right)\right] \times R_a \quad (1)$$

Where;
R_s is the global solar radiation, MJ/m^{2}day
R_a is the extraterrestrial radiation, MJ/m^2/day
n is sunshine duration, hours
N is maximum possible sunshine duration, hours
a and b are the empirical coefficients peculiar to locations.

The monthly average daily extraterrestrial radiation on a horizontal surface (R_a) can be computed from the following equation as given by Duffie and Beckman (1991):

$$R_a = \frac{24}{\pi} I_{sc} \times \left(1 + 0.033\cos\frac{360D}{365}\right) \times (\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta) \quad (2)$$

Where;
I_{sc} is the solar constant, 1353 W/m^2
ϕ is the latitude of the site
δ is the solar declination
ω_s is the mean sunrise hour angle for the given month
D is the number of days of the year starting from January first to December 31.

The solar declination (δ) and the mean sunrise hour angle (ω_s) can be calculated by utilizing equations 3 and 4 respectively as reported by Duffie and Beckman (1991).

$$\delta = 23.45\sin\left[\frac{360(D+284)}{365}\right] \quad (3)$$
$$\omega_s = \cos^{-1}[-\tan(\delta)\tan(\phi)] \quad (4)$$

For a given month, the maximum possible sunshine duration (N) can be computed by using equation 5 expressed by Duffie and Beckman (1991):

$$N = \frac{2}{15}\omega_s \quad (5)$$

Model 2

Louche model. Louche *et al* (1991) modified the Angstrom-Prescott model through the use of the ratio of (n/N_{nh}) instead of (n/N). The new expression is as follows:

$$R_s = \left[a + b\left(\frac{n}{N_{nh}}\right)\right] \times R_a \quad (6)$$

$$\frac{1}{N_{nh}} = \frac{0.8706}{N} + 0.0003 \quad (7)$$

Where;
a and b are the empirical coefficients for the location.

Model 3

Glover-McCulloch model, (GM). Latitudes of locations are known to have effect on the amount of solar radiation received by locations. Glover and McCulloch (1958) suggested an expression that put the effect of latitude of the location into consideration. This serves as an additional input and is applicable for φ<60.

$$R_s = \left[a \cos\phi + b\left(\frac{n}{N}\right)\right] \times R_a \quad (8)$$

Where;
a and b are the empirical coefficients

Model 4

Almorox-Hontoria model (AH). Almorox and Hontoria (2004) derived an exponential type equation as follows:

$$R_s = \left[a + b\exp\left(\frac{n}{N}\right)\right] \times R_a \quad (9)$$

Where;
a and b are the empirical coefficients.

2.2.2. Temperature-Based Models

Model 5

Hargreaves-Samani model (HS). Hargreaves and Samani (Hargreaves and Samani, 1982; Hargreaves, 1994) recommended a simple equation to estimate R_s which required only maximum and minimum temperature data; the equation is presented as follows:

$$R_s = K_s(\sqrt{T_{\max} - T_{\min}}) \times R_a \quad (10)$$

Where;
$T_{\min}$ and $T_{\max}$ are the mean minimum air temperature and mean maximum air temperatures
K_s is the empirical coefficient which according to Hargreaves (1994) is taken to be 0.16 for locations found in the interior regions, and 0.19 for coastal regions. Makurdi, the Benue state capital is an hinterland town.

Model 6

Annandale model (AN). Annandale *et al.*, (2002) in their work derived a model based on Hargreaves-Samani model by accounting for the effects of reduced altitude and atmospheric thickness on R_s. The equation is presented as follows:

$$R_s = \left[a(1 + 2.7 \times 10^{-5}Z)\left(Tmin_{max}{}^{0.5}\right) \times R_a\right] \quad (11)$$

Where;
a is an empirical coefficient
Z is the altitude of the location, km
The empirical regression coefficients of 'a' and 'b' are calculated from the relationship given by **Tiwari *et al*.**, (1997).

$$a = -0.110 + 0.235\cos\phi + 0.323\left(\frac{n}{N}\right) \quad (12)$$

$$b = 1.449 - 0.553\cos\phi - 0.694\left(\frac{n}{N}\right) \quad (13)$$

The recommended average day and declination by Klein (1977) for each month are given in Table 1.

Table 1. Recommended average day and declination for each month (Klein, 1977)

Months	Day of the year	Date	Declination (°)
January	17	17 Jan.	-20.92
February	47	16 Feb.	-13.29
March	75	16 Mar	-2.42
April	105	15 Apr.	9.41
May	135	15 May	18.79
June	162	11 June	23.09
July	198	17 July	21.18
August	228	16 Aug.	13.45
September	258	15 Sept.	2.22
October	288	15 Oct.	-9.60
November	318	14 Nov.	-18.91
December	344	10 Dec.	-23.05

2.3. Statistical Evaluation

To evaluate the performance of the studied models for their adequacy to estimate R , the following statistical tools of errors were used; Coefficient of Determination (R^2), Root Mean Square Error (RMSE), Relative Root Mean Square Error (RRMSE), Nash–Sutcliffe Coefficient (NS), Mean Bias Error (MBE), Mean Percentage Error (MPE), and Coefficient of Residual Mass (CRM) (Bandyopadhyay *et al.,* 2008;Feng *et al.,* 2017; Feng *et al.,* 2017)..

Where;

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i-\overline{X})(Y_i-\overline{Y})\right]^2}{\sum_{i=1}^{n}(X_i-\overline{X})^2\sum_{i=1}^{n}(Y_i-\overline{Y})^2} \quad (14)$$

$$RMSE = \sqrt{1/n\sum_{i=1}^{n}(Y_i - X_i)^2} \quad (15)$$

$$RRMSE = \frac{\sqrt{1/n\sum_{i=1}^{n}(Y_i-X_i)^2}}{\overline{X}} \quad (16)$$

$$NS = 1 - \frac{\sum_{i=1}^{n}(Y_i-X_i)^2}{\sum_{i=1}^{n}(X_i-\overline{X})^2} \quad (17)$$

$$CRM = \frac{\sum(X_i-Y_i)}{n\overline{Y}_{smean}} \quad (18)$$

$$MBE = \frac{\sum_{i=1}^{n}(Y_i-X_i)}{n} \quad (19)$$

$$MPE = \sum_{i=1}^{n}\left(\frac{\frac{Y_i-X_i}{\overline{X}}}{n}\times 100\right) \quad (20)$$

Where;

X_i and Y_i denote the measured and estimated values, $\overline{X}$ and $\overline{Y}$ represent the corresponding mean R_s values, respectively, the subscript i refers to the ith value of the

3.Results and Discussions

Table 2: Summary of monthly mean sunshine duration, maximum possible sunshine hours, estimated empirical constants, and extraterrestrial radiation for Makurdi (1999-2008)

Months	a	b	n	N	n/N	R_a	Measured R_s
January	0.311	0.494	6.79	11.60	0.5853	33.38	17.93
February	0.300	0.519	6.47	11.75	0.5506	35.71	19.83
March	0.289	0.543	6.16	11.95	0.5154	37.37	19.89
April	0.294	0.532	6.47	12.17	0.5316	36.36	18.79
May	0.305	0.511	6.95	12.35	0.5627	33.05	18.31
June	0.272	0.580	5.75	11.82	0.4864	30.49	17.53
July	0.236	0.658	4.35	12.40	0.3508	30.76	15.40
August	0.217	0.699	3.56	12.25	0.2906	33.87	13.25
September	0.247	0.635	4.61	12.04	0.3828	36.73	16.63
October	0.299	0.521	6.43	11.82	0.5439	36.90	19.02
November	0.340	0.434	7.84	11.64	0.6735	34.02	20.09
December	0.331	0.454	7.45	11.56	0.6444	32.43	19.22

Table 3: Estimated monthly mean of global solar radiation for various models

Months	Model 1 (R_s)	Model 2 (R_s)	Model 3 (R_s)	Model 4 (R_s)	Model 5 (R_s)	Model 6 (R_s)
January	20.03	18.81	19.93	39.98	17.19	33.43
February	20.91	19.63	20.82	42.85	21.77	40.82
March	21.25	19.94	21.16	44.77	20.82	37.61
April	20.97	19.68	20.87	43.60	14.87	27.33
May	19.58	18.38	19.49	39.72	15.88	30.27
June	16.89	15.81	16.82	37.05	15.70	26.70
July	14.35	13.46	14.29	36.00	13.03	19.22
August	14.22	13.36	14.16	39.00	14.17	19.22
September	18.00	16.87	17.91	43.27	16.31	25.19
October	21.48	20.17	21.38	44.15	16.83	31.45
November	21.51	20.25	21.40	40.52	19.70	41.86
December	20.22	19.02	20.12	38.77	21.63	44.76

Table 4: Summary of mean monthly clearness index for Makurdi for variation models (1999-2008)

Months	Measured R_s/R_a	Model 1 R_s/R_a	Model 2 R_s/R_a	Model 3 R_s/R_a	Model 4 R_s/R_a	Model 5 R_s/R_a	Model 6 R_s/R_a
January	0.537148	0.600060	0.563511	0.597064	1.197723	0.514979	1.001498
February	0.555307	0.58555	0.549706	0.58303	1.199944	0.609633	1.143097
March	0.532245	0.568638	0.533583	0.56623	1.19802	0.557131	1.006422
April	0.516777	0.576733	0.541254	0.573982	1.19912	0.408966	0.751650
May	0.554009	0.592436	0.556127	0.589713	1.201815	0.480484	0.915885
June	0.574943	0.553952	0.518531	0.551656	1.215153	0.514923	0.875697
July	0.500650	0.466515	0.437581	0.464564	1.170351	0.423602	0.624837
August	0.391202	0.419841	0.394449	0.418069	1.151461	0.418364	0.567464
September	0.452763	0.490063	0.459298	0.487612	1.178056	0.444051	0.685815
October	0.515447	0.582114	0.546612	0.579404	1.196477	0.456098	0.852304
November	0.593535	0.632275	0.595238	0.629042	1.191064	0.579071	1.230453
December	0.592661	0.623497	0.586494	0.620413	1.195498	0.666975	1.380204

Table 5: Maximum, minimum and average monthly mean global solar radiation for various Models

Rank	Measured	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Maximum	20.09	21.51	20.25	21.40	44.77	21.63	44.76
Minimum	13.25	14.22	13.36	14.16	36.00	13.03	19.22
Average	17.99	19.11	17.94	19.03	40.81	17.33	31.49

Table 6: Statistical error indicators values for the models

Models	RRMSE	RMSE	MPE	NS	CRM	MBE
Angstrom (1)	0.0836	1.5052	0.06263	0.7075	-0.0626	1.1267
Louche (2)	0.0502	0.9034	-0.00236	0.8946	0.0024	-0.0425
Glover-McCulloch (3)	0.0796	1.4321	0.05771	0.7352	-0.0577	1.0383
Almorox-Hontoria (4)	1.2755	22.9461	1.26825	-66.9826	-1.2683	22.8158
Hargreaves-Samani (5)	0.1101	1.9815	-0.03701	0.4930	0.0370	-0.6658
Annandale (6)	0.8336	14.9975	0.75028	-28.0416	-0.7503	13.4975

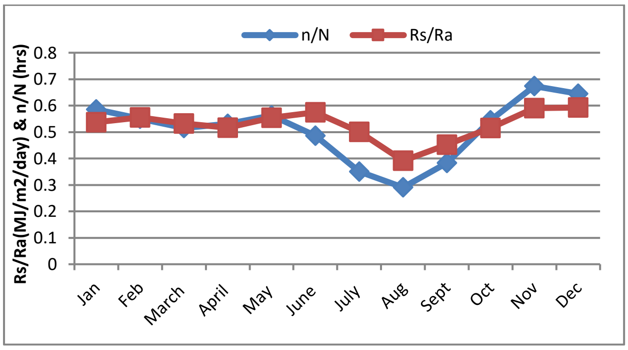

Figure 1: Correlation of monthly variation of R_s/R_a and n/N for Makurdi (1999 - 2008)

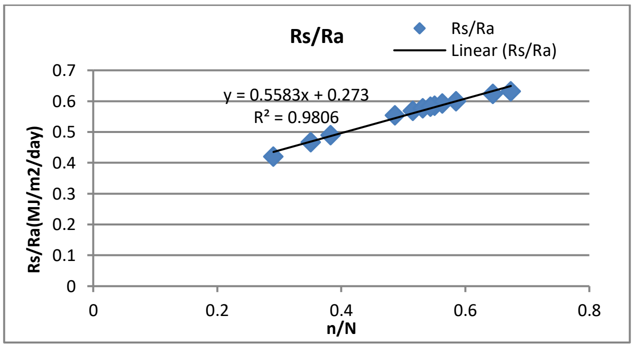

Figure 4: Angstrom-Prescolt (1940) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration (n/N) for Makurdi (1999 - 2008)

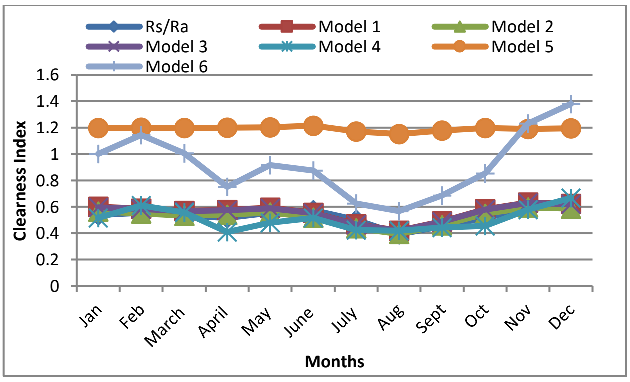

Figure 2: The comparison between estimated clearness index and the six modeled values for Makurdi (1999-2008)

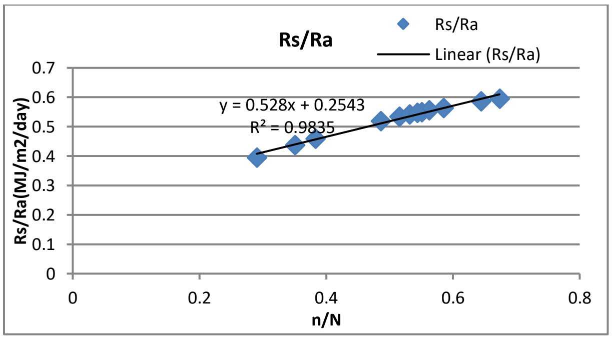

Figure 5: Louche (1991) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration(S/So) for Makurdi (1999 - 2008)

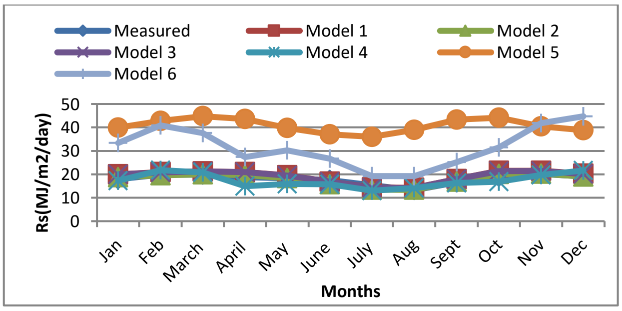

Figure 3: Measured and estimated monthly mean global solar radiation for Makurdi (1999-2008)

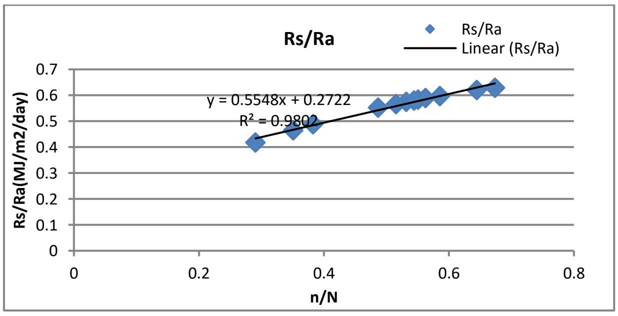

Figure 6: Glover Mc-culloch (1958) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration (n/N) for Makurdi (1999 - 2008)

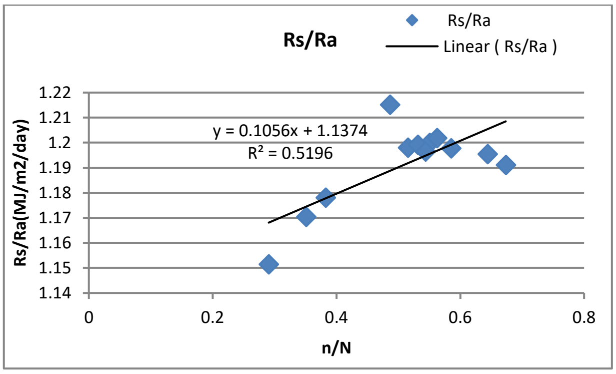

Figure 7: Almorox-Hontaria (2004) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration (n/N) for Makurdi (1999 - 2008)

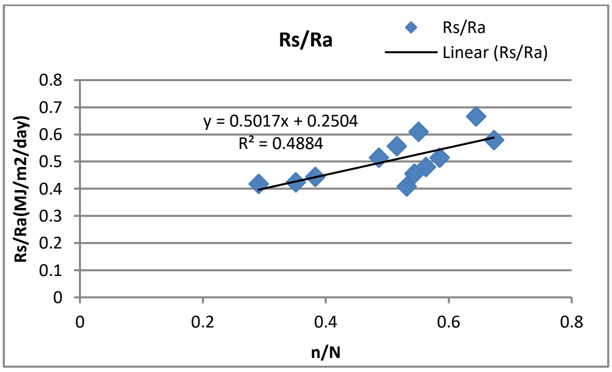

Figure 8: Hargreaves Samani (1982) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration (n/N) for Makurdi (1999 - 2008)

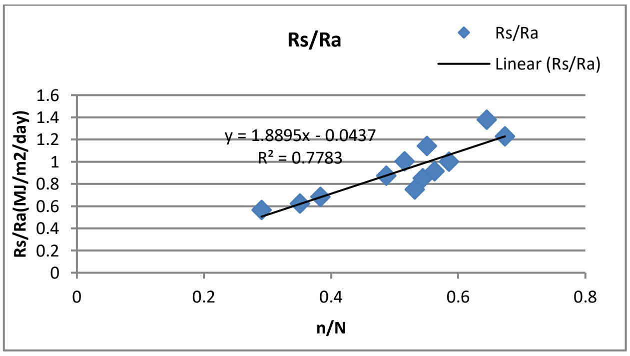

Figure 9: Annadale (2002) model fitting for variation of clearness index (R_s/R_a) versus sunshine duration (n/N) for Makurdi (1999-2008)

The extraterrestrial solar radiation, R_s (MJ/m^2/day) and the monthly day length, N (hrs) were calculated using relevant equations. The input variables for the computation of the monthly mean global solar radiation for Makurdi (1999- 2008) is shown in Table 2. It is evident that the sunshine duration is up to 50 percent throughout the year with exception in the months of June, July, September and August. The months of August exhibited the lowest value of 0.2906, while the month of November has the highest value of 0.593535 (Table 2). Equations 12 and 13 were used to calculate the monthly empirical constants of 'a' and 'b' as shown in table 2. The empirical constants were then used to compute the average global solar radiation for the selected models. With the empirical constants of 'a' and 'b' as 0.273 and 0.558 respectively, the developed correlation for solar radiation estimate for Makurdi is:

$$R_s = \left[0.273 + 0.558\left(\frac{n}{N}\right)\right] \times R_a$$

The coefficient of determination, R^2, (98.0%) obtained for this investigation is shown in Figure 4. The value of R_s/R_a (0.391202) corresponding to the lowest value of n/N (=0.2906) and R_s (13.25MJ/m^2/day) in the month of August is a clear indication of the poor sky condition of the location. This is often the weather condition during the wet season which is from April to October observed in Makurdi. This period is mainly characterized to a great extend by cloud cover. It can be seen from Table 4 that, both the measured and estimated clearness indexes have the lowest values in the month of August for the year. The comparisons between estimated clearness index and the six modeled values for Makurdi for a duration of ten years (1999-2008) are shown in Table 4 and Figure 2. There exist a resemblance in both patterns of R_s/R_a and n/N as observed from the figure, a trench for the months of June to September with its peak in the month of August. This period is noted usually characterized by heavy downpour with peak in the month of August. Accompanying this is poor state of the atmospheric condition (cloudy sky condition) with low solar radiation. Nevertheless, after the August minimum value, both the clearness index and the sunshine duration increased remarkably with the cloud cover crossing over the clearness index with climax values for both in the month of November. This clearly indicates that a clear sky will visibly fall in the dry season and high solar radiation will be experience. From the analyses of the data obtained, Makurdi has maximum, minimum and mean global solar radiation of 20.09 MJ/m^2/day, 13.25 MJ/m^2/day, and 17.99 MJ/m^2/day respectively. Predicted values using Angstrom-Prescolt model, Louche model, Glover Mc-culloch model and Hargreaves Samani model gave values close to the measured ones. However, the estimated values for Almorox-Hontaria model and Annadale model had wide deviation from the measured values. The monthly mean global solar radiation of 21.77 MJ/m^2/day obtained in this study for Makurdi in the month of February is close to the value obtained by Bernadette *et al*., (2013) (23.831 MJ/m^2/day) using Hagreaves-Sammani model. The mean bias error (MBE) provides information on the long term performance of the models. A positive value for MBE indicates an overestimation while, a negative MBE shows underestimation. The root mean square error (RMSE) gives information on the short term performance of a model. It is desirable that a positive low value is obtained. Mean percentage error (MPE) test provides information on long term performance. A positive value for MPE indicates an average overestimation while, a negative value of observed MPE gives underestimation. A positive value for coefficient of residual mass (CRM) indicates underestimation of the measured values while a negative value indicates overestimation of the measured values. A zero value of CRM gives a perfect estimation. The relative root mean square error (RRMSE) is dimensionless, and takes values from 0 (perfect fit) to ∞ (the worst fit) while, NS is dimensionless, taking on a value from 1 (perfect fit) to−∞ (the worst fit). From the statistical error indicators values (Table 5), it clearly shows that Angstrom, Glover McCulloch, Almorox-Hontaria and Annadale have overestimated the solar radiation values while, Louche and Hargreaves-Samani models have underestimated values. The performance of the models in terms of their empirical constants and coefficient of determination (R^2), are shown in figures 5-10. The developed empirical correlation models for the six models for Makurdi (1999 - 2008). The results are summarized below:

1) The empirical correlation for Angstrom-Prescolt model in equation (1) is given as:

$$R_s = \left[0.273 + 0.558\left(\frac{n}{N}\right)\right] \times R_a$$

The coefficient of determination, R^2 (98%) obtained for this analysis shows that the model is excellently fits for the data (Figure 3).

2) The empirical correlation for Louche model in equation (6) is

$$R_s = \left[0.254 + 0.528\left(\frac{n}{N_{nh}}\right)\right] \times R_a$$

The coefficient of determination, R^2 (98.30%) obtained for this analysis shows that the model is excellently fits for the data (Figure 6).

3) The empirical correlation Glover-McCulloch model in equation (8) is

$$R_s = \left[0.272\, cos\, \phi + 0.554\left(\frac{n}{N}\right)\right] \times R_a$$

The coefficient of determination, R^2 (98%) obtained for this analysis shows that the model is excellently fits for the data (Figure 7).

4) The empirical correlation for Almorox-Hontoria model in equation (9) is

$$R_s = \left[1.137 + 0.105\, exp\left(\frac{n}{N}\right)\right] \times R_a$$

The coefficient of determination, R^2 (51.90%) obtained for this analysis shows that the model is not fit for the data despite measuring up to 50% (Figure 8).

5) The empirical correlation for Hargreaves-Samani (HS) model in equation (10) is

$$R_s = K_s(\sqrt{T_{\max} - T_{\min}}) \times R_a$$

The coefficient of determination, R^2 (48.8%) obtained for this analysis shows that the model did not fit well for the data as it fails to meet a 50% mark (Figure 9).

6) The empirical correlation for Annandale model in equation (11) is

$$R_s = \left[-0.043(1 + 2.7 \times 10^{-5}Z)\left(Tmin_{max}{}^{0.5}\right) \times R_a\right]$$

The coefficient of determination, R^2 (77.80%) obtained shows a partial fit of the data (Figure 10). Louche model performed excellently in term of coefficient of regression (R^2), MPE, RMSE, and NS than the other models. This work is in confirmation to that of Isikwue *et al*., (2012) who used solar radiation data from 2001-2010 for Makurdi and obtained empirical constants ‘a’ and ‘b’ of 0.138 and 0.488 respectively with coefficient of determination, R^2 of 79.5%.

Conclusion

The results from the study clearly demonstrate the significance of developing empirical equations for estimating solar radiations for locations using primary data from meteorological stations. From the measured data analyzed, the maximum values of global solar radiation appears in the month of November with 20.09 MJm^2/day during the dry season, while minimum value of 13.25 MJm^2/day was obtained in August in the wet season with mean annual value of 17.99 13.25 MJm^2/day. With the amount of solar radiation endowed with, Makurdi and its environs can utilize solar thermal and photovoltaic systems for space heating application for drying, room heating in homes, health and educational facilities; solar water heating, solar cooking, solar distillation, electricity production among others if proper design and development of such systems is encourage.

References

[1]. Almorox J., M. Bocco M., and Willington E. (2013), Estimation of Daily Global Solar Radiation from Measured Temperatures at Ca˜nada de Luque, C´ordoba, Argentina, Journal of Renewable Energy, Vol. 60, pp. 382–387.

[2]. Mehdizadeh S., Behmanesh J. and Khalili K (2016), Comparison of Artificial Intelligence Methods and Empirical Equations to Estimate Daily Solar Radiation, Journal of Atmospheric and Solar Terrestrial Physics, Vol. 146, pp. 215–227

[3]. Massaquoi, J.G.M. Global solar radiation in Sierra Leone (West Africa) (1988), Solar Wind Technology, Vol. 5, pp 281–283.

[4]. Ibrahim S.M.A (1985), Predicted and Measured Global Solar Radiation in Egypt, Solar Energy, Vol. 35, pp. 185-188.

[5]. Hassan G.E., Youssef, M.E., Mohamed, Z.E., .Ali, M.A and. Hanafy A.A. (2016), New Temperature-Based Models for Predicting Global Solar Radiation. Applied Energy, Vol.179, pp. 437–450.

[6]. Piri J and Kisi O (2015), Modelling Solar Radiation Reached to the Earth using ANFIS, NN-ARX, and Empirical Models (Case studies: Zahedan and Bojnurd stations), Journal of Atmospheric and Solar Terrestrial Physics, Vol. 123, pp. 39–47

[7]. Arinze, E.A and Obi, S.E (1983). Solar Energy Availability and Prediction in Northern Nigeria. Nigeria Journal of Solar Energy, Vol. 3, pp. 3-10

[8]. Burari, F.W, Sambo, A.S and Mshelia, E.D. (2001), Estimation of Global Solar Radiation in Bauchi. Nigeria Journal Renewable Energy, Vol. 9, pp. 34 - 36.

[9]. Louis E. Akpabio and Sunday E. Etuk (2003), Relationship Between Global Solar Radiation and Sunshine Duration for Onne, Nigeria, Turkish Journal of Physics, Vol. 27, pp. 161-167

[10]. Isikwue, B.C., Amah, A.N. and Agada, P. O (2012), Empirical Model for the Estimation of Global Solar Radiation in Makurdi, Nigeria, Global Journal of Science Frontier Research Physics and Space Science, Vol. 12, No. 1, pp. 59-61

[11]. M. S. Kaltiya, M. S. Abubakar and I.N. Itodo (2014), Prediction of Global Solar Radiation Using Angstrom-Page Equation Model for Makurdi Benue State, Nigeria, American Journal of Engineering Research, AJER, Vol. 3, No. 8, pp. 145-150

[12]. Audu M. O, Utah U. E and Ugwanyi J. U (2014), Estimation of Global Solar Radiation over Makurdi, Nigeria, Asian Journal of Applied Sciences, Vol. 2, No. 2, pp. 126-132.

[13]. Adesina, M. Adedeji, Ibrahim, J. Sunday and Ponzi. U. Dul (2015), A Model for Predicting Solar Radiation for Nasarawa, Nigeria, International Journal of Modern Engineering Sciences, Vol. 4, No. 1, pp. 22-30

[14]. Innocent A. J, Jacob O. E, Chibuzo G. C, James I. and Odeh .O (2015), Estimation of Global Solar Radiation in Gusau, Nigeria, International Journal of Research in Engineering and Technology, IJRET, Vol. 3, No. 2, pp. 27-32

[15]. Gajere E. N and Abdullahi Ayegba (2017), Estimation of Global Solar Radiation of Plateau state, Nigeria, International Journal for Research and Development in Technology, Vol. 7, No. 6, pp. 159-163

[16]. S. Salisu (2017), New Model for Solar Radiation Estimation from Measured Air Temperature and Relative Humidity in Nigeria, Nigerian Journal of Technology, NIJOTECH, Vol. 36, No. 3, pp. 917- 922

[17]. Abdullahi Ayegba, Jegede, John Olu and Ahiaba Nelson Odoma (2017), A Study of the Global Solar Radiation of Makurdi, Benue State, Nigeria, American International Journal of Research in Science, Technology Engineering and Mathematics, Vol. 18, No. 1, pp. 70-75.

[18]. Salihu M. Aliyu and Chifu E. Ndikilar (2019), Empirical Models for Estimation of Global Solar Radiation in Jos, Plateau State, Nigeria, Dutse Journal of Pure and Applied Sciences, DUJOPAS, Vol. 5, No. 2, pp. 114-121.

[19]. J. Almorox, C. Hontoria, and M. Benito (2011), Models for obtaining daily global solar radiation with measured air temperature data in Madrid (Spain), Applied Energy, Vol. 88, No. 5, pp. 1703-1709.

[20]. M. G. Abraha and M. J. Savage (2008), Comparison of Estimates of Daily Solar Radiation from Air Temperature Range for Application in Crop Smulations, Agricultural and Forest Meteorology, Vol. 148, No. 3, pp. 401–416.

[21]. F. Besharat, A.A. Dehghan, and A.R. Faghih (2013), Empirical models for Estimating Global Solar Radiation: Are View and Case Study Renewable and Sustainable Energy Reviews, Vol. 21, pp. 798–821.

[22]. Angstrom. Solar and Terrestrial Radiation (1924), Report to the International Commission for Solar Research on Actino-Metric Investigations of Solar and Atmospheric Radiation, Quarterly Journal of the Royal Meteorological Society, Vol. 50, No. 210, pp. 121-126.

[23]. J. A. Prescott (1940), Evaporation from Water Surface in Relation to Solar Radiation, Transactions of the Royal Society of South Australia, Vol. 64, pp. 114-118

[24]. Louche, G. Notton, P. Poggi and G. Simonnot (1991), Correlations for Direct Normal and Global Horizontal Irradiationon a French Mediterranean Site, Solar Energy, Vol. 46, No. 4, pp. 261-266.

[25]. J. Glover and J. S. G. McCulloch (1958), The Empirical Relation Between Solar Radiation and Hours of Sunshine, Quarterly, Journal of the Royal Meteorological Society, Vol. 84, No. 360, pp. 172-175

[26]. G. H. Hargreaves and Z. A. Samani (1982), Estimating potential evapotranspiration, Journal of the Irrigation and Drainage Division, Vol. 108, No. 3, pp. 225–230.

[27]. G. H. Hargreaves (1994), Simplified Coefficients for Estimating Monthly Solar Radiation. In North America and Europe, DepartmenTal paper, Departmental of Biological and Irrigation Engineering, Utah State University.

[28]. J. Almorox and C. Hontoria (2004), Global Solar Radiation Estimation using Sunshine Duration in Spain, Energy Conversion and Management, Vol. 45, No. 9-10, pp. 1529-1535.

[29]. J. Annandale, N. Jovanovic, N. Benad´e,and R.Allen (2002), Software for missing Data Error Analysis of Penman-Monteith Reference Evapotranspiration. IrrigationScience, Vol. 21, No. 2, pp. 57–67.

[30]. Tiwari, R.F and Sangeeta, T.H (1997), Solar Energy, Vol. 24, No. 6, pp. 89-95.

[31]. Klein, S.A (1977), Calculation of Monthly Average Insolation on Titled Surfaces, Solar Energy, Vol. 19, pp. 325-329

[32]. Bandyopadhyay A., Bhadra A., Raghuwanshi N. S., and Singh R (2008), Estimation of Monthly Solar Radiation from Measured Air Temperature Extremes, Agricultural and forest meteorology, Vol. 148, No. 11, pp. 1707–1718.

[33]. Y. Feng, N. Cui, D. Gong, Q. Zhang, and L. Zhao (2017), Evaluation of Random Forests and Generalized Regression Neural Networks for Daily Reference Evapotranspiration Modeling, Agricultural Water Management, Vol. 193, pp. 163-173.

[34]. Y. Feng,Y.Jia, N.Cui, L. Zhao, C.Li, and D. Gong (2017), Calibration of Hargreaves Model for Reference Evapotranspiration Estimation in Sichuan Basin of Southwest China, Agricultural Water Management, Vol. 181, pp. 1-9.

[35]. Bernadette Isikwue , Salisu Dandy and Moses Audu (2013), Testing the Performance of Some Empirical Models for Estimating Global Solar Radiation Over Makurdi, Nigeria, Journal of Natural Sciences Research, Vol. 3, No. 5, pp. 165-170.

[36]. Duffie J. and Beckman W. (1991). Solar Engineering of Thermal Processes. John Wiley and Sons Inc., Second edition