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Estimation of Global Solar Radiation, Sunshine Hour Distribution and Clearness Index in Three Geopolitical Regions of Southern Nigeria

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Abstract

The concept of solar energy and its applications in this present day world would come to be one of the solutions to the present problem of instability and epileptic power supply in Nigeria. In this research work, the baseline data for the mean monthly global solar radiation (*H*) and sunshine hours (*S*) for three geopolitical regions of Nigeria, namely Port-Harcourt (South-southern Nigeria) (5.00^{0}N, 6.950E), Enugu (South-eastern Nigeria) (6.7^{0}N, 7.6^{0}E) and Ikeja (South-western Nigeria) (6.58^{0}N, 3.32^{0}E), were obtained from the Nigeria Metrological Agency (NIMET) in Nigeria over the period from 1996 to 2010. The data for global solar radiation were measured using a Gunn-Bellani radiometer, and a linear regression correlation model was developed. The clearness index estimated for each station and other surrounding towns/villages with similar meteorological conditions was also developed. The results show that using the Angstrom-Prescott model, the Angstrom coefficients (a and b) for estimating the global solar radiation were: 0.07 and 0.12; 0.27 and 0.58; 0.25 and 0.63 for Port-Harcourt, Enugu and Ikeja respectively.The average sunshine hour for the period of the study was estimated to be four hours, five hours, forty minutes and five hours, 0 minutes and six seconds for the three meteorological stations in this study. The average global solar radiation for these stations was estimated to be 10.003 MJm^{-2}day^{-1}, 15.006 MJm^{-2}day^{-1} and 14.440 MJm^{-2}day^{-1}respectively. The results show that the root-mean-squared-error, mean-bias-error and mean percentage error were generally less than 0.6, 0.2 and 3.84 respectively for all of the stations considered. The study concluded that the Angstrom- Prescott model plays a significant role in predicting and estimating solar energy potentials in these geopolitical zones

Keywords: Angstrom-Prescott model, Global solar radiation, Sunshine Hour, Clearness Index.

1. Introduction

Solar radiation can be considered as the most important meteorological element which affects all climatological and biological processes such as evaporation and transpiration, snowmelt (increase in sea level) and plant growth either directly or indirectly (Mojarrad et al., 2015). In addition, the global solar radiation is the sun total of all radiation reaching the earth surface i.e. it includes both the direct and the diffused solar radiation reaching the earth surface measured at any location. It has been established that sunshine duration has a direct correlation with global solar radiation (Okonkwo, 2014). Moreover, solar radiation data over the years have been used in different solar applications such as solar ovens, solar water heaters, photovoltaic systems, atmospheric energy balance studies, meteorological forecasting among others. However, for most developing countries, solar radiation measurements are not easy to obtain due to the shortage of measurement instruments. To overcome this limitation, most estimates of Global solar radiation (GSR) are focused on readily available meteorological parameters. However, the number of weather stations recording the different meteorological parameters are becoming rapidly increasing in recent times but even so, data for previous years (going back 50 years) on global radiation are still very rare in Nigeria. Solar Energy, which is a renewable energy, is one of the foremost and ancient sources of underutilized energy. It forms the basis for the fundamental elements of most fossil and renewable energies (Innocent et al., 2015). Radiation from the sun (solar and atmospheric) has been identified as the largest renewable energy resource on earth (Gana and Akpootu, 2013).

Solar radiation reaching the earth is considered to be affected by some parameters like diffusion, reflection, and so on. Most of the time, this radiation is reflected or scattered by air molecules, clouds, aerosols (dust) (Aweda et al., 2016). The application/utilization of renewable energy resources has increased largely in recent times owing to the ever increasing need for electrical/thermal energy (Sanusi and Abisoye, 2013). However, fossil fuel resources needed for the generation of conventional electrical power are quite limited and there is also the problem of the global environmental concerns over the use of fossil fuels. The over dependency of present day Nigeria on hydro power generation, transmission and distribution of electricity has failed to satisfy the citizens' demands for an uninterruptable power supply, hence, there is a big need to search for other forms of renewable energy sources. The estimation of the clear sky irradiance components of solar radiation is very important in many solar energy applications (systems design and simulation,

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control process of the accuracy of radiometers, data quality control, gaps filling process, etc.), as well as in some routine engineering practices (e.g., the peak cooling load of buildings is determined for a hot, cloudless, summer day) (Islahi et al., 2015).

The south southern part of Nigeria is characterised by cloudiness conditions which occur frequently even during the dry seasons of the year. This could be attributed to the influence of the Inter-Tropical Convergence Zone (ITCZ), producing Tropical Continental (TC) associated with dry and dusty North-Easterly winds which blow from the Sahara Desert and finally prevail over Nigeria producing the dry season conditions (Sunday et al., 2016). The clearness index for the south southern part of Nigeria was estimated to be 0.40 using the two major cities of Calabar and Port-Harcourt in a research carried out by Augustine and Nnabuchi, 2009. The city of Enugu, along sides its south eastern counterpart cities of Awka, Owerri, was seen to have Angstrom Constants of 0.226 and 0.677; 0.259 and 0.589; and 0.251 and 0.617 respectively in a research carried out by (Elekalachi et al., 2016). Enugu was seen to have a correlation percentage of 65.9 % between the measured and the estimated global solar radiation; 69.6 % correlation for Awka and 83.1 % for Owerri carried out by values in the research.

The average values of the angstrom Constant for South eastern Nigeria using Akwa, Owerri and Enugu were given to be 0.24 and 0.62. The clearness index for the south eastern part of Nigeria was estimated using the two major cities of Uyo and Warri to be 0.5 in a research carried out on the Correlation of cloudiness index with a clearness index for four selected cities in Nigeria by (Augustine and Nnabuchi, 2009). Other researchers investigated the monthly average clearness index and the sunshine duration for Iseyin in the southwest region of Nigeria. The clearness index, which is a fraction of the solar radiation at the top of the atmosphere that reaches the city of Iseyin varied between 0.34 in August and 0.65 in November, with an annual average of 0.53 these findings were part of a research carried out by (Yusuf, 2017) on the characterization of sky conditions using clearness index and relative sunshine duration for Iseyin, Nigeria Similarly, the current research investigates the global solar radiation, sunshine hour distribution and clearness index of Enugu, Port Harcourt and Ikeja respectively.

In a research carried out on the Empirical model for the estimation of global radiation from sunshine duration in Ijebu-Ode in south western Nigeria, it was discovered that the angstrom constants were found to be 0.18 and 0.79 with a correlation of about 89.13 % (Ogunsanwo et al., 2016). The clearness index for the south western Nigeria is given to be 0.59 by another research carried out on the evaluation of clearness index and diffuse ratio of some locations in south western, Nigeria using solar radiation data (Sanusi and Ojo, 2015). This slight difference in the patterns may be attributed to the latitudinal difference that exists between the locations. Hence, the global solar radiation in the locations varied from $12.248 - 20.844 MJm^{-2} day^{-1}$ in Abeokuta, $12.880 - 21.744 MJm^{-2} day^{-1}$ in Ado Ekiti, $12.064 - 21.888 MJm^{-2} day^{-1}$ in Akure, $12.600 - 19.224 MJm^{-2} day^{-1}$ in Ikeja, $12.960 - 22.916 MJm^{-2} day^{-1}$ in Ogbomoso, $12.420 - 21.276 MJm^{-2} day^{-1}$ in Osogbo .

The clearness index (K_t) value ranges between 0.35 – 0.59 (Abeokuta), 0.36 – 0.61 (Ado Ekiti), 0.34 – 0.61 (Akure), 0.32 – 0.48 (Ikeja), 0.39 – 0.61 (Ogbomoso) and 0.34 -0.53 (Osogbo). In Abeokuta, the highest K_t (0.59) was observed in January and December, while the lowest K_t(0.35) occurred in August. In Ado Ekiti, the highest value of K_t (0.613) was observed in January and December, and the lowest value of K_t (0.38) was observed in July. The highest value of K_t (0.61) was observed in Akure in January, while the lowest K_t (0.35) occurred in August. In Ikeja, the highest value of K_t (0.57) was observed in December and the lowest value of K_t (0.38) was in July. In Ogbomoso, the highest value of K_t (0.617) was observed in January and December, and the lowest value of K_t (0.37) was observed in August (Sanusi and Ojo, 2015). In Osogbo, the highest value of K_t (0.60) occurred in January, while the lowest value of K_t (0.34) was observed in August. This indicates that the sky is very clear over Akure, Ado Ekiti, Ogbomoso and Osogbo in south western Nigeria throughout the year except in June to September. This study is aimed at estimating the global solar radiation, sunshine hour distribution and clearness index in three geopolitical regions of southern Nigeria. The model used in this study is the principal Angstrom-Prescott model on which other empirical models such as El – Metwally Model (2005), Bakirci Model (Exponential) (2009), Glower and McCulloch Model (1958) have been built over time for estimating solar radiation using sunshine hour data.

2. Methodology

In this study, the baseline data for the mean monthly global solar radiation (H) and sunshine hours (S) for Port-Harcourt (5.00^0N, 6.95^0E), Enugu (6.7^0N, 7.6^0E) and Ikeja (6.58^0N, 3.32^0E) were obtained from the Nigeria Metrological Agency (NIMET) in Oshodi Lagos, Nigeria over the period from 1996 to 2010.

The regression coefficients, a and b, the monthly average daily global radiation H, the monthly extraterrestrial solar radiation H_0, the sunset hour angle W_s, the aolar declination angle δ, and the monthly average of the maximum possible daily hours of bright sunshine S_0,

$$\left[H, H_0, \frac{H}{H_0}, w_s, S_0, \delta \right]$$

were calculated by means of simulation of the corresponding equations into Java program compatible with netbeans which served as a calculator for the parameters.

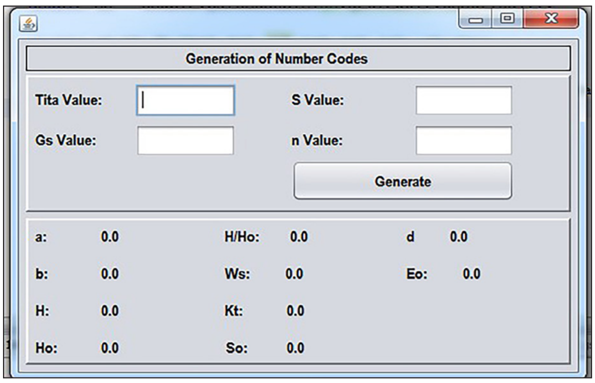


Figure 1. Number Code generation interface used in the estimation by means of Java scripts.

Graphical analyses were also exploited by plotting graphs of monthly mean estimated and calculated global solar radiation, monthly mean sunshine hour data and yearly mean sunshine hour data.

The original Angstrom-type regression equation relates the monthly average daily radiation to the clear day radiation at any station and the average fraction of possible sunshine hours:

$$\frac{\overline{H}}{\overline{H}_c} = a' + b'\frac{\overline{n}}{\overline{N}} \quad (1)$$

where $\overline{H}$ = the monthly average of daily solar radiation on a horizontal surface

$\overline{H}_c$ = the average clear sky daily solar radiation for the location and month

a', b' = empirical constants

$\overline{n}$ = monthly average daily hours of bright sunshine

$\overline{N}$ = monthly average of the maximum possible daily hours of bright sunshine.

Equation (1) has been modified to be based on extraterrestrial radiation on a horizontal surface rather than on a clear day radiation and was given as equations (2a) and (2b):

$$\frac{H}{H_0} = \left(a + b\frac{S}{S_0}\right) \quad (2a)$$

$$H = H_0\left(a + b\frac{S}{S_0}\right) \quad (2b)$$

where : H_0 is the radiation outside of the atmosphere subject to latitude of the location

$a = -0.1\ . + 0.235(\phi) + 0.323\left(\frac{S}{S_0}\right)$ and

$b = 1.449 - 0.553\cos(\phi) - 0.694\left(\frac{S}{S_0}\right)$

S is the monthly average daily hours of bright sunshine, and S_0 is the monthly average of the maximum possible daily hours of bright sunshine, and ϕ is the latitude of the locations in consideration.

$$S_0 = \frac{2}{15}\omega_s \quad (3)$$

$\frac{H}{H_0}$ gives the clearness index over a particular location and denoted by K_T

$$H_0 = \frac{24\times 3600 G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\times\left[\cos\phi\cos\delta\sin\omega_s + \frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right] \quad (4)$$

Where $w_s = \cos^{-1}(-\tan\phi\tan\delta)$ and $\delta = 23.45\sin\left(360\frac{284+n}{365}\right)$

3. Statistical Analysis

Mean Bias Error (MBE) helps to calculate the error or the deviation of the calculated values from the measured values, and provides information on long-term performance. A low mean bias error value is desired. A negative value gives the average amount of underestimation in the calculated value.

$$MBE = \frac{1}{n}\sum_{1}^{n}(H_{est} - H_{meas}) \quad (5)$$

The value of Root Mean Square Error is always positive, representing zero in the ideal case. The normalized root mean square error gives information on the short-term performance of the correlations by allowing a term by term comparison of the actual deviation between the predicted and measured values. The smaller the value is, the better the correlation will be (Namrata, 2012).

$$RMSE = \left[\frac{1}{2}\sum_{1}^{n}(H_{est} - H_{meas})^2\right]^{1/2} \quad (6)$$

The Mean Percentage Error is one of the measures used to evaluate forecasts using forecast errors. A forecast error is defined as the actual observation minus forecast. The mean percentage error is the average or mean of all the percentage errors. A percentage error between −10 % and +10 % is considered acceptable (Muzathik et al., 2011).

$$MPE(\%) = \frac{1}{n}\sum_{1}^{n}\left(\frac{(H_{est} - H_{meas})}{H_{meas}}\right)\times 100 \quad (7)$$

The majority of the equations used in this study were taken from (Duffie and Beckman, 2013).

4. Results and Discussion

Tables 1, 2, and 3 show the estimated monthly global solar radiation, Angstrom coefficient, sunshine hour, and clearness index for each station in the study.

Table 1. Estimated monthly global solar radiation, Angstrom coefficient, Sunshine hour and Clearness index for Port-Harcourt

Month	Mean Sunshine Hour S	H_{est} $(MJm^{-2}day^{-1})$	Mean Anomaly	H_{meas} $(MJm^{-2}day^{-1})$	a	b	$\frac{S}{S_0}$	K_t
JAN	4.55	13.40	-1.67	13.40	0.039	0.112	0.387	0.474
FEB	4.52	16.90	1.83	15.30	0.037	0.112	0.382	0.468
MAR	3.94	16.10	1.03	14.10	0.020	0.116	0.328	0.402
APR	4.50	15.80	0.73	13.70	0.034	0.138	0.372	0.456
MAY	4.90	15.30	0.23	12.90	0.043	0.113	0.400	0.490
JUN	3.19	15.10	0.03	11.50	0.018	0.121	0.260	0.313
JUL	2.24	13.80	-1.27	7.90	0.026	0.126	0.183	0.205
AUG	2.38	12.30	-2.77	8.80	0.022	0.125	0.196	0.224
SEP	2.93	14.30	-0.77	9.10	0.007	0.122	0.244	0.291
OCT	3.87	14.80	-0.27	10.20	0.019	0.116	0.325	0.399
NOV	4.79	17.10	2.03	11.50	0.457	0.110	0.407	0.497
DEC	5.53	15.90	0.83	12.80	0.066	0.106	0.472	0.569

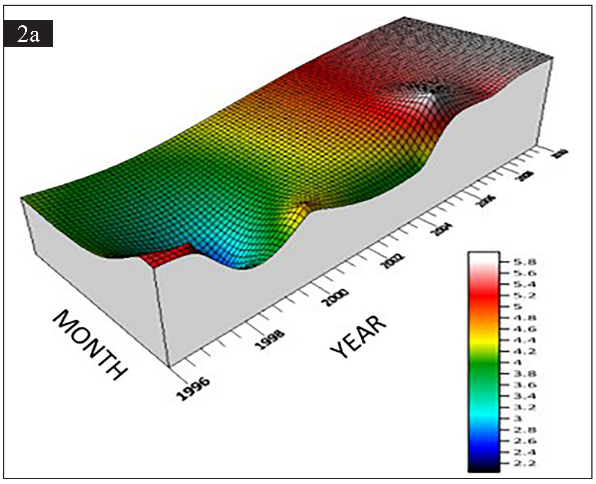
Table 2. Estimated monthly global solar radiation, Angstrom coefficient, Sunshine hour and Clearness index for Enugu

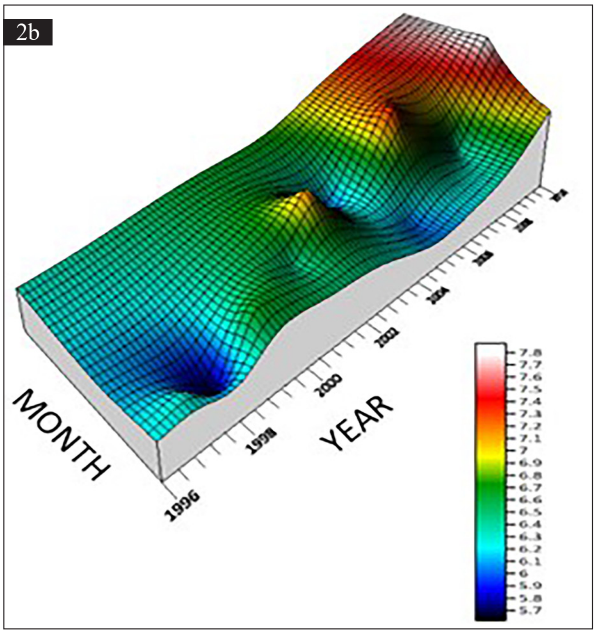
Month	Mean Sunshine Hour S	H_{est} $(MJm^{-2}day^{-1})$	Mean Anomaly	H_{meas} $(MJm^{-2}day^{-1})$	a	b	$\frac{S}{S_0}$	K_t
JAN	6.45	13.9	-0.54	14.27	0.300	0.520	0.553	0.588
FEB	6.58	15.4	0.96	15.89	0.301	0.517	0.557	0.590
MAR	6.02	16.6	2.16	15.30	0.283	0.557	0.500	0.561
APR	6.15	14.7	0.26	14.39	0.285	0.553	0.506	0.561
MAY	6.30	15.3	0.86	14.70	0.286	0.549	0.513	0.565
JUN	5.10	14.1	-0.34	13.62	0.255	0.618	0.412	0.568
JUL	3.78	12.5	-1.94	11.62	0.221	0.689	0.309	0.435
AUG	3.77	11.3	-3.14	11.12	0.221	0.689	0.309	0.434
SEP	4.20	13.1	-1.34	13.00	0.234	0.662	0.349	0.465
OCT	5.64	14.7	0.26	14.34	0.275	0.574	0.476	0.548
NOV	7.08	16.7	2.26	15.71	0.316	0.484	0.605	0.610
DEC	6.98	15.0	0.56	15.13	0.315	0.487	0.600	0.608

Table 3. Estimated monthly global solar radiation, Angstrom coefficient, Sunshine hour and Clearness index for Ikeja

Month	Mean Sunshine Hour S	H_{est} $(MJm^{-2}day^{-1})$	Mean Anomaly	H_{meas} $(MJm^{-2}day^{-1})$	a	b	$\frac{S}{S_0}$	K_t
JAN	5.86	10.80	0.77	10.76	0.275	0.575	0.502	0.56
FEB	6.54	10.80	0.77	12.34	0.292	0.538	0.555	0.59
MAR	5.82	12.80	2.77	13.06	0.269	0.588	0.483	0.55
APR	5.64	13.10	3.07	13.29	0.263	0.601	0.464	0.54
MAY	5.82	12.70	2.67	11.94	0.265	0.595	0.472	0.54
JUN	3.71	11.20	1.17	10.28	0.209	0.715	0.299	0.42
JUL	2.68	7.60	-2.43	8.140	0.183	0.773	0.217	0.35
AUG	3.12	5.10	-4.93	7.35	0.195	0.746	0.256	0.38
SEP	3.86	6.90	-3.13	8.95	0.217	0.700	0.321	0.44
OCT	5.24	8.50	-1.53	10.32	0.256	0.616	0.443	0.52
NOV	6.28	10.20	0.17	11.80	0.286	0.550	0.537	0.58
DEC	6.36	10.70	0.67	12.13	0.290	0.543	0.548	0.58

Figs 2a, 2b, and 2c show the yearly averages mean monthly sunshine hour distribution, mean monthly variation in Sunshine hour, and the mean yearly variation for sunshine hour for the three different stations in the study from 1996 to 2010. In each case, the sunshine hour varies from 2.68 hours to 7.8 hours.





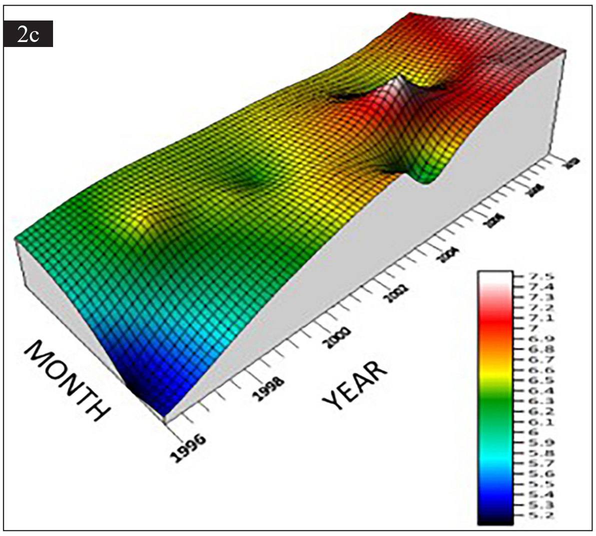
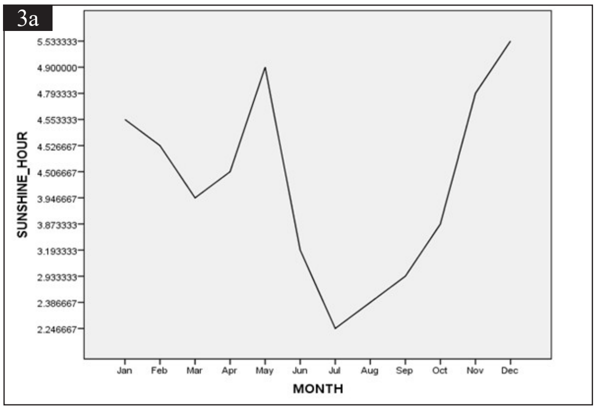
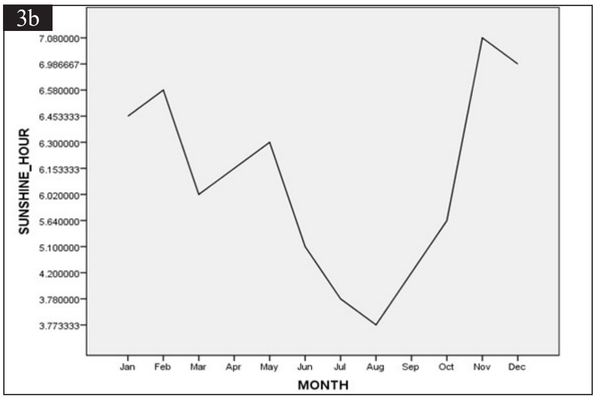


Figure 2. Plots of (a) Distribution of Sunshine Hour for Port-Harcourt, (b) Distribution of Sunshine Hour for Enugu, (c) Distribution of Sunshine Hour for Ikeja.

Fig 2a shows Port-Harcourt with the minimum value of sunshine hour for this study with values ranging from 2.2 to 5.8 maximum values for sunshine hour. The years 2005, 2006, 2007, 2008, 2009, and 2010 have the highest value for sunshine hour with February of 2006 as highest for the whole period of study as seen by the monthly distribution along the z axis and the yearly distribution along the x-axis. The month of January of 1996 also showed a high value of sunshine hour, while the month of February 1999 showed a very low value of 2.2 average sunshine hours as in Fig 2a. From the distribution, the green colour code (3 to 4.2 sunshine hours) is seen to dominate the period from 1996 to 2004, while 2005 to 2010 is on the high side. The Early part of 1996 showed a low sunshine hour measurement as shown by Fig 1b with the distribution of sunshine hour for Enugu improving along the year 2002 up to 2010 for which the study is carried out. January for the following years of 2005, 2006, 2007, 2008, 2009, and 2010 in Enugu showed values of sunshine hour as 7.0 to 7.8 compared to 5.2 to 5.8 sunshine hours for 1996 to 1998. The year 2010 showed a favourable distribution of sunshine hour throughout the year. Fig 2c shows the distribution of sunshine hour for Ikeja. To a large extent the distribution of sunshine hour ranges from 5.7 to 6.1 hours. The month of October to December 2005, October to December 2008, and April to December 2010 showed higher values of 7.1 to 7.8 hours of sunshine duration as shown for Ikeja. Fig 2c shows that the minimum value of sunshine hour was recorded in the month of February 1998.





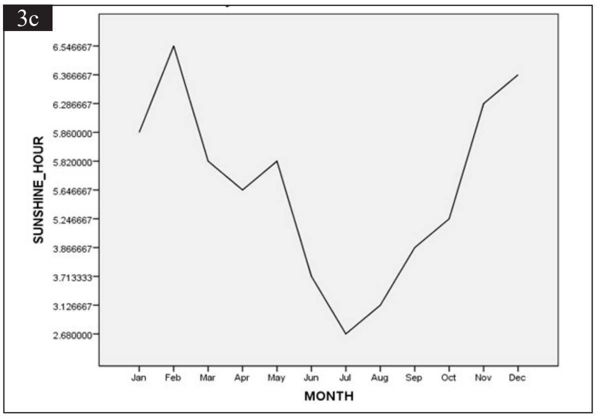


Figure 3. Plots of (a) Mean monthly variation in sunshine hour for Port-Harcourt, (b) Mean monthly variation in sunshine hour for Enugu, (c) Mean monthly variation in sunshine hour for Ikeja.

Fig 3a shows that December has the mean highest sunshine hour. The notable south-southern city of Nigeria has its lowest sunshine in July. December is associated with little or no rainfall whereby making clouds over this station thin and allowing for high sunshine hour reaching Port- Harcourt during the Month. The months of June, July, September and October would be noticed to have low sunshine duration in Port- Harcourt. This is as a result of the raining season which is associated with a heavy cloud cover and hence, little sunshine recordings are gotten as rainfall could take hours of the day during these months. The mean monthly sunshine hour for Enugu happens to be highest in the month of November, and the lowest in the month of August as reported by Fig 3b. The maximum average rainfall for Enugu falls in the Month of August which explains the fall in the number of possible sunshine hours for this location. The month of August for Ikeja happens to be the month with the lowest mean sunshine hour recorded for the fifteen- year study period of 1996 to 2010 as shown in Fig 3c. These can be associated with heavy rainfall in the area during the Month, thereby reducing the sunshine hour due to more absorption, reflection or scattering of solar radiation over Ikeja in this Month. Fig 3 is characterised by a significant fall in the sunshine hour in the months of June, July, August, and September. This fall is predominantly noticed in the month of July and August. This significant fall can be associated with the August break (period of heavy rainfall) in Nigeria. Port-Harcourt has the month of July characterised by low sunshine hours from 1996 to 2010 according to Fig 3a which formed a pattern of sunshine hour distribution for this region (south-southern) of Nigeria

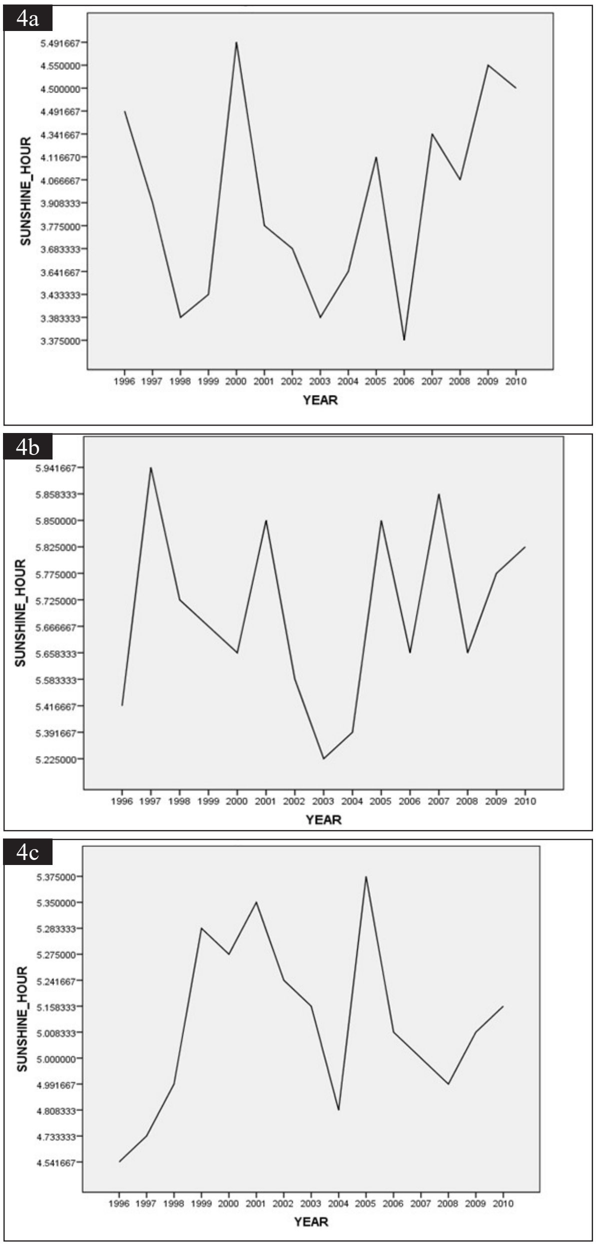


Figure 4. Plots of (a) Mean yearly variation in Sunshine Hour for Port-Harcourt, (b) Mean yearly variation in Sunshine Hour for Enugu, (c) Mean yearly variation for Sunshine Hour in Ikeja.

The yearly estimation of mean sunshine hour for Port-Harcourt reported by Fig 4a shows that the year 2000 has the highest value of sunshine hour, while the years 1998 and 2003 have the same sunshine values and happen to have the lowest sunshine hour for this station. This could be associated with rainfall, humidity, and cloud cover over this location for the various years. For the years 1998 and 2003, the average rainfall recorded was 214.09mm and 208.46mm respectively compared with the value of 166.19mm for average rainfall in year 2000. The value for the average rainfall for 2000 explains why the year had high sunshine duration for this location. According to Fig 4b, the year 2003 had the least sunshine hour recorded between 1996 and 2010, while 1997 can be seen to have the highest value of sunshine hour in Enugu. The years 2003 and 2004 are characterised by an average rainfall of 205.6mm and 171.9mm respectively compared with 147.5mm average rainfall in 1997. This clearly shows that the years 2003 and 2004 should normally have low sunshine duration as days in this year have abundant rainfall. The year 2005 was very favourable for Ikeja for recording the highest sunshine hour under the width band of the study. With the year 1996 having the lowest sunshine hour, Ikeja also had a major drop in 2004 as seen in Fig 4c.

The graphs of the correlation between the measured and estimated global solar radiation for the various stations in the study were plotted and shown in Fig 5. This representation shows the degree of agreement and variation between the measured and the estimated values of global solar radiation for these stations. Fig 5 shows the various values (measured and estimated) for each month of the year. Generally, the months of June, July, August and September have considerably low values of global solar radiation which can be attributed to the raining season in Nigeria which is characterised by thick cloud covers.

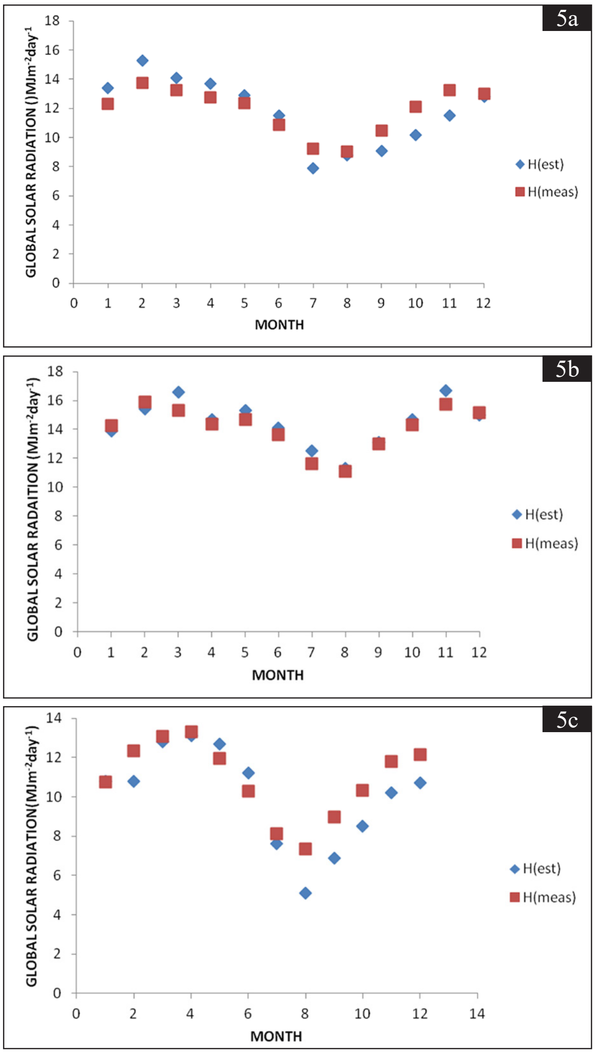


Figure 5. Plots of (a) Correlation between estimated global solar radiation and measured global solar radiation for Port-Harcourt (b) Correlation between estimated global solar radiation and measured global solar radiation for Enugu (c) Correlation between estimated global solar radiation and measured global solar radiation for Ikeja.

Fig 5a shows a correlation of 0.88 between the measured and estimated values of global solar radiation in Port-Harcourt. The 0.88 value for correlation makes the angstroms constants good estimates for finding values of global solar radiation in Port- Harcourt and the nearby cities with similar latitude and sunshine duration. The correlation also serves as a means of checking the correctness of the values of the angstrom constants in relation to the estimation of global solar radiation for this station. In Fig 5b, the 0.94 value for correlation between the measured and estimated values of global solar radiation in Enugu makes the angstroms constants estimated in this study for Enugu good estimates for finding values of global solar radiation in Enugu and the nearby cities with similar latitude and sunshine duration. The correlation also serves as a means of checking the correctness of the values of the angstrom constants in relation to the estimation of global solar radiation for Enugu. For Ikeja (South-Western Nigeria), the correlation between the measured and the estimated values of global solar radiation was found to be 0.91 which makes the results of the current study regarding the estimated solar radiation very good estimates as shown in fig 5c.

Statistical Test Results

Mean Bias Error (MBE) helps to calculate the error or the deviation of the calculated values from the measured values, and provides information on long-term performance. A low mean bias error value is desired. A negative value gives the average amount of underestimation in the calculated value.

Table 4. Statistical Error result presentation

STATION	$H_{est}\left(MJm^{-2}day^{-1}\right)$	$H_{meas}\left(MJm^{-2}day^{-1}\right)$	MBE	RMSE	MPE (%)
PORT-HARCOURT	11.76667	11.87000	-0.0589	0.0730	0.43
ENUGU	14.44167	14.09277	0.1744	0.2467	1.23
IKEJA	10.03333	10.86722	-0.4169	0.5896	3.83

Table 5. Clearness index for different locations of study

Station	$K_t(Max)$	$K_t(Min)$	K_t
PORT-HARCOURT	0.4902	0.2053	0.3992
ENUGU	0.6101	0.4350	0.5447
IKEJA	0.5915	0.3511	0.5087

The clearness index for the south southern part of Nigeria was estimated to be 0.399 in this study which agrees strongly with that of Augustine and Nnabuchi in their research which investigates the clearness index using the cities of Calabar and Port-Harcourt in 2009 in the south southern Nigeria which was found to be 0.40.[9]

The monthly average of Angstrom Constants for Port-Harcourt, Enugu, and Ikeja were estimated to be 0.07 and 0.12; 0.27 and 0.58; 0.25 and 0.63, respectively. The values of 0.23 and 0.68 were Angstrom constants obtained for Enugu by [10] and agree with the values of 0.27 and 0.575 recorded in this study.

5. Conclusions

The trend of global solar radiation, sunshine hour, and clearness index were investigated in this study. The results obtained in this research clearly indicate the importance of developing empirical models for estimating global solar radiation reaching a particular geographical location. The Angstrom Prescott type model presented can also be used to predict the global solar radiation of nearby cities with a latitude, climate, vegetation, elevation and topography similar to those of Enugu.

The results obtained from this research clearly show that the level of sunshine hour distribution and clearness index in Enugu are sufficiently adequate to support solar energy application in this geographical location, and can, therefore, be utilized in the evaluations of their design and performance.

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