Journal of
Renewable Energy Research and Applications (RERA)

Vol 1, No 2, 2020, 161-174 *DOI: 10.22044/rera.2020.9101.1016*

Global Solar Radiation, Sunshine-hour Distribution, and Clearness Index: A Case Study of Sub-Sahara Region in Nigeria

N.O. Adeniji [*1], J.O. Adeniji[2] and O. Ojeikere[3]

1. *Department of Physics and Solar Energy, Bowen University, Iwo, Osun State, Nigeria.*
2. *Department of Computer and Information Technology, Bowen University, Iwo, Osun State, Nigeria.*
3. *Department of Mathematics and Statistics, Bowen University, Iwo, Osun State, Nigeria.*

Receive Date 08 November 2019; Revised 23 January 2020; Accepted Date 09 February 2020
**Corresponding author: nathaniel.adeniji@bowen.edu.ng (N.O. Adeniji)*

Abstract

Global solar radiation is the total sum of all radiations reaching the earth surface, i.e. it includes the direct and the diffused solar radiation reaching the earth surface. The instrument used for measuring this very important component arriving from the whole hemisphere is the pyranometer. This is one of the most important parameters for applications, developments, and researches related to the alternative source of clean and renewable energy. In cases where this data is not available, it is very common to use computational models to estimate the missing data, which is based mainly on the search for relationships between the weather variables such as temperature, humidity, precipitation, cloud cover, and sunshine hours, among others. In this research work, the baseline data for mean monthly global solar radiation (H) and sunshine hours (S) for three geopolitical zones of Nigeria (sub-sahara regions of Nigeria) with Sokoto (North-western Nigeria) (12.91^0N, 5.20^0E), Maiduguri (North-eastern Nigeria) (11.85^0N, 13.08^0E), and Ilorin (North- Central Nigeria) (8.43^0N, 4.50^0E) is obtained from the Nigeria Metrological Agency from 1996 to 2010. A linear regression correlation model is developed and the clearness index is estimated for each station. The results obtained show the angstrom coefficients *a* and *b* for estimating the global solar radiation for zone respectively using the angstrom-prescott model. The average global solar radiation for these stations is estimated, and the results obtained, subjected to statistical tests, are proven to be good estimates. It can be concluded that the Angstrom-Prescott model plays a significant role in predicting and estimating the solar energy potentials in these regions.

Keywords: *Global solar radiation, Angstrom-Prescott model, Sunshine hour, Clearness index, Northern Nigeria.*

1. Introduction

Solar radiation can be considered as the most important meteorological parameter that affects all the climatological and biological processes such as evaporation and transpiration, snowmelt (increase in sea level), and plant growth, either directly or indirectly [1]. The solar radiation data over the years has been used in different solar applications such as solar ovens, solar water heaters, photovoltaic systems, atmospheric energy balance studies, and meteorological forecasting. Notwithstanding, for most developing countries, solar radiation measurements are not easy to obtain due to the shortage of measurement instruments. In order to overcome this limitation, most estimates of global solar radiation (GSR) are focused on the readily available meteorological parameters. However, the number of weather stations recording the different meteorological parameters are becoming rapidly increasing in the recent times. Even so, the data for the previous years (going back to 50 years) on global radiation is still very rare. In order to overcome these difficulties, mathematical models have been formulated to reduce challenges posed by the inability of having solar radiation measurement instruments at every point on the Earth [2]. The Angstrom–Prescott model, Bakirci (Exponential) model, and El- Metwally model are among the several empirical methods so far formulated in estimating GSR from the sunshine-hour data. The solar radiation parameters of sunshine and temperature over different places differ with respect to a location longitude, latitude, and altitude. These parameters also depend on the accuracy of the meteorological instrument used and its stability. The beauty of the variables of sunshine hour GSR is that they give reasonable solar energy conclusions for agricultural research works, solar energy research works, solar energy application research works/installations, and architectural designs, among others. Until the recent times, renewable energy sources were completely discriminated for economic reasons such as the embezzlement of funds for recurrent expenditure of fuelling gasoline engines instead of a permanent solution of solar systems in powering street lights across the country. However, the recent approaches are favorably considered for renewable source cases as compared to the conventional (traditional/non-renewable) sources of energy generation. The importance of renewable energies is that they are inexhaustible (durable), omnipresent (found everywhere in the world unlike fossils fuels and minerals), and essentially clean and environmentally friendly. Solar energy ranks topmost in renewable energy sources because of its abundance and distribution quality uniform in nature [3]. A knowledge of solar radiation is extremely important for the optimal design and the prediction of solar-powered system performance. In spite of the fact that the Sokoto state is blessed with abundant hours of sunshine, it still suffers from epileptic power supply. It has, therefore, become necessary to find the relationship between GSR and sunshine hour with a view of assessing the potentiality of solar energy as an alternative major source of electrical power supply [4]. The results, however, have shown that Sokoto has a clear weather as the clearness index is more than 0.5 throughout the year, and the month of December has the highest clearness index of 0.629 in a research work carried out [4]. In a study carried out to estimate GSR reaching Gusau town in the Zamfara state NW Nigeria, the value of GSR was estimated to $18.80 MJm^{-2}day^{-1}$ be using the data of daily sunshine hour for 1995 to 2000 [5]. The values for Angstrom constants for Gusau were found to be 0.288 and 0.530. This shows that the level of GSR reaching Gusau can adequately support the development of any form of solar energy system. For example, even with the least value of GSR radiation of $16.16 MJm^{-2}day^{-1}$, it theoretically means that for a particular day, a solar energy of 4.491 kwh can be obtained with a square solar plate of side 1 m in one hour in the same study carried out by [5]. The clearness index for Maiduguri was estimated to be 0.5780, showing that Maiduguri was a partly clear sky country [6] in a research carried out on an Angstrom type empirical correlation for estimating GSR in NE Nigeria. The clearness index for Maiduguri for the month of November was 0.6607, and in December, 0.6574, using the data of sunshine duration for 1990 to 2005 [6, 7], and the values for the Angstrom constants were estimated to be 0.413 and 0.320 in their study of the estimation of GSR using sunshine-based model in Maiduguri, NE Nigeria. Maiduguri was seen to have the Angstrom constants of 0.30 and 0.54 in a research into the estimation of GSR in Maiduguri, Nigeria using the Angstrom model using the data of sunshine hour for the years 2004 to 2007 [8]. The value for clearness in Ilorin North Central Nigeria was noticed to be the highest in December and lowest in August with values of 0.678 and 0.405, respectively [9]; also present is 0.53 for the clearness index of Ilorin [10] in his research work titled characterization of sky conditions using clearness index and relative sunshine duration for Iseyin, Nigeria.

2. Methodology

Nigeria is a country located between 4.86 ^{0}N and 14.69 ^{0}N, and 3.80 ^{0}E and 14.67 ^{0}E of the equator. Nigeria has different climatic distributions to different parts of the country. Consisting 36 states with its federal capital territory in the north central, the country can be grouped into six geopolitical zones, which are shown in figure 1.

The monthly mean GSR (H) and monthly mean sunshine hour (S) data for this study were obtained from the Nigeria Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria. The global solar radiation data was measured with a Gunn-Bellani radiometer. The data covered a period of fifteen years spanning from 1996 to 2010 at the selected meteorological stations. Some geographical characteristics of the selected stations are presented in table 1.

Table 1. Geographical and characteristic vegetation of the selected site.

Stations	Latitude (North)	Longitude (East)	Altitude (meters)	Vegetation type
Sokoto	12.91	5.20	269	Savanna/Thorn Scrub
MAIDUGURI	11.85	13.08	325	Sudan Savanna/ Southern Sahel
ILORIN	8.43	4.50	335	Forest and Savanna

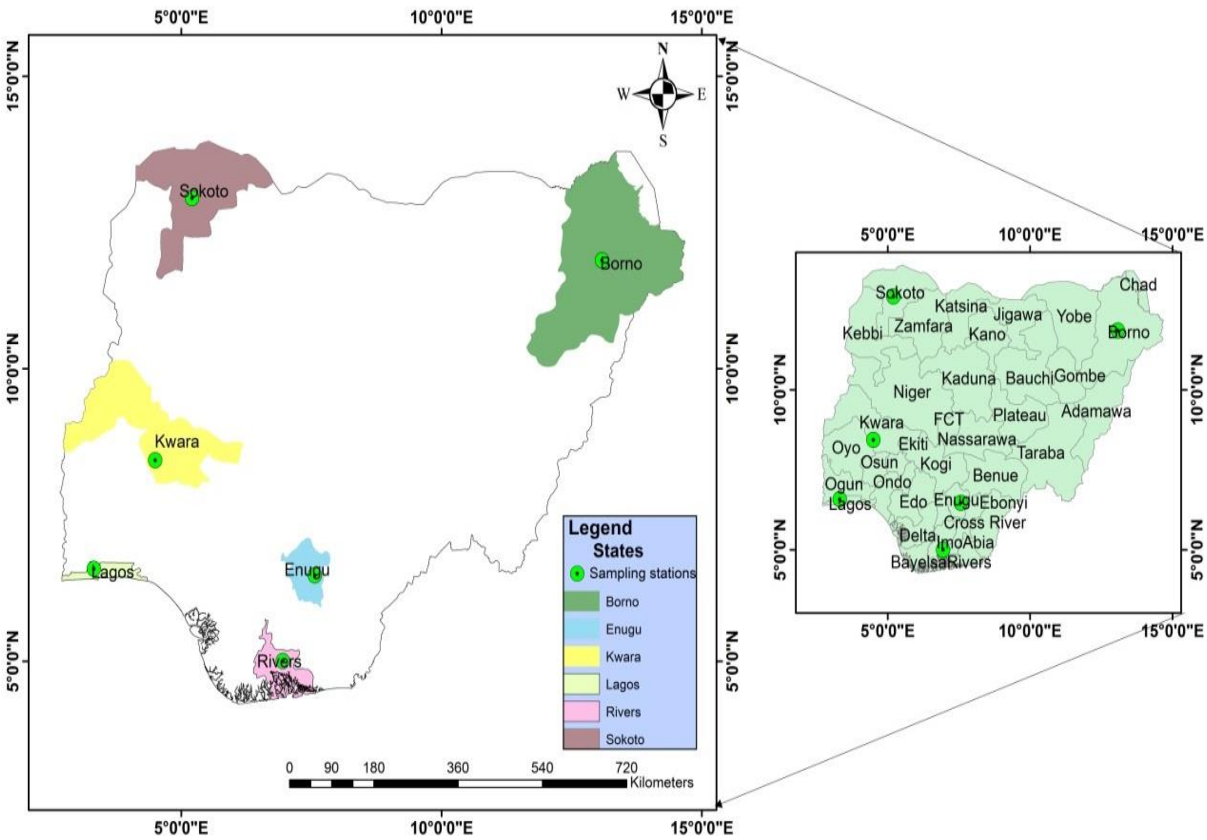

Figure 1. Map of Nigeria showing six geopolitical zones [11].

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

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

Where

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

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

a', b' =empirical constants;

$\overline{n}$ =monthly average of 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 the extraterrestrial radiation on horizontal surface rather than on clear day radiation:

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

Where $H_0$is the radiation outside of the atmosphere subject to latitude of the location.

$$a = -0.110 + 0.235\cos(\phi) + 0.323\left(\frac{S}{S_0}\right) ....(2a)$$

$$b = 1.449 - 0.553\cos(\phi) - 0.694\left(\frac{S}{S_0}\right) ....(2b)$$

Where 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.

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

$\frac{H}{H_0}$ is the clearness index, K_T.

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

where:

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad (5)$$

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \quad (6)$$

3. Results and Discussion

The yearly and monthly variations in the sunshine hour for the duration of the study are as follow:

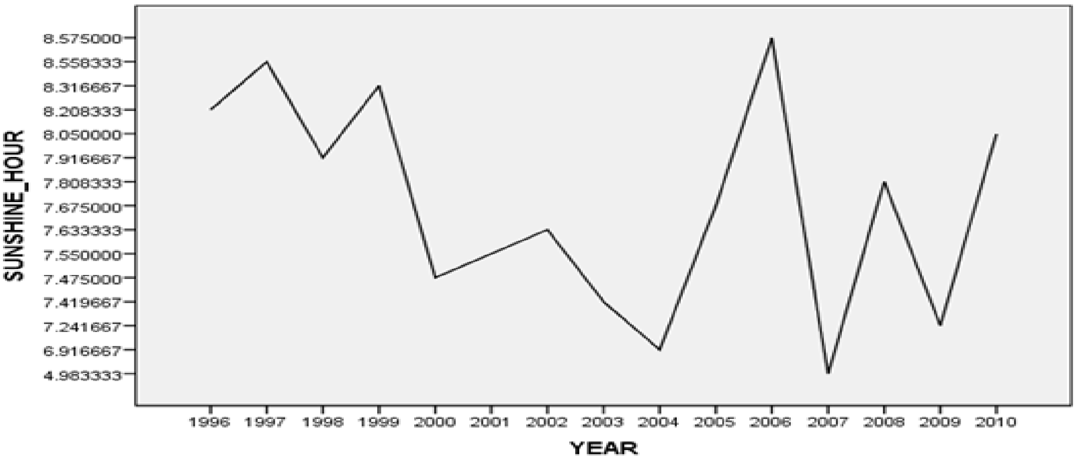

Figure 2a. Variation in mean sunshine hour for Sokoto (1996-2010).

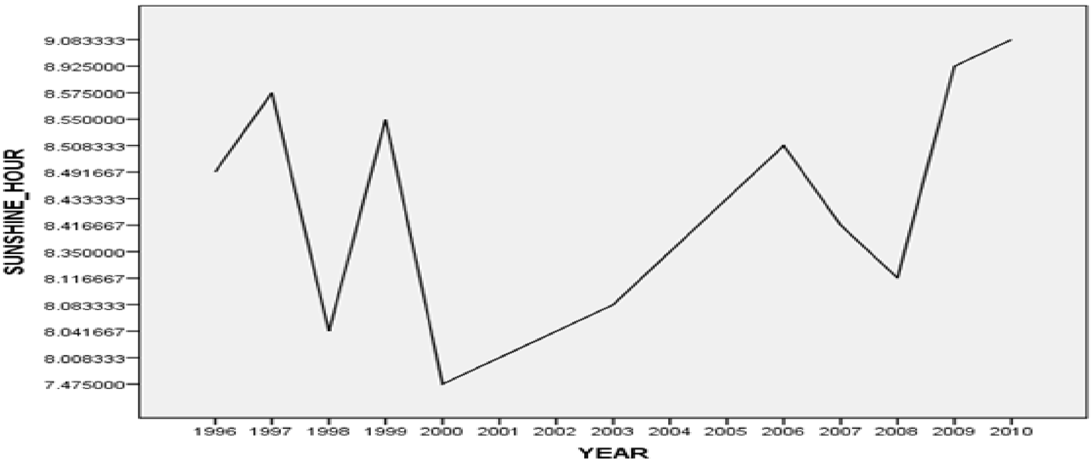

Figure 2b. Variation in mean sunshine hour for each Maiduguri (1996-2010).

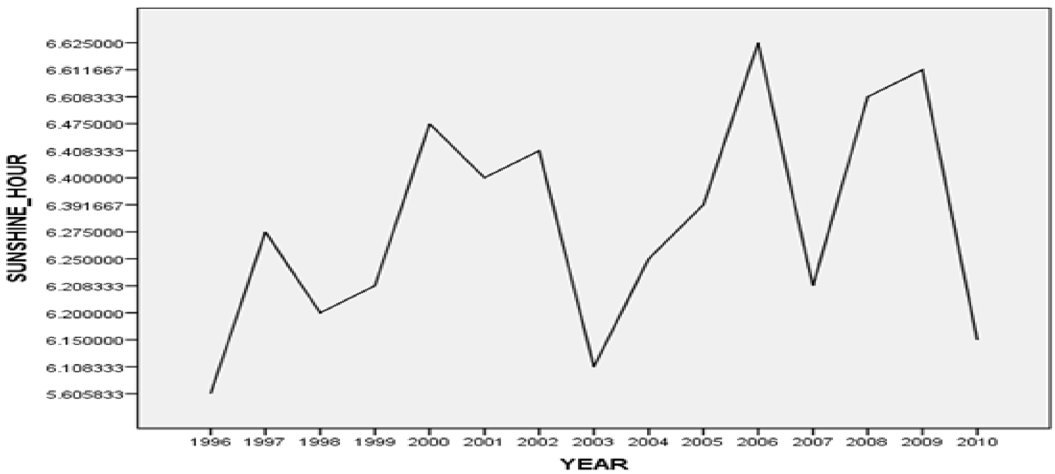

Figure 2c. Variation in mean sunshine hour for Ilorin (1996-2010).

Figure 2a shows the variation in the sunshine hour in Sokoto for the whole period of this study; the year with the highest sunshine hour is the year 2006 with a mean sunshine hour of 8.57 followed by the year 1997 with 8.55 as its mean sunshine hour. The year with the least sunshine hour for the duration of study in Sokoto is 2007. Based on the computation and estimation of the average yearly sunshine hour for Sokoto, the year 2006 with the highest sunshine hours is characterized by a high temperature than the other years under this study for Sokoto. The forgoing may result from a lower rainfall, humidity, and cloud cover among others for 2006. The recorded highest values of sunshine hours preceding the lowest year of sunshine hours for Sokoto suggest a large decrease in the clearness index as against the previous year (2006), a fall in temperature, and an increase in rainfall as against 2006. Figure 2a shows that the sunshine duration for Sokoto is not even as expected throughout the years of study. Each year has a characteristic summary of sunshine different from the other years. The years 2000 to 2004 have a relatively low sunshine duration as compared with 2006. This is due to a higher rainfall between 2000 and 2004 to that of 2006. A total average sunshine duration of 7.24 hours was observed. According to figure 2b, Maiduguri has its highest sunshine hour recorded in 2010, and following from the same figure, the corresponding lowest value for sunshine hour was in the year 2000, followed by the years 2001 and 1998. The years with the lowest values for sunshine hours could be attributed to a higher rainfall in those years. The year 1996 has the lowest sunshine hour, recorded according to figure 2c. This characteristic feature is noticeable on this figure. This figure also does not fail to show that the highest sunshine hour recorded in Ilorin is in the year 2009 with 6.11 as its mean sunshine hour over the 6.60 value of 2008.

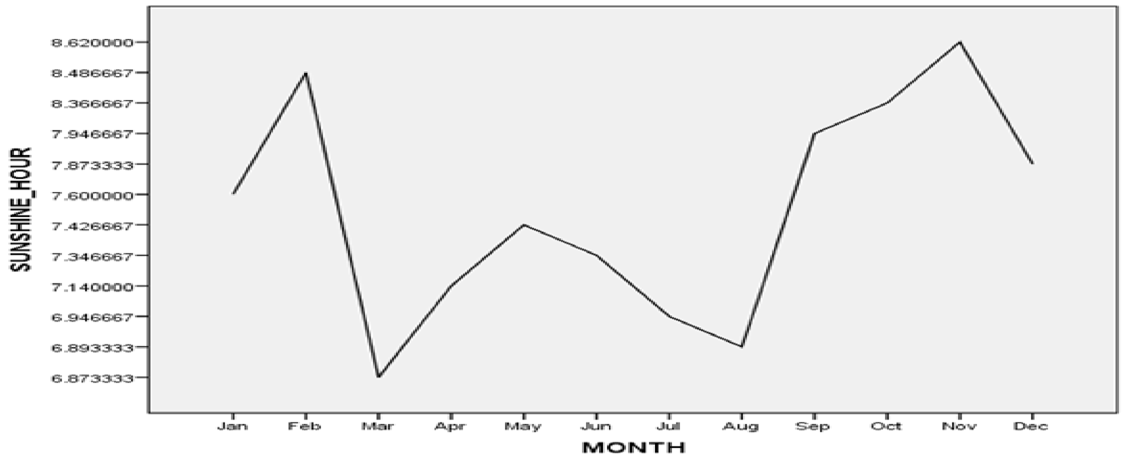

Figure 3a. Variation in mean monthly sunshine hour for Sokoto (1996-2010).

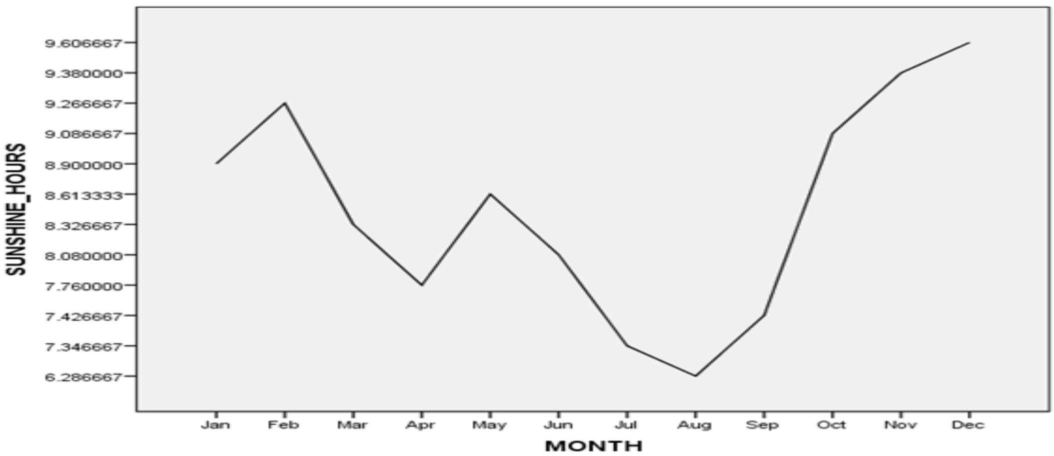

Figure 3b. Variation in mean monthly sunshine hour for Maiduguri (1996-2010).

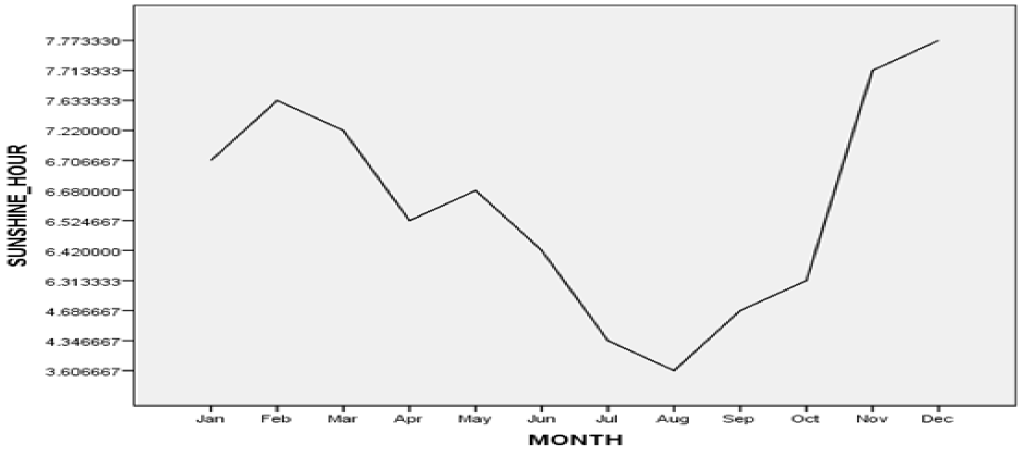

Figure 3c. Variation in mean monthly sunshine hour for Ilorin (1996-2010).

It can be observed in figure 3a that the highest sunshine hour for Sokoto for the period of 1996 to 2010 is in November, while the same figure shows that the lowest sunshine hour recorded is in March and August. The reason for the highest and lowest values of sunshine hour for Sokoto can be attributed to the difference in temperature, rainfall, and clearness index in relation to the cloudiness index of these months. The month of November for Sokoto is characterized by little or no rainfall over the period of this study, and hence, increase in temperature and clear sky conditions of this location. The value of 0.35 cloudiness index for November shows it as a reasonable conclusion for the value of sunshine hour being the highest. The month of March, which happens to have the least sunshine hours, holds the largest rainfall for the period of study for Sokoto. The cloudiness index is estimated to be 0.6018, which happens to be the highest value for the location. Temperature, humidity, rainfall, clearness, cloudiness indices, and rotation of the earth about its axis are not constant throughout the year; hence, the sunshine hour cannot be constant throughout the year, as shown in figure 3a. Figure 3b clearly shows that Maiduguri experiences its highest sunshine in the month of December for the 15 years of study and the lowest value recorded in the Month of August, which shows the August break, as shown in figure 3b. Like figure 3a, the North-Central Nigeria in figure 3c has its sunshine hour highest in the month of December and its corresponding lowest value in the month of August.

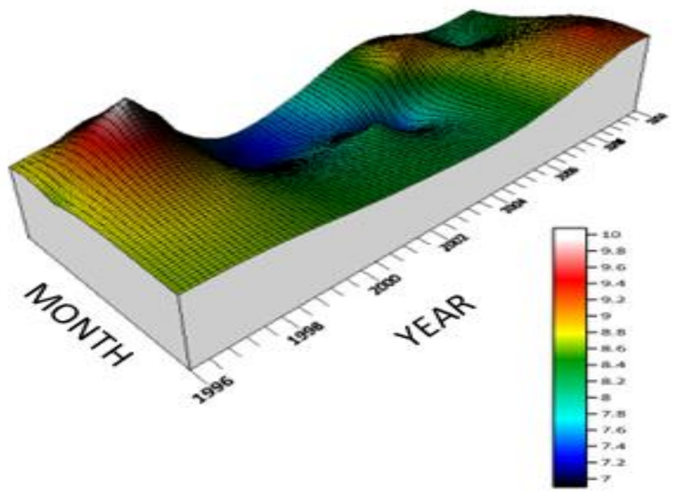

Figure 4a. Distribution of sunshine hour for Sokoto (1996-2010).

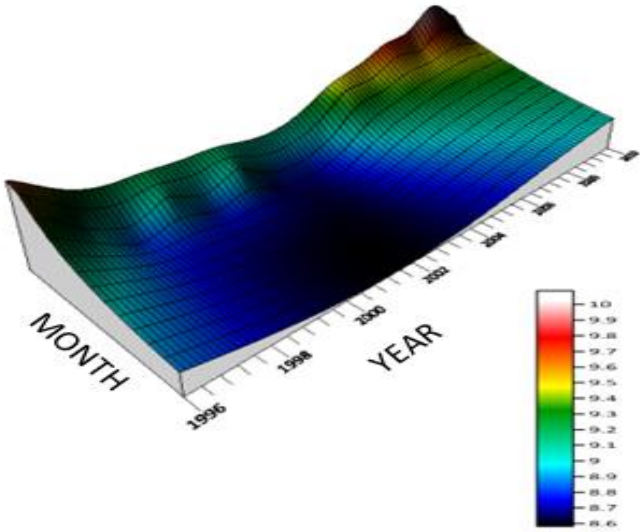

Figure 4b. Distribution of sunshine hour for Maiduguri (1996-2010).

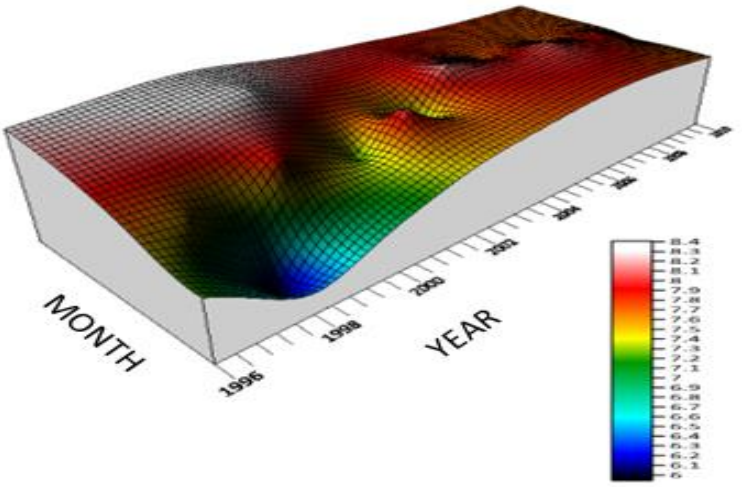

Figure 4c. Distribution of sunshine hour for Ilorin (1996-2010).

Figure 4a shows the distribution of sunshine hours in Sokoto. It shows a well-detailed picture of this distribution from the value of 10 as maximum to values of 7.2 and 7.0 as minimum possible values for sunshine hours for this distribution. The monthly distribution along the z-axis and the yearly distribution along the x-axis show that for October to December 1996 and October 1998, the sunshine hour for Sokoto is between the peak values of 9.6 to 10.0 with December 1998 having the highest value of 10 hours for average sunshine hour. The minimum sunshine hour was seen to be between July to December 2000, July to December 2002, July to December 2003, and June to August 2004. The month of January 2010 saw a high sunshine hour duration as compared with the other years in the study. The colour coding ranges from blue to hot-red, then white as maximum colour for figure 4. Figure 4b differs from figure 4a to a large extent as its key ranges from 8.6 as minimum value to 10.0 as maximum value of sunshine hour. The figure distribution can be seen to show the monthly distribution along the z-axis and the yearly distribution along the x-axis. Figure 4b shows that the month of January for every year under the study with exemptions to 2009 and 2010 has values ranging from 8.6 to 8.8, as shown by the blue colour code on the key. January to June 2001 has the least value of sunshine hour for Maiduguri. The months of December 2005, 2006, 2007, 2008, 2009, and 2010, as shown by figure 4b, is seen to have high values of sunshine hour when compared to the other years. This can be attributed to the absence of rainfall and clear sky conditions for Maiduguri for those periods. The city of Ilorin, as shown in figure 4c, is blessed with sunshine hour distribution virtually all through the year for the period of study. With the exemption of January to March 1998, the entire period of the study for Ilorin is seen to be doing well in terms of sunshine hour throughout the year with values of sunshine ranging from 6.0 to 8.4, as shown by the colour coding by the key.

Table 2. Estimated monthly GSR, Angstrom correlation constants, relative sunshine, and clearness index for Sokoto (1996-2010)

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	K_d
JAN	7.60	14.10	-2.12	15.68	0.3196	0.4826	0.6714	0.6436	0.356
FEB	8.48	17.20	0.98	17.56	0.3394	0.4400	0.732	0.6618	0.338
MAR	6.87	17.70	1.48	18.76	0.2866	0.5533	0.569	0.6018	0.398
APR	7.14	19.00	2.78	19.04	0.2901	0.5458	0.580	0.6069	0.393
MAY	7.42	16.60	0.38	18.18	0.2928	0.5399	0.588	0.6108	0.389
JUN	7.34	17.80	1.58	17.52	0.2886	0.5491	0.575	0.6047	0.395
JUL	6.94	14.50	-1.72	15.34	0.2795	0.5686	0.547	0.5908	0.409
AUG	6.89	14.70	-1.52	14.29	0.2820	0.5633	0.555	0.5947	0.405
SEP	7.94	15.00	-1.22	16.26	0.3156	0.4911	0.659	0.6393	0.360
OCT	8.36	16.60	0.38	17.02	0.3340	0.4516	0.716	0.6573	0.342
NOV	8.62	14.90	-1.32	16.65	0.3474	0.4228	0.757	0.6677	0.332
DEC	7.87	16.50	0.28	15.52	0.3290	0.4622	0.700	0.6529	0.347

Table 3. Estimated monthly GSR, Angstrom coefficient constants, relative sunshine, and clearness index for Maiduguri (1996-2010).

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	K_d
JAN	8.90	11.10	-1.83	14.22	0.3169	0.4962	0.7819	0.704	0.295
FEB	9.26	12.60	-0.33	15.43	0.3219	0.4854	0.7970	0.709	0.291
MAR	8.32	15.50	2.57	17.04	0.2871	0.5602	0.6890	0.673	0.326
APR	7.76	16.70	3.77	17.91	0.2685	0.6002	0.6320	0.647	0.352
MAY	8.61	15.40	2.47	16.59	0.2858	0.5630	0.6850	0.671	0.328
JUN	8.08	13.30	0.37	14.66	0.2699	0.5970	0.6360	0.650	0.350
JUL	7.34	10.70	-2.23	13.27	0.2523	0.6350	0.5810	0.621	0.378
AUG	6.28	10.80	-2.13	12.08	0.2283	0.6864	0.5070	0.576	0.423
SEP	7.42	12.80	-0.13	14.82	0.2633	0.6112	0.6160	0.640	0.360
OCT	9.08	13.20	0.27	15.62	0.3148	0.5005	0.7750	0.703	0.296
NOV	9.38	12.70	-0.23	14.87	0.3292	0.4697	0.8200	0.714	0.285
DEC	9.60	10.30	-2.63	13.22	0.3387	0.4493	0.8490	0.720	0.279

Table 4. Estimated monthly GSR, Angstrom coefficient constants, relative sunshine, and clearness index for Ilorin (1996-2010).

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	K_d
JAN	6.70	14.30	-0.93	14.07	0.060	0.137	0.580	).734	0.265
FEB	7.63	16.90	1.67	17.20	0.030	0.132	0.650	).822	0.177
MAR	7.22	17.20	1.97	17.00	0.054	0.135	0.599	).759	0.240
APR	6.52	18.30	3.07	17.02	0.075	0.140	0.534	).674	0.325
MAY	6.68	17.50	2.27	15.60	0.073	0.139	0.538	).680	0.319
JUN	6.42	13.30	-1.93	13.90	0.080	0.141	0.513	).645	0.354
JUL	4.34	12.80	-2.43	12.05	0.134	0.153	0.349	).399	0.600
AUG	3.60	12.50	-2.73	11.71	0.152	0.156	0.293	).308	0.691
SEP	4.68	14.50	-0.73	14.63	0.122	0.503	0.389	).460	0.539
OCT	6.31	16.50	1.27	16.36	0.074	0.401	0.535	).675	0.324
NOV	7.71	17.10	1.87	16.95	0.032	0.131	0.664	).839	0.160
DEC	7.77	14.90	-0.33	15.18	0.029	0.130	0.675	).851	0.148

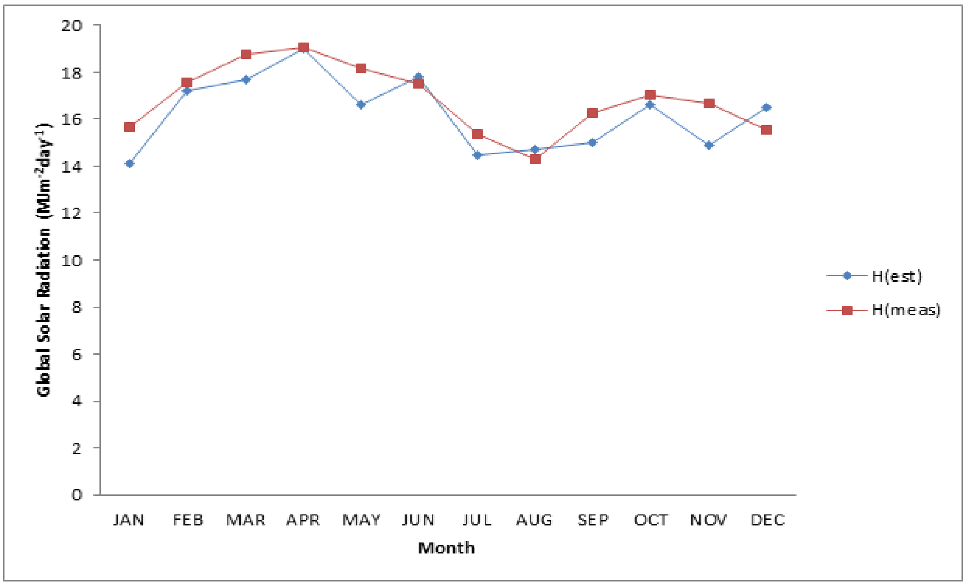

Figure 5a. Monthly variation in the estimated and measured GSR for Sokoto (1996-2010).

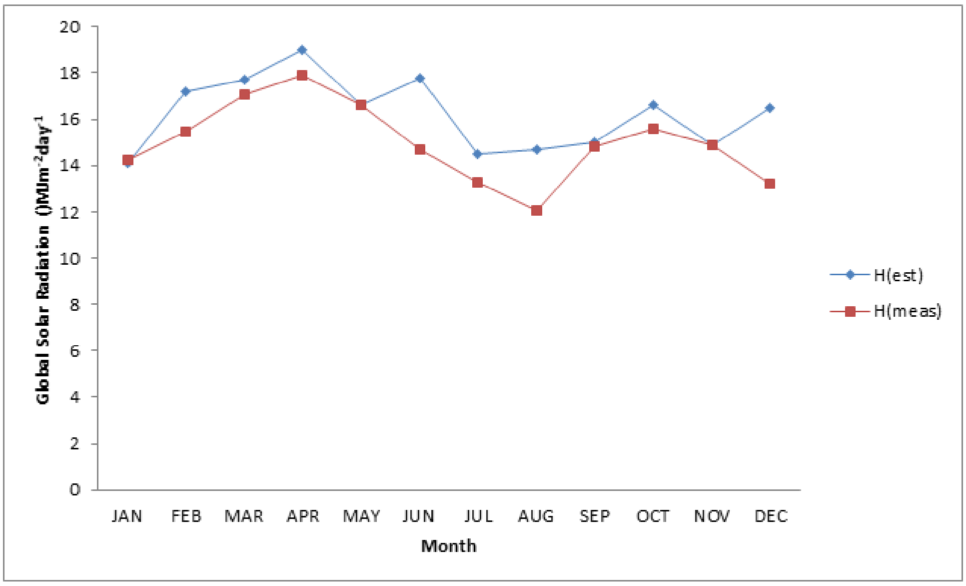

Figure 5b. Monthly variation in the estimated and measured GSR for Maiduguri (1996-2010).

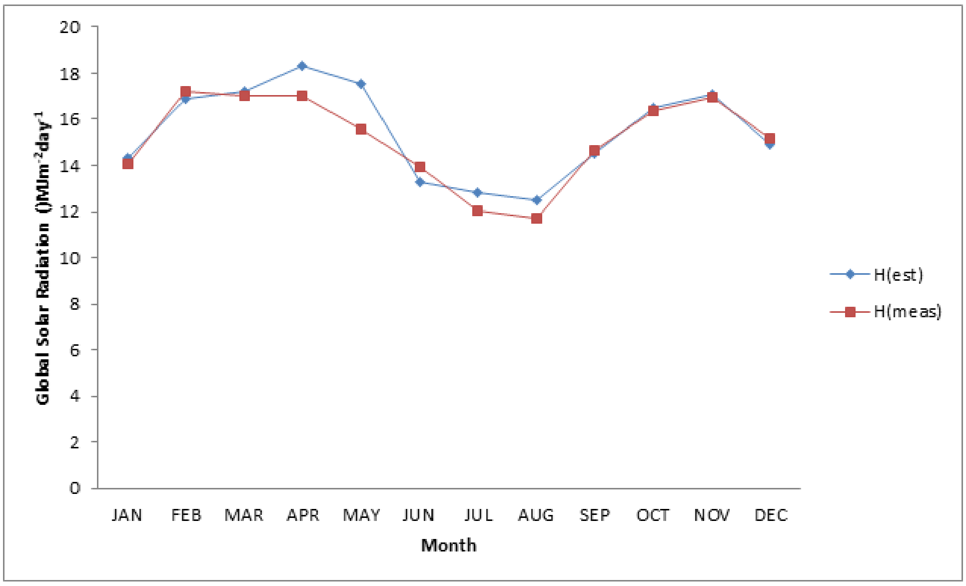

Figure 5c. Monthly variation in the estimated and measured GSR for Ilorin (1996-2010).

Figure 5a shows the variation in the measured and estimated GSR for Sokoto. The percentage difference and variation between the measured and the estimated values was found to be 3.57%. This value of percentage variation shows a high level of agreement between the measured values and the estimated values of GSR in Sokoto, and by extension, the north-western part of Nigeria. Figure 5b shows a plot of the measured and estimated GSR for Maiduguri. The percentage variation between the measured and the estimated values was found to be 13.19%. This value of percentage variation shows a range of difference between the measured values and the estimated values of GSR in Maiduguri, and by extension, the north-east of Nigeria by this study. Figure 5c shows a plot of the measured and estimated GSR for Ilorin. The percentage variation between the measured and the estimated values was found to be 2.25%. This value of percentage variation gives a very good correlation between the measured values and the estimated values of GSR in Ilorin, and by extension, the north-center of Nigeria.

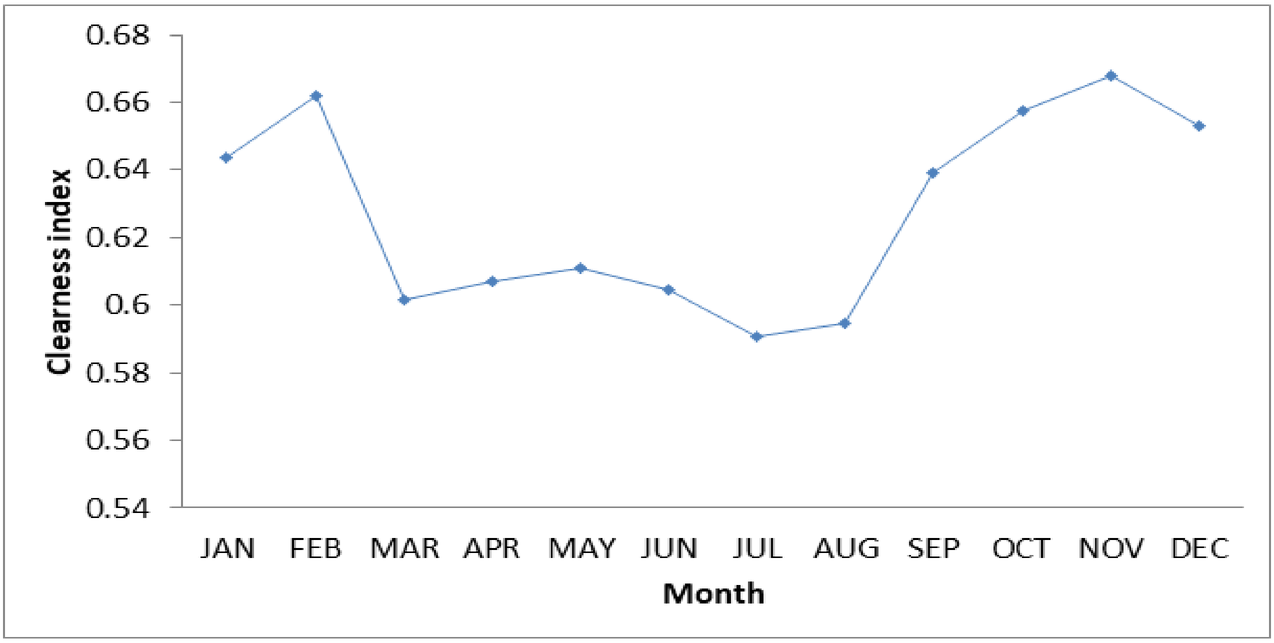

Figure 6a. Monthly variation in the estimated clearness index for Sokoto.

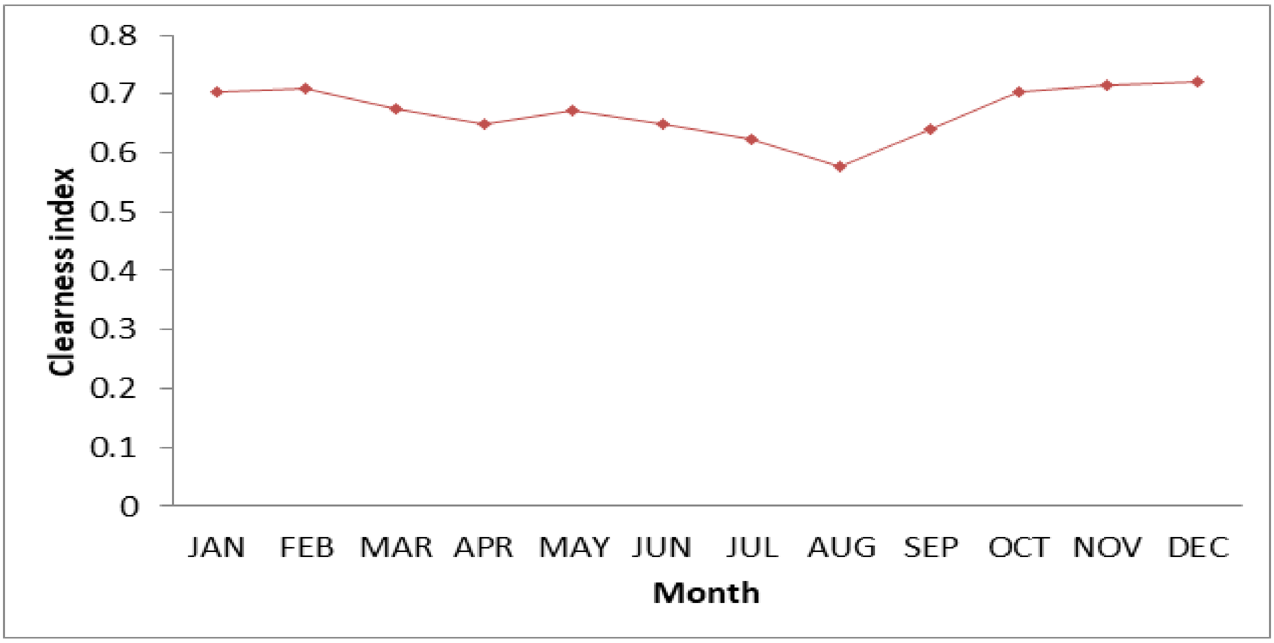

Figure 6b. Monthly variation in the estimated clearness index for Maiduguri.

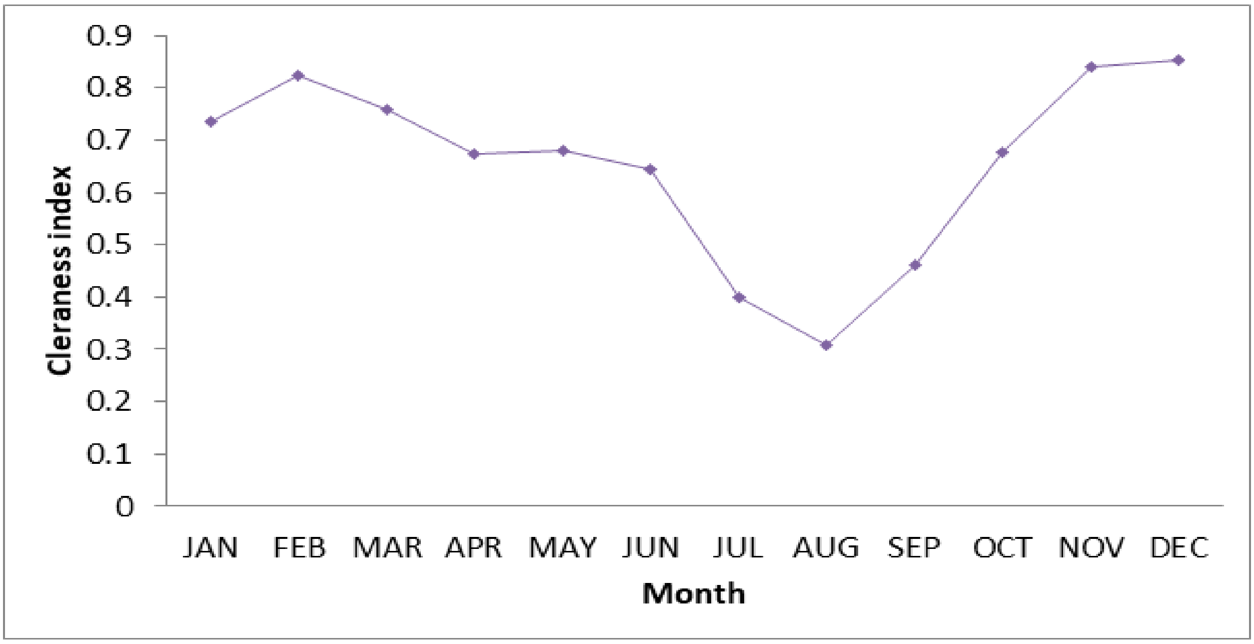

Figure 6c. Monthly variation in the estimated clearness index for Ilorin.

Figure 6a shows that the month with the least clearness index in Sokoto is July. This fact can be associated with the excessive rainfall in this month, which would have led to cloudy days during the month of July for this station. The months of November, December, January, and February are seen to have a more clear sky, which can be attributed to the less rainfall and increase in sunshine hour as a result. The clearness index for Maiduguri can be seen to be almost constant but with little variations in the months of March, April, September with significant variation in July and August. Figure 6b shows that the north-east has a relatively clear sky all through the year. Figure 6c presents the month of August as the cloudiest month of the year for Ilorin during the study. Significantly important to mention is the month of February with the value of 0.822 as its clearness index.

Correlation between H_{est} and H_{meas} for Sokoto

Figure 7 shows the correlation between the estimated GSR and the measured GSR for Sokoto. This figure shows a correlation of 0.82 between these variables. A percentage of 82% accuracy for the correlation makes the angstroms constants good estimates for finding values of GSR in Sokoto and nearby cities with similar latitudes and sunshine durations. The correlation also serves as a means of checking the correctness of the values of the angstrom constants in relation to the estimation of GSR.

Table 5. Values of estimated GSR and measured GSR for Sokoto.

Month	H_{est} $(MJm^{-2}day^{-1})$	H_{meas} $(MJm^{-2}day^{-1})$
JAN	14.10	15.68
FEB	17.20	17.56
MAR	17.70	18.76
APR	19.00	19.04
MAY	16.60	18.18
JUN	17.80	17.52
JUL	14.50	15.34
AUG	14.70	14.29
SEP	15.00	16.26
OCT	16.60	17.02
NOV	14.90	16.65
DEC	16.50	15.52

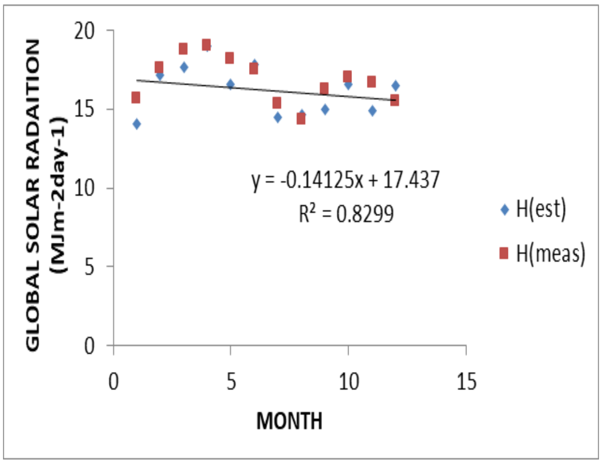

Figure 7. Correlation between the estimated GSR and the measured GSR for Sokoto.

Correlation between H_{est} and H_{meas} for Maiduguri

Figure 8 shows the correlation between the estimated GSR and the measured GSR for Maiduguri. This figure shows a correlation of 0.72 between these variables. The value of 0.72 for correlation makes the angstroms constants for estimating GSR for Maiduguri good. The correlation also serves as a means of checking the correctness of the values of the angstrom constants in relation to the estimation of GSR for this station.

Table 6. Values of estimated GSR and measured GSR for Maiduguri.

Month	H_{est} $(MJm^{-2}day^{-1})$	H_{meas} $(MJm^{-2}day^{-1})$
JAN	14.22	11.10
FEB	15.43	12.60
MAR	17.04	15.50
APR	17.91	16.70
MAY	16.59	15.40
JUN	14.66	13.30
JUL	13.27	10.70
AUG	12.08	10.80
SEP	14.82	12.80
OCT	15.62	13.20
NOV	14.87	12.70
DEC	13.22	10.30

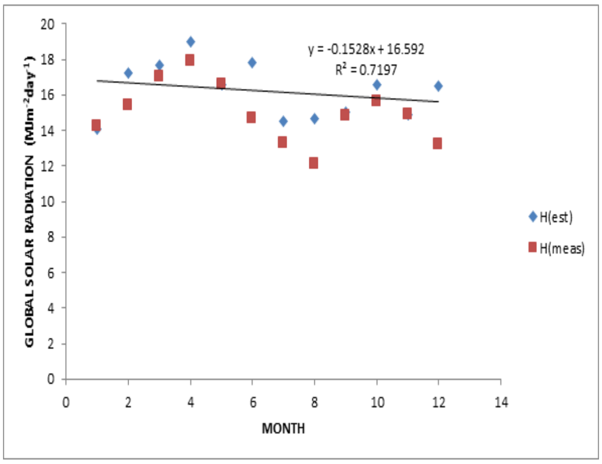

Figure 8. Correlation between the estimated GSR and the measured GSR for Maiduguri.

Correlation between H_{est} and H_{meas} for Ilorin

Figure 9 shows the correlation between the estimated GSR and the measured GSR for Ilorin. This figure shows a correlation of 0.93 between these variables. The value of 0.93 for the correlation shows that the angstroms constants for estimating GSR for Ilorin are good for estimating GSR. The correlation between the estimated and the measured GSR for Ilorin and the values of Angstrom constants agree more than the correlation for the estimated values of the measured and estimated GSR for Maiduguri.

Table 7. Values of estimated GSR and measured GSR for Ilorin.

Month	H_{est} $(MJm^{-2}day^{-1})$	H_{meas} $(MJm^{-2}day^{-1})$
JAN	14.30	14.07
FEB	16.90	17.20
MAR	17.20	17.00
APR	18.30	17.02
MAY	17.50	15.60
JUN	13.30	13.90
JUL	12.80	12.05
AUG	12.50	11.71
SEP	14.50	14.63
OCT	16.50	16.36
NOV	17.10	16.95
DEC	14.90	15.18

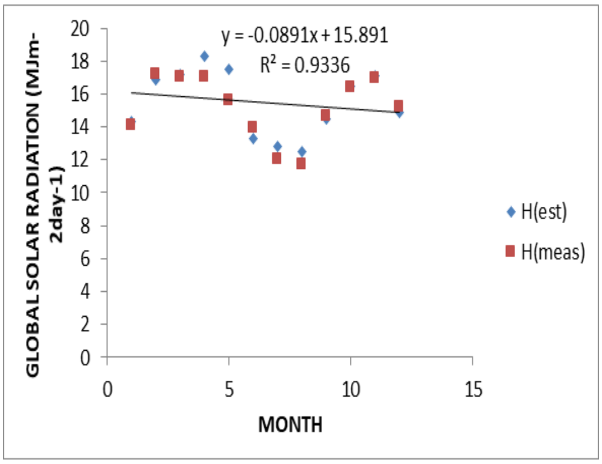

Figure 9. correlation between the estimated GSR and the measured GSR for Ilorin.

4. Conclusion

The values of 0.32 and 0.46 for Sokoto (north-western) agree with the values for the angstrom constants 0.30 and 0.43 for estimating the solar radiation for Sokoto, NW Nigeria [12], 0.25 and 0.55 for Sokoto, and 0.29 and 0.48 for NW Nigeria. The Angstrom constants estimated in the study for Maiduguri agree with the values of 0.30 and 0.54 presented in a research by [8] as against the values of 0.41 and 0.32 obtained by [7]. The northern region of Nigeria is seen to be an advantage in solar irradiance when compared with their southern counterparts, as reported in [14].

Statistical Test

The simple first-order angstrom constant regression correlation model was developed for each one of the stations in this work to estimate H (GSR) at each one of the respective meteorological stations.

Table 8. Statistical error result presentation.

Station	H_{est} $(MJm^{-2}day^{-1})$	H_{meas} $(MJm^{-2}day^{-1})$	MBE	RMSE	MPE (%)
SOKOTO	16.21667	16.82167	-0.3025	0.4278	1.79
MAIDUGURI	16.21667	14.98111	0.61778	0.8736	4.12
ILORIN	15.48333	15.14055	0.17139	0.2424	1.13

1) SOKOTO

$$\frac{H}{H_0} = 0.329 + 0.4622\frac{S}{S_0} \tag{7}$$

2) MAIDUGURI

$$\frac{H}{H_0} = 0.2897 + 0.5545\frac{S}{S_0} \tag{8}$$

3) ILORIN

$$\frac{H}{H_0} = 0.0762 + 0.191\frac{S}{S_0} \tag{9}$$

References

[1] Mojarrad, F., Fathnia, A., & Rajaee, S. (2015). The Estimation of Receiving Solar Radiation at Earth's Surface in Kermanshah Province. Arid Regions Geography Studies, 5(19).

[2] Ibrahim, H. (2015). Estimation of Global Solar Radiation using Sunshine- based and Temperature-based Models; case study of Adama Town. Haramaya University.

[3] Rezrazi, A., Hanini, S., & Laidi, M. (2013). Estimation ofsolar radiation with Artificial Neural Networks: analysis and synthesis of published works. In Conférence Internationale des Energies Renouvelables (CIEAR'13) (Vol. 2). Retrieved from http://ipco-co.com/CIER'13-IJSET/ID_170.

[4] Ndilemeni C. C. (2013). Evaluation of Clearness Index of Sokoto Using Estimated Global Solar Radiation. IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT), 5(3), 51–54. Retrieved from http://www.iosrjournals.org/iosr-jestft/papers/vol5-issue3/K0535154.pdf?id=3481.

[5] Innocent, A. J., Jacob, O. E., Chibuzo, G. C., James, I., & Odeh, D. O. (2015). Estimation of Global Solar Radiation in Gusau , Nigeria. International Journal of Research in Engineering & Technology, 3(2), 27–32.

[6] Gana, N. N., & Akpootu, D. O. (2013). Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North-Eastern Nigeria. The International Journal Of Engineering And Science (IJES), 2(11), 58–78.

[7] Garba, A. A., Amusat, R. O., & Ngadda, Y. H. (2016). Estimation of Global Solar Radiation Using Sunshine-Based Model in Maiduguri, North East, Nigeria. Applied Research Journal, 2(1), 19–26. Retrieved from http://arjournal.org/files/2015/05/ARJ-V.2n.1.19-26.

[8] Musa, B., Zangina, U., & Aminu, M. (2012). Estimation of Global Solar Radiation in Maiduguri, Nigeria Using Angstrom Model. ARPN Journal of Engineering and Applied Sciences, 7(12), 1623–1627.

[9] Olayinka, S. (2011). Estimation of global and diffuse solar radiations for se- lected cities in Nigeria. International Journal of Energy and Environmental Engineering, 2(3), 13–33.

[10] Yusuf, A. (2017). Characterization of sky conditions using clearness index and relative sunshine duration for Iseyin, Nigeria. International Journal of Physical Sciences Reseach, 1(1), 53–60.

[11] Adeniji, N. O. (2018). Determination of Angstroms canstants for the Estimation of global solar radiation for energy utilization in Nigeria. Bowen University.

[12] Gana, N. N., Rai, J. K., & Momoh, M. (2014). Angstrom Constants for Estimating Solar Radiation in Sokoto, North-Western, Nigeria. International Journal of Scientific & Engineering Research, 5(1), 1636–1647.

[13] Adenji, N., Akinpelu, J., Adeniji, J., & Adeola, S. (2019). Estimation of Global Solar Radiation , Sunshine Hour Distribution and Clearness Index in Three Geopolitical Regions of Southern. *Jordan Journal of Earth and Enviromental Sciences*, *10*(2), 97–104.