

Developed Empirical Models for the Estimation of Global Solar Radiation with Sunshine Hours and other Meteorological Data on a Horizontal Surface in Some Cities in North Central Geopolitical Zone in Nigeria

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ABSTRACT

Measurement of global solar radiation and its components is not possible for all locations due to non-availability of solar radiation measuring instruments. This prompted the use of different empirical models that based on climatological parameters of a location for the estimation of global solar radiation. In this study, monthly measured global solar radiation H_m , monthly mean extraterrestrial global solar radiation H_o , monthly mean daylight hours (N) and monthly mean hours of bright sunshine (n), latitudes (Φ), maximum temperature (T_{max}) and relative humidity (RH) as geographical and meteorological parameters for estimating monthly mean global solar radiation in Abuja (9.067° N, 7.483° E), Minna (9.613° N, 6.557° E) and Ilorin (8.500° N, 4.550° E) cities in north central geopolitical zone of Nigeria for the period of 11 years (2000 – 2010) were investigated. Meteorological data for this investigation were gotten from the archives of National Aeronautics and Space Administration (NASA). Using empirical Angstrom model as a base model, sunshine based regression equations, maximum temperature and relative humidity based equations were developed for the cities. The correlation coefficient (R) and Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Percentage Error (MPE) and t - stat values were determined for each proposed models and were used to evaluate the performance of each of the developed models.

Key Words: Renewable energy, global solar radiation, sunshine hours, empirical models, maximum temperature.

INTRODUCTION

Solar energy is the clean, abundant, renewable and sustainable energy resource from the sun which reaches the earth in form of light and heat (Okonkwo and Nwokoye, 2011). Among the various types of clean and renewable sources, solar energy appears to be the most favoured option because of its infinite and nonpolluting nature. According to Bolaji (2005), solar energy is an ideal alternative source of energy because it is abundant and inexhaustible. As the solar radiation passes through the atmosphere, it undergoes absorption and scattering by various constituents of the atmosphere. The amount of solar radiation finally reaching the surface of earth depends quite significantly on the concentration of airborne particulate matter, gaseous pollutants and water (vapour, liquid or solid) in the sky, which can further attenuate the solar energy and change the diffuse and direct radiation ratio (Falayi *et al.*, 2011). The global solar radiation can be divided into two components: diffuse solar radiation, which results from scattering caused by gases in the Earth's atmosphere, dispersed water droplets and particulates; and direct solar radiation, which have not been scattered. Global solar radiation is the algebraic sum of the two components.

Since the solar radiation reaching the earth's surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is essential. The availability of these data may be of the form of types of irradiance, total, diffuse, direct, surface placement and horizontal, inclined, facing south or deviated from south or in terms of time: hourly, daily, monthly or yearly. Each of these forms is important and has particular usage in specific applications (Debazit and Bimal, 2013).

The design of a solar energy conversion system requires accurate knowledge about the availability of global solar radiation and its components at any location of interest. Precise knowledge of the solar radiation data for a particular location is a key to estimation of the current performance and economic sustainability of solar energy systems. More recently global solar radiation has been studied due to its importance in providing energy for Earth's climatic system. In some places where radiation measurements are scanty, theoretical forecast of the available of solar energy can be used to predict these measurements from measured standard weather parameters such as air temperature, relative humidity, effective sunshine duration (Falayi *et al.*, 2008).

Many researchers have developed empirical equations that correlate the global solar radiation with sunshine hours and other meteorological data of different locations in Nigeria. Okonkwo and Nwokoye (2014) analyzed solar energy parameters in Bida, Nigeria for a time period of thirteen years (2000 – 2012). Agbo et al (2010) developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna. Ugwu and Ugwuanyi (2011) studied on the performance assessment of Hargreaves model in estimating solar radiation in Abuja using Minimum Climatological Data. Adekunle and Emmanuel (2014) studied on the correlation of global solar irradiance with some meteorological parameters and validation of some existing solar radiation models with measured data over selected climatic zones in Nigeria of which Minna is part of their studied site. Yakubu and Medugu (2012) studied the relationship between the global solar radiation and the sunshine duration in Abuja, Nigeria.

Accurate modeling depends on the quality and quantity of the measured data used and is a better tool for predicting the global solar radiation of location where measurements are not available. Quality of data deals with the source of the data used, while quantity deals with the number of years collected data used for the estimation of global solar radiation covered. The main aim of this study is to develop both one-parameter and multiple-parameter regression models (equations) for predicting monthly daily global solar radiation on horizontal surface for Abuja, Minna and Ilorin in north central geopolitical zone of Nigeria

Data Acquisition

Daily values of global solar radiation, sunshine duration, hours of bright sunshine, maximum temperature, relative humidity were obtained from the archives of National Aeronautics and Space Administration (NASA). The obtained data covered the period of 11 years (2000 – 2010) for Abuja, Minna and Ilorin. The monthly data were analyzed into monthly mean values as presented in table 1, table 2 and table 3 below.

Table 1: Monthly Mean of Climate Parameters for Abuja (2000 - 2010)

MONTH	$\bar{H}_0$ (MJm ⁻² day ⁻¹)	$\bar{H}_m$ (MJm ⁻² day ⁻¹)	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	$\bar{T}_{MAX}$ (°C)	$\bar{RH}$ (%)
January	32.33	21.30	6.62	11.50	0.66	0.57	31.65	36.86
February	34.87	22.30	7.71	11.60	0.64	0.67	32.19	44.68
March	37.10	23.25	7.63	12.50	0.63	0.61	31.12	62.29
April	37.88	21.98	6.17	11.90	0.58	0.52	29.12	80.64
May	37.46	20.04	6.23	12.20	0.54	0.51	28.32	82.81
June	36.84	18.13	5.32	12.40	0.49	0.43	26.94	85.04
July	36.95	15.95	4.44	12.50	0.43	0.36	25.97	86.63
August	37.38	14.75	3.61	12.50	0.39	0.29	25.72	87.1
September	37.06	17.14	4.39	12.30	0.46	0.36	26.83	85.23
October	35.29	19.24	5.71	12.00	0.55	0.47	28.17	81.68
November	32.89	21.45	6.20	11.80	0.65	0.52	30.36	63.23
December	31.75	21.00	6.53	11.60	0.66	0.56	31.13	46.58

Table 2: Monthly Mean of Climate Parameters for Minna (2000 – 2010)

MONTH	$\bar{H}_0$ (MJm ⁻² day ⁻¹)	$\bar{H}_m$ (MJm ⁻² day ⁻¹)	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	$\bar{T}_{MAX}$ (°C)	$\bar{RH}$ (%)
January	32.32	20.72	6.78	11.43	0.64	0.59	32.55	39.50
February	34.86	21.92	7.23	11.89	0.63	0.61	33.00	46.96
March	37.10	23.15	6.94	12.34	0.62	0.56	31.93	63.69
April	37.91	22.14	6.64	12.56	0.58	0.53	30.11	79.88
May	37.44	20.43	6.02	12.63	0.55	0.48	29.33	81.79
June	36.83	18.64	4.87	12.67	0.51	0.38	27.97	84.03
July	36.95	16.43	4.59	12.68	0.44	0.36	27.00	85.73
August	37.39	15.50	4.18	12.62	0.41	0.33	26.78	85.94
September	37.05	17.56	5.24	12.08	0.47	0.43	27.80	84.47
October	35.32	19.68	7.47	11.91	0.56	0.63	29.03	81.40
November	32.82	21.05	8.63	11.73	0.64	0.74	31.18	65.07
December	31.39	20.89	8.52	11.48	0.67	0.74	32.63	43.55

Table 3.11: Monthly Mean of Climate Parameters for Ilorin (2000 – 2010)

MONTH	$\bar{H}_0$ (MJm ⁻² day ⁻¹)	$\bar{H}_m$ (MJm ⁻² day ⁻¹)	$\bar{n}$ (hrs)	$\bar{N}$ (hrs)	K	$\bar{n}/\bar{N}$	$\bar{T}_{MAX}$ (°C)	$\bar{RH}$ (%)
January	32.79	20.55	6.58	11.89	0.63	0.55	31.32	52.94
February	35.18	21.54	7.29	11.58	0.61	0.63	31.05	63.02
March	37.22	22.12	7.10	11.87	0.59	0.60	30.07	76.5
April	37.84	20.71	5.98	12.1	0.55	0.49	29.16	83.73
May	37.20	19.22	5.86	12.65	0.52	0.46	28.72	84.22
June	36.54	17.47	5.37	12.57	0.48	0.43	27.47	85.52
July	36.68	15.19	3.68	12.41	0.41	0.30	26.57	86.45
August	37.24	13.95	3.13	12.12	0.37	0.26	26.42	86.38
September	37.09	16.18	4.10	11.99	0.44	0.34	27.32	85.77
October	35.56	17.97	5.81	11.74	0.51	0.49	28.48	83.37
November	33.25	20.15	7.69	11.62	0.61	0.66	29.9	75.52
December	31.85	20.33	8.18	11.58	0.64	0.71	31.18	60.43

METHODOLOGY

Angstrom (1924) developed the earliest model used for estimating global radiation, in which the sunshine duration data and clear sky radiation (H_c) data were used.

$$\frac{H}{H_c} = a + b \left(\frac{\bar{n}}{\bar{N}} \right) \quad (1)$$

Because there may be problems in calculating clear sky radiation accurately, by replacing clear sky radiation with extraterrestrial radiation (H_0), this model was modified to a more convenient form by Prescott in 1940 (Prescott, 1940). Prescott (1940), Page (1961) and others have modified equation (1) using the value of the extraterrestrial radiation H_0 on a horizontal surface rather than the clear day radiation H_c (Duffie and Beckman, 1991).

$$\frac{\bar{H}}{H_0} = a + b \left(\frac{\bar{n}}{\bar{N}} \right) \quad (2)$$

Where $\bar{H}$ is the monthly average daily global radiation on a horizontal surface ($MJ.m^{-2}.day^{-1}$). $\bar{H}_0$ is the daily extraterrestrial radiation on a horizontal surface $MJ.m^{-2}.day^{-1}$, $\bar{n}$ is the monthly average daily hours of bright sunshine, $\bar{N}$ is the monthly average day length, (a and b) values are known as angstrom empirical constant or regression coefficients. Their values have been obtained from the relationship given by (Tiwari and Sangetta, 1977) and also confirmed by (Frere et al., 1980) as

$$a = -0.110 + 0.235 \cos \phi + 0.323 \left(\frac{n}{N}\right), \quad (3)$$

$$b = 1.449 - 0.553 \cos \phi - 0.694 \left(\frac{n}{N}\right). \quad (4)$$

The monthly average daily extraterrestrial irradiation H_0 can be calculated from the equation below.

$$H_0 = \frac{24}{\pi} I_{sc} \left[1 + 0.0333 \cos \left(\frac{360 d_n}{365} \right) \right] \left[\cos \phi \cos \delta \cos \bar{w}_s + \frac{2\pi \bar{w}_s}{360} \sin \phi \sin \delta \right],$$

$$H_0 = \frac{24}{\pi} I_{sc} E_0 \left[\cos \phi \cos \delta \cos \bar{w}_s + \frac{2\pi \bar{w}_s}{360} \sin \phi \sin \delta \right], \quad (5)$$

where I_{sc} is the solar constants ($= 1367 \text{ Wm}^{-2}$) and can also be expressed in $Jm^{-2}day^{-1}$ in equation (6),

$$I_{sc} = \frac{1367 \times 3600}{1000000} MJm^{-2}day^{-1} \quad (6)$$

E_0 is the eccentricity correction factor expressed in equation (7)

$$E_0 = \left[1 + 0.0333 \cos \left(\frac{360 d_n}{365} \right) \right] \quad (7)$$

ϕ is the latitude of the site under study, δ is the solar inclination angle given as

$$\delta = 23.45 \sin \left(360 \left(\frac{d_n + 284}{365} \right) \right) \quad (8)$$

$\bar{w}_s$ is the mean sunrise hour angle for the given month expressed as;

$$\bar{w}_s = \cos^{-1} -\tan \phi \tan \delta \quad (9)$$

n is the characteristic day number for each month: $d_n = 1$ on 1st of January to 365 on 31st of December. The mean day length $\bar{n}$ is expressed as;

$$\bar{N} = \frac{2}{15} \bar{w}_s \quad (10)$$

The expression for the MBE ($MJm^{-2}day^{-1}$), RMSE ($MJm^{-2}day^{-1}$), and MPE (%) as stated by (El – Sebaai and Trabea, 2005) are:

$$MBE = \frac{\sum (H_{ical} - H_{imeas})}{n} \quad (11)$$

$$RMSE = \left[\frac{\sum (H_{ical} - H_{imeas})^2}{n} \right]^{1/2} \quad (12)$$

$$MPE = \frac{\left[\sum \left(\frac{H_{imeas} - H_{ical} \times 100}{H_{imeas}} \right) \right]}{n} \quad (13)$$

$$t - stat = \frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2} \quad (14)$$

Where $\bar{H}_{ical}$ and $\bar{H}_{imeas}$ are the i th calculated and measured values of global solar radiation respectively, and n is the total number of observations. The r -value defines the linear relationship between the observed and predicted values of global solar radiations. The R^2 statistic gives the percentage variation of the dependent variable in connection with the independent variables while MBE, RMSE, and MPE are common error terms often used in comparing models. For better data modelling, these error indicators should be closer to zero, but r and R^2 should approach unity as closely as possible.

Although these tools are commonly used indicators, the t -stat in terms of MBE and RMSE as defined in equation (14) has satisfactory accuracy for analyzing solar radiation data because it determines whether the estimated value from the used model is statistically significant at a particular confidence level (considered in this study as 95%). To determine if the value of global solar radiation estimated from the model is statistically significant, one has to determine the critical t -stat at α level of significance and $(n - 1)$ degree of freedom, where n refers to the 12 months of the year from standard statistical tables. A model's estimate is statistically significant if the calculated t -stat is less than the critical $t - stat$. Standard equations available for calculating $t - stat$ is given in equation (14), by (Okundamiya and Nzeako, 2010),

In general, MBE provides information on the long term performance of the models. Positive MBE shows overestimation while a negative MBE indicates underestimation. RMSE provides information on the short term

performance of the model. It is always positive and a low value of it is desirable. The demerit of this parameter is that a single value of higher error leads to a higher value of RMSE. MPE test provides information on long – term performance of examined regression. A negative value of MPE indicates the average amount of underestimation while a positive value indicates overestimation.

RESULTS AND DISCUSSION

The developed linear single and multiple empirical equations for the estimation of global solar radiation in Abuja, Minna and Ilorin using different meteorological data are presented in table 4, table 5 and table 6 for Abuja, Minna and Ilorin respectively. The equations developed are sunshine based models in combination with either maximum temperature, relative humidity or both. Estimated global solar radiation gotten from the five developed empirical equations for each of the three cities are given in table 7 for Abuja, table 8 for Minna and table 9 for Ilorin. The measured global solar radiation and calculated value of global solar radiation obtained from the model equations were plotted against months of the year as shown in Figure 1, Figure 2 and Figure 3 for Abuja, Minna and Ilorin respectively. The five graphs plotted show almost the same pattern. This revealed that the proposed model equations can be used to predict the global solar radiation at Abuja, Minna and Ilorin in north central part of Nigeria. Statistical error indicators given in equations (11), (12), (13) and (14) were used to evaluate the performance of the developed empirical equations. The values of MBE and MPE for the models developed for the three cities show that global solar radiations were slightly underestimated except for H2 and H3 in Minna. Values of RMSE is relatively low with highest values of 1.648 and 1.188 obtained for Abuja in models H3 and H1 respectively and 1.198 obtained for Minna in model H1.

Table 4: Empirical Equations Developed for Abuja

Models	Empirical Equations	R ² Values
I	$H_1 = H_0 \left(0.178 + 0.772 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$	0.851
II	$H_2 = H_0 \left(-0.577 + 0.021 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0388(\bar{T}_{max}) \right)$	0.934
III	$H_3 = H_0 \left(0.401 + 0.555 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.166 \left(\frac{RH}{100} \right) \right)$	0.892
IV	$H_4 = H_0 \left(-1.247 - 0.215 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0620(\bar{T}_{max}) + 0.163 \left(\frac{RH}{100} \right) \right)$	0.944
V	$H_5 = H_0 \left(-0.876 + 0.0471(\bar{T}_{max}) - 0.0985 \left(\frac{RH}{100} \right) \right)$	0.940

Table 5: Empirical Equations Developed for Minna

Models	Empirical Equations	R ² Values
I	$H_1 = H_0 \left(0.264 + 0.558 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$	0.827
II	$H_2 = H_0 \left(-0.290 + 0.225 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0244(\bar{T}_{max}) \right)$	0.965
III	$H_3 = H_0 \left(0.470 + 0.398 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.173 \left(\frac{RH}{100} \right) \right)$	0.891
IV	$H_4 = H_0 \left(-0.652 + 0.204 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0341(\bar{T}_{max}) + 0.120 \left(\frac{RH}{100} \right) \right)$	0.975
V	$H_5 = H_0 \left(-0.970 + 0.0473(\bar{T}_{max}) + 0.163 \left(\frac{RH}{100} \right) \right)$	0.941

Table 6: Empirical Equations Developed for Ilorin

Models	Empirical Equations	R ² Values
I	$H_1 = H_0 \left(0.234 + 0.598 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$	0.932
II	$H_2 = H_0 \left(-0.484 + 0.251 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0307(\bar{T}_{max}) \right)$	0.985
III	$H_3 = H_0 \left(0.434 + 0.488 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.189 \left(\frac{RH}{100} \right) \right)$	0.962
IV	$H_4 = H_0 \left(-0.724 + 0.212 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0378(\bar{T}_{max}) + 0.07 \left(\frac{RH}{100} \right) \right)$	0.987
V	$H_5 = H_0 \left(-1.378 + 0.0608(\bar{T}_{max}) + 0.190 \left(\frac{RH}{100} \right) \right)$	0.975

Table 7: Measured and Calculated Global Solar Radiation for Abuja

MONTH	Hm	H1	H2	H3	H4	H5
January	21.30	20.09	21.43	22.97	21.07	21.04
February	22.30	24.18	23.92	25.87	23.64	23.86
March	23.25	24.10	23.87	24.12	24.22	24.16
April	21.98	21.89	21.36	20.78	21.92	21.79
May	20.04	21.50	19.95	20.19	19.99	20.21
June	18.13	18.81	17.58	18.43	17.29	17.56
July	15.95	16.73	16.18	17.00	15.80	15.98
August	14.75	15.02	15.96	15.47	15.97	15.74
September	17.14	16.81	17.47	16.15	17.74	17.48
October	19.24	19.21	18.56	17.39	18.72	18.75
November	21.45	19.15	20.13	18.63	20.58	20.27
December	21.00	19.40	20.40	20.16	20.27	20.20

Table 8: Measured and Calculated Global Solar Radiation for Minna

MONTH	Hm	H1	H2	H3	H4	H5
January	20.72	19.23	20.61	20.61	20.24	20.48
February	21.92	21.03	22.73	21.99	22.79	23.27
March	23.15	21.44	22.84	21.65	23.30	23.90
April	22.14	21.19	21.37	20.56	21.93	22.15
May	20.43	19.84	19.95	19.40	20.35	20.62
June	18.64	17.62	17.64	17.59	17.72	18.05
July	16.43	17.22	16.63	17.21	16.45	16.50
August	15.50	16.78	16.38	16.94	16.15	16.34
September	17.56	18.75	18.01	18.40	18.01	17.89
October	19.68	21.69	19.76	20.44	19.90	18.92
November	21.05	22.14	20.88	21.34	20.98	20.05
December	20.89	21.29	21.13	21.66	20.86	20.23

Table 9: Measured and Calculated Global Solar Radiation for Ilorin

MONTH	Hm	H1	H2	H3	H4	H5
January	20.55	18.52	20.22	19.80	20.15	20.56
February	21.54	21.48	22.06	21.89	22.06	22.14
March	22.12	22.02	21.93	21.64	22.07	22.16
April	20.71	20.04	20.25	19.56	20.49	20.96
May	19.22	19.01	19.13	18.63	19.31	19.66
June	17.47	17.88	17.05	17.57	16.99	16.62
July	15.19	15.09	14.90	15.23	14.81	14.73
August	13.95	14.47	14.60	14.78	14.53	14.62
September	16.18	16.26	16.35	16.27	16.37	16.55
October	17.97	18.84	18.29	18.42	18.34	18.20
November	20.15	20.94	19.95	20.42	19.93	19.39
December	20.33	20.91	20.72	21.16	20.59	20.15

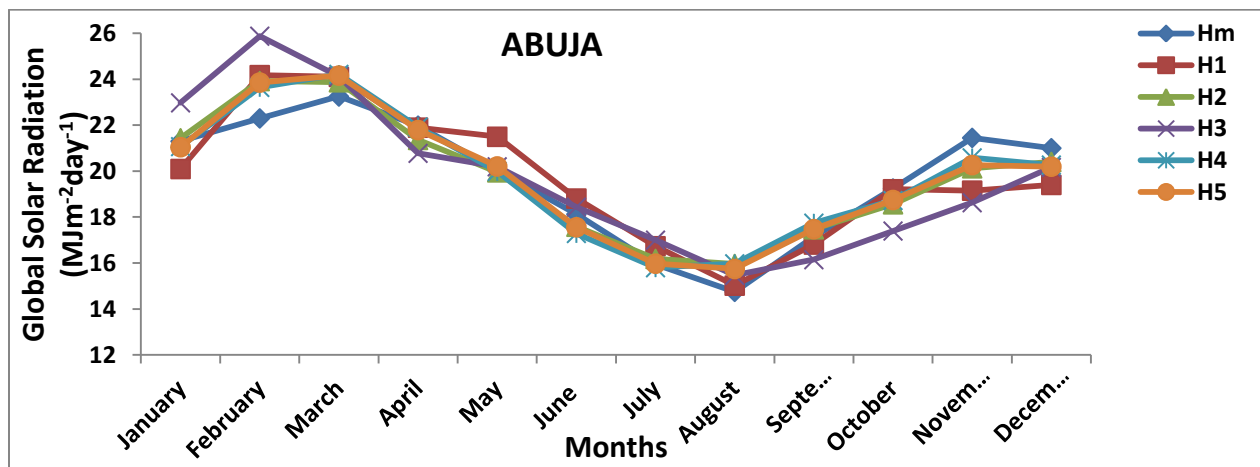


Figure 1: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Abuja

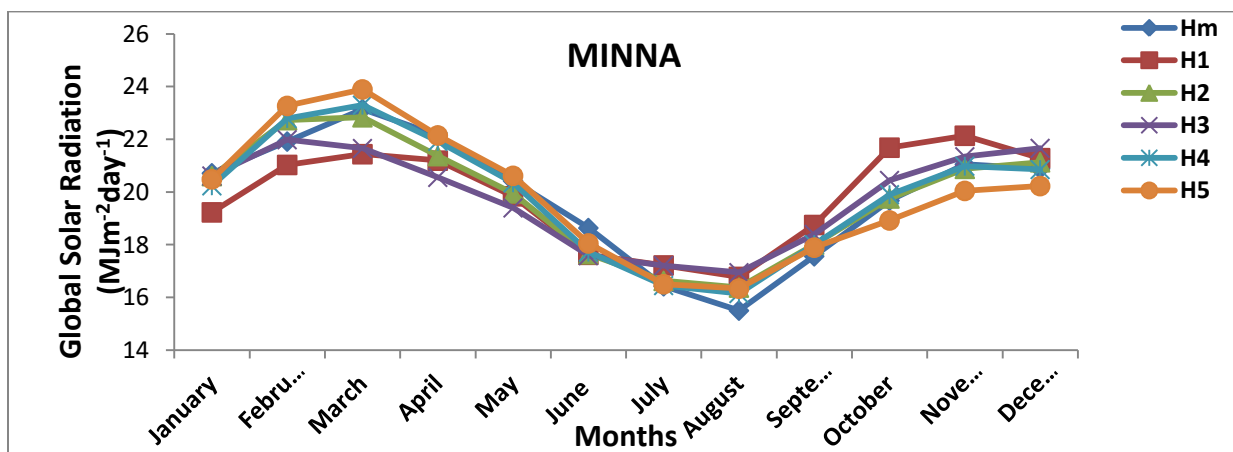


Figure 2: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Minna

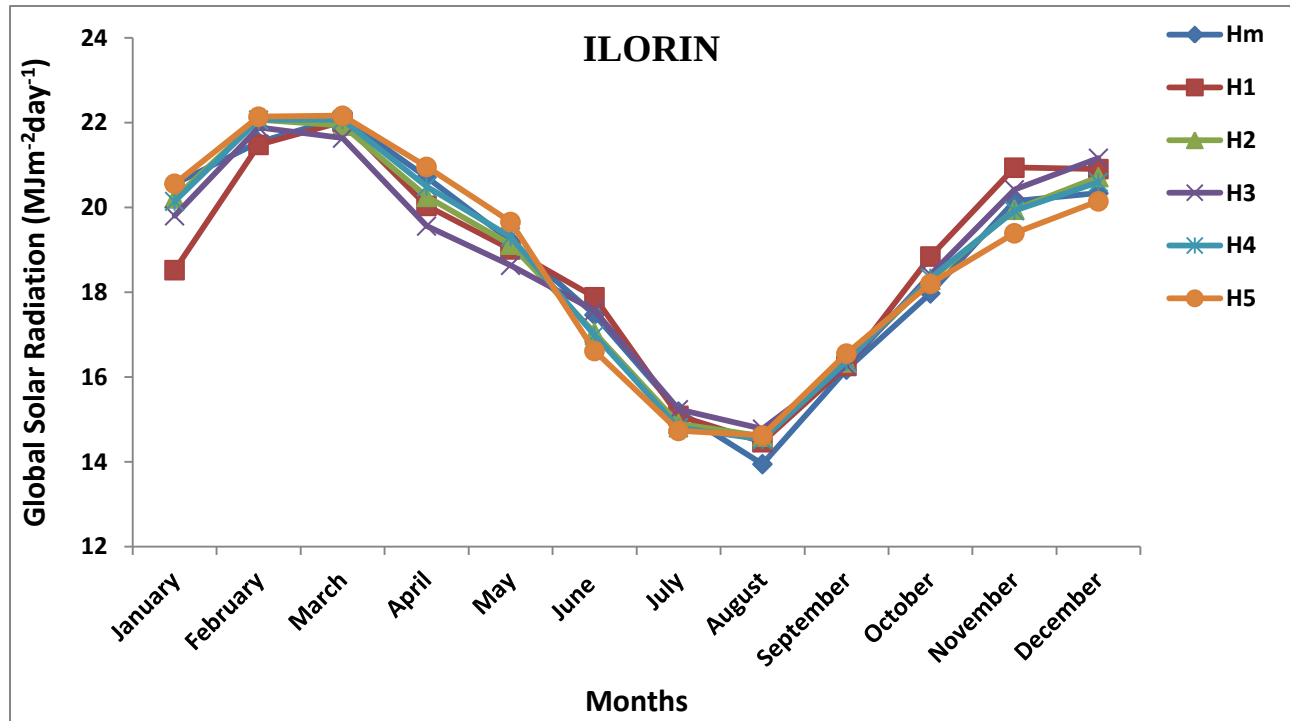


Figure 3: Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Ilorin

These relatively low values of RMSE show that these developed models can be used in short term evaluation of global solar radiation in these sites. The t – stat values of the developed empirical equations were specifically used to determine if the estimated models are statistically significant. According to the standard t – stat table, the critical t – stat value at 95 % confidence level or 0.025 level of significance and (12-1) degree of freedom is 2.201. From table 10, all the t – stat values for the developed models are below the critical t – stat value. This result suggested that all the developed models for estimation of global solar radiation at the three sites are statistically significant. The t – stat values of the models were used to evaluate the performance of the models. A t – stat value of zero is desirable. All the developed empirical equation for estimating global solar radiation in Ilorin performed well. The t – stat values of 0.00148 and 0.212 for $H_3 = H_0 \left(0.434 + 0.488 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.189 \left(\frac{RH}{100} \right) \right)$ and $H_5 = H_0 \left(-1.378 + 0.0608(\bar{T}_{max}) + 0.190 \left(\frac{RH}{100} \right) \right)$ respectively clearly indicated that H_3 performed best while H_5 is the worst empirical equation for Ilorin. The five empirical equations developed for estimating global solar radiation at Minna are good according to their t – stat values. $H_1 = H_0 \left(0.264 + 0.558 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$ with t – stat value of 0.281 gives estimated global solar radiation values that closely correlate with the measured global solar radiation from NASA while $H_4 = H_0 \left(-0.652 + 0.204 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0341(\bar{T}_{max}) + 0.120 \left(\frac{RH}{100} \right) \right)$ with a t – stat value of 0.351 is the worst performed empirical equation developed for Minna. In Abuja, all the five empirical equations developed are all good for the estimation of global solar radiation. $H_1 = H_0 \left(0.178 + 0.772 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$ with t – stat value of 0.0882 performed best while $H_4 = H_0 \left(-1.247 - 0.215 \left(\frac{\bar{n}}{\bar{N}} \right) + 0.0620(\bar{T}_{max}) + 0.163 \left(\frac{RH}{100} \right) \right)$ with a t – stat value of 0.247 is the worst empirical equation developed for Abuja.

Table 10: Statistical Error Values of the Modeled Empirical Equations for North Central Cities

CITIES	NORTH CENTRAL ZONE					
ILORIN	Errors	H1	H2	H3	H4	H5
	MBE	-0.00732	-0.00506	-0.00026	-0.02056	-0.03083
	RMSE	0.751961	0.370273	0.594114	0.353077	0.483826
	MPE	-0.21953	-0.06938	-0.1596	-0.11969	-0.15414
	t-stat	0.032273	0.045339	0.001476	0.193429	0.211795
MINNA	Errors	H1	H2	H3	H4	H5
	MBE	-0.01016	0.013566	0.024695	-0.04881	-0.02529
	RMSE	1.197865	0.554235	0.981031	0.463901	0.686713
	MPE	-0.49257	0.022615	-0.15318	-0.22905	-0.11556

	t-stat	0.028125	0.081203	0.083513	0.350911	0.122229
ABUJA	Errors	H1	H2	H3	H4	H5
	MBE	-0.03158	-0.02495	-0.05359	-0.0566	-0.04109
	RMSE	1.187911	0.813378	1.648229	0.761026	0.769891
	MPE	-0.28515	-0.14327	-0.04164	-0.2115	-0.14418
	t-stat	0.088216	0.101787	0.107893	0.247357	0.177275

Table 11: Best Performed Empirical Models Developed for Estimation of Global Solar Radiation at studied Sites.

Cities	Best Models	t - stat
Abuja	$H_1 = H_0 \left(0.178 + 0.772 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$	0.0882
Minna	$H_1 = H_0 \left(0.264 + 0.558 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$	0.281
Ilorin	$H_3 = H_0 \left(0.434 + 0.488 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.189 \left(\frac{RH}{100} \right) \right)$	0.00148

CONCLUSION

We have successfully developed empirical models for the estimation of global solar radiations for Abuja, Minna and Ilorin using data from the archives of National Aeronautics and Space Administration (NASA) for a period of 11 years (2000 – 2010). The models are sunshine based models, sunshine – maximum temperature based models, sunshine – relative humidity based models, sunshine – maximum temperature – relative humidity based models and temperature – relative humidity based models. From the result obtained, the best performing model for Abuja is $H_1 = H_0 \left(0.178 + 0.772 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$ with t – stat of 0.0882, the best for Minna is $H_1 = H_0 \left(0.264 + 0.558 \left(\frac{\bar{n}}{\bar{N}} \right) \right)$ with t – stat value of 0.281 and the best performing model for Ilorin is $H_3 = H_0 \left(0.434 + 0.488 \left(\frac{\bar{n}}{\bar{N}} \right) - 0.189 \left(\frac{RH}{100} \right) \right)$ with t – stat value of 0.00148. The best performed model for Abuja and Minna is the sunshine based model while that of Ilorin is sunshine – relative humidity based model. These statistical error values showed that this research work is meaningful for the estimation of global solar radiation using meteorological data from NASA. This indicates that the estimated values of global solar radiation can be very efficiently used to compensate for the lack of global solar radiation data caused non-availability of measuring instruments.

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