Research Article

Analysis of Global Solar Irradiance over Climatic Zones in Nigeria for Solar Energy Applications

Adekunle Ayodotun Osinowo,¹ Emmanuel Chilekwu Okogbue,²
Stephen Bunmi Ogungbenro,² and Olugbenga Fashanu³

¹Department of Marine Science and Technology, Federal University of Technology, PMB 704, Akure 340001, Nigeria

²Department of Meteorology, Federal University of Technology, PMB 704, Akure 340001, Nigeria

³Department of Agricultural Engineering, Federal University of Technology, PMB 704, Akure 340001, Nigeria

Correspondence should be addressed to Adekunle Ayodotun Osinowo; voxfox99@yahoo.com

Received 1 June 2015; Revised 4 September 2015; Accepted 27 September 2015

Academic Editor: Ruijiang Hong

Copyright © 2015 Adekunle Ayodotun Osinowo et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Satellite derived solar irradiance over 25 locations in the 5 climatic zones of Nigeria (tropical rainforest TRF, Guinea savannah GS, Sahel savannah SHS, Sudan savannah SUS, and Mangrove swamp forest MSF) was analyzed. To justify its use, the satellite data was tested for goodness of agreement with ground measured solar radiation data using 26-year mean monthly and daily data over 16 locations in the 5 climatic zones. The well-known R^2 , RMSE, MBE, and MPE statistical tests were used and good agreement was found. The 25 locations were grouped into the 5 climatic zones. Frequency distribution of global solar irradiance was done for each of the climatic zones. This showed that 46.88%, and 40.6% of the number of days (9794) over TRF and MSF, respectively, had irradiation within the range of 15.01–20.01 MJ/m²/day. For the GS, SHS, and SUS, 46.19%, 55.84% and 58.53% of the days had total irradiation within the range of 20.01–25.01 MJ/m²/day, respectively. Generally, in all the climatic zones, coefficients of variation of solar radiation were high and mean values were low in July and August. Contour maps showed that high and low values of global solar irradiance and clearness index were observed in the Northern and Southern locations of Nigeria, respectively.

1. Introduction

Some solar energy applications such as modeling, photovoltaic system sizing, and design of solar crop dryers require the vast knowledge of global solar insolation. The intensity of solar radiation per day is usually one of the variables collected by meteorological stations in tropical Africa, Nigeria especially. These stations are limited in number due to the cost involved in establishing and maintaining them. This limits the availability of data to a few locations. There are at the moment only 44 weather stations in Nigeria that routinely measure climatic parameters like sunshine hours, temperature, rainfall, atmospheric pressure, and humidity. However, out of these 44 weather stations, only about 16 of them measure solar radiation, leaving most of the locations in the country with no solar radiation ground measured data. Furthermore, there are even areas of Nigeria with

no meteorological stations. Thus, alternative means have to be developed to generate solar radiation data and other meteorological variables for locations with no meteorological stations. A number of researchers used data from satellites to compensate for some locations without ground stations in some countries.

Nigeria is located between 4°N and 14°N latitude (Figure 1) and hence, the country receives a vast supply of solar energy all year round. This energy can be utilized for the development of solar energy systems. For this purpose, solar radiation data are required in various forms depending on the type of application. Numerous researchers, for example [1–3], have highlighted the importance of solar radiation data for design and efficient operation of solar energy systems. Proper design and performance of these solar appliances require accurate information on solar radiation availability [3]. Hourly averaged values of both global and diffuse radiation

FIGURE 1: Map of Nigeria showing the study locations.

flux densities during the period of March 1992–December 2002 were measured using two Kipp and Zonen pyranometers models: CM11 for the global radiation, CM11/121 (incorporating a shadow ring) for diffuse radiation, and a LICOR LI-210SA photometric sensor for the photometric illuminance at the rooftop of the Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria. The diurnal and seasonal patterns of both the hourly and daily clearness and the cloudiness index were manifested in the datasets [4, 5]. Using dataset of monthly global solar irradiance for a period covering at least 20 years, the optical sky conditions over some selected stations in the major vegetation zones of Nigeria have also been investigated [6]. Many empirical studies on the portioning of solar irradiance have been presented for various regions of the world, for example [7, 8].

Ground and satellite derived solar radiation data complement each other and are required to build a comprehensive solar radiation database. Satellite data are instantaneous measurements over a small solid viewing angle, while ground measurements are integrated over a time and solid angle of 2π [9]. It is difficult to have sufficient high capability solar radiation monitoring networks in many parts of the world, Nigeria inclusive. Hence, the need for interpolation of data but accuracy in the interpolation of data decreases with increasing distance between sites. However, satellite measurements and short time interval data are needed for the engineering and site-specific studies. Therefore, combining these two, ground based measurements and satellite derived data create a comprehensive solar radiation database.

The accuracy of satellite data is determined by validation or comparison of satellite data series against ground data series. However, it is important to quantify the similarities or the differences between the two series. Usually graphics and correlation are most commonly used methods for this task. The validation of data measured from satellite against ground data focuses usually on the root mean square (RMS) differences and mean bias (MB) difference as shown in

the studies of [10–15]. Other parameters are the coefficient of determination by [16, 17], standard deviation by [18, 19], and, in some other cases, the variation coefficient, and difference between the mean and the median [19] and the analysis of the residuals [20] were used.

More recently, in informing decision making in the energy sector, [21] highlighted the societal benefits of earth observation satellites which augment ground based observations serving as input for renewable-energy resource assessment applications.

In Rochambeau, Saint-Georges, Maripasoula, and Saint-Laurent which are four weather stations in French Guiana in the Northeast coast of South America, [22] validated the daily mean global solar irradiance data obtained from the HelioClim-3 database and produced by the Heliosat-2 method applied to Meteosat satellite imagery with the ground truth data for each of the 4 stations. They concluded that the Heliosat-2 method contributes a new knowledge of global solar irradiance over French Guiana. Reference [23] used temperature data such as (T (°C), $T_{\max}$ (°C), and $T_{\min}$ (°C)) obtained from National Aeronautics and Space Administration (NASA) to predict global solar irradiance by using Artificial Neural Network (ANN) models over 26 selected cities of varying climatic zones in India. Following a paper from [24], an eight-year hourly global and beam irradiance data retrieved from geostationary satellite images over 18 European and Mediterranean sites were validated on an hourly and monthly basis using a ground based hourly data of the same radiation components collected over the same sites and for the same period. A seasonal comparison between HelioClim-3 satellite SSI derived data and ground based radiometric measurements of hourly global solar irradiance data covering a period of 3 years for Ajaccio, Corte, and Bastia which are 3 stations in Corsica was made by [25]. 30-minute average ground measurements of direct normal irradiance (DNI) were statistically compared to DNI data from satellite-to-irradiance model SUNY by [26] over Merced, David, Berkeley, and San Diego in California. They concluded that, due to the maintenance cost of DNI ground measurements, the SUNY-modeled data is excellent in assessing the DNI at 30-minute intervals. Reference [27] validated a monthly mean surface solar irradiance (SSI) data as measured by an ozone monitoring instrument (OMI) with a baseline surface radiation network (BSRN) measurements at 19 stations for the year 2008. Solar radiation is a required variable for the designers of solar energy systems. It is often provided in the form of solar radiation maps, which is usually a preferable approach, more efficient, and easier to handle [28]. It requires knowing solar radiation at many points spread wide across the region of interest.

For a significant contribution to knowledge, energy readers stand to benefit from this paper in the fact that solar radiation data from satellites over areas of poorly instrumented meteorological stations or stations with dearth of skilled personnel can be utilized for solar energy applications especially by engineers who fabricate solar energy conversion systems and the climatology of solar radiation parameters such as the clearness index with the unavailable energy which are clear indicators of the average sky conditions over

TABLE 1: Locations in Nigeria considered in the study.

Location	Latitude (°N)	Longitude (°E)	Elevation (m)
Ikom	5.97	8.7	119
Uyo	5.05	7.95	38
Makurdi	7.73	8.53	112.9
Lokoja	7.8	6.73	62.5
Ilorin	8.483	4.583	307.4
Potiskum	11.7	11.03	414.8
Zaria	11.07	7.75	110.9
Bursari	12.45	11.72	318
Damaturu	11.74	11.96	444
Ikeja	6.58	3.33	39.4
Port- Harcourt	4.85	7.12	19
Calabar	4.97	8.35	61.9
Akure	7.28	5.3	375
Enugu	6.47	7.55	141.8
Warri	5.52	5.73	6.1
Benin	6.32	5.6	77.8
Ibadan	7.43	3.9	227.2
Yola	9.23	12.47	186.1
Ibi	8.18	9.75	110.7
Minna	9.62	6.53	256.4
Maiduguri	11.85	13.08	353.8
Nguru	12.88	10.47	343.1
Sokoto	12.92	5.2	350.8
Bauchi	10.28	9.82	609.7
Kano	12.05	8.53	427.5

any location reference materials for energy and agricultural planners in addition to providing information on the solar radiation of the study area for purposes of research.

Using satellite data, this paper aimed at generating annual and seasonal solar irradiance maps for Nigeria. Fractal distribution of solar irradiance and its coefficient of variation over the various climatic zones of the country were also investigated.

2. Materials and Methods

2.1. Data Source and Preparation. Twenty-six-year (1984–2009) daily satellite global irradiance data obtained from the archives of the National Aeronautics and Space Administration (NASA) was used for this study. The data set which was obtained at a screen resolution of 1° by 1° was validated using surface global irradiance obtained from the archives of the Nigerian Meteorological Agency (NIMET) for the corresponding years. Tables 1 and 2 show the geographical details of the stations and statistical parameters such as the coefficient of determination mean bias error, root mean square error, and mean percentage error between the observed and satellite data, respectively, for the five climatic zones. On average, R^2 , MBE, RMSE, and MPE values for the climatic zones were as follows: 0.7799, 0.1602, 1.6553, and −1.8807 for tropical rainforest; 0.8843, −0.5688, 1.2116,

TABLE 2: R^2 , MBE, RMSE, and MPE between the observed and satellite data for the climatic zones.

Location	R^2	MBE	RMSE	MPE
Sahel savannah				
Maiduguri	0.9576	0.2165	0.5038	−1.1619
Nguru	0.7265	−1.0556	1.4817	4.6014
Average	0.8421	−0.4196	0.9928	1.7198
Sudan savannah				
Sokoto	0.7464	0.0656	1.0147	−0.2388
Bauchi	0.8174	−0.3916	0.9382	1.6019
Kano	0.8819	−0.9646	1.2449	4.3573
Yola	0.9527	−1.8471	1.9594	8.0707
Average	0.8496	−0.7844	1.2893	3.4477
Mangrove swamp forest				
Port Harcourt	0.8237	−0.7075	1.4233	4.8967
Calabar	0.6315	−0.5341	2.1099	3.9059
Warri	0.6727	−1.7629	2.2924	9.7824
Average	0.7093	−1.0015	1.9418	6.1950
Guinea savannah				
Ibi	0.9220	−1.3204	1.4689	6.4532
Minna	0.8466	0.1828	0.9543	−1.2337
Average	0.8843	−0.5688	1.2116	2.6098
Tropical rain forest				
Ikeja	0.8446	2.6295	2.7663	−18.7371
Akure	0.7163	−1.2940	1.8379	6.7471
Enugu	0.7483	−0.2038	1.1372	1.0537
Ibadan	0.8119	0.4458	1.1308	−2.9164
Benin	0.7785	−0.7767	1.4044	4.4493
Average	0.7799	0.1602	1.6553	−1.8807

and 2.6097 for Guinea savannah; 0.8421, −0.4195, 0.9925, and 1.7197 for Sahel savannah; 0.8496, −0.7844, 1.2893, and 3.4477 for Sudan savannah; and 0.7799, 0.1601, 1.6553, and −1.8806 for Mangrove swamp forest. Clearly, there is a good relationship between the observed and satellite data.

2.2. Data Analysis. Using satellite data, the overall averaged monthly mean and coefficient of variation of daily global solar irradiance for each of the climatic zones have been computed (Table 3).

The coefficient of variation is defined here as the ratio of the standard deviation to the mean value. The percentage frequency distribution of the daily global irradiance for each of the 25 locations and for each month of the 26-year period under review has been done.

The flux of energy received from the sun at the top of the atmosphere, per unit of area and per interval of one day (H_0), is estimated analytically by the familiar expressions according to [29]. Contour maps of the averaged daily global irradiance and clearness index on both annual and seasonal basis were generated using the surfer software.

2.3. Statistical Tests of Performance. To validate the satellite data used in this work, four statistical methods have been

TABLE 3: Monthly mean and coefficient of variation (COV) of global solar irradiance for the climatic zones.

Tropical rainforest												
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Means	19.88	20.4	19.98	18.97	17.68	15.89	14.16	13.83	14.73	16.49	18.52	19.37
COV	0.12	0.11	0.12	0.12	0.13	0.15	0.16	0.17	0.16	0.14	0.12	0.12
Guinea savannah												
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Means	20.81	21.6	21.73	20.67	19.31	17.65	16.05	15.12	16.44	18.26	20.35	20.55
COV	0.11	0.1	0.1	0.11	0.12	0.13	0.14	0.15	0.14	0.12	0.11	0.11
Sahel savannah												
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Means	20.32	22.9	24.5	24.64	23.71	22.82	20.54	19.2	20.66	21.22	20.56	19.29
COV	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.1	0.1	0.09	0.09	0.1
Sudan savannah												
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Means	20.31	22.6	23.73	23.55	22.55	21.56	19.43	18.16	19.89	20.99	20.96	19.83
COV	0.1	0.08	0.08	0.08	0.08	0.08	0.09	0.1	0.09	0.09	0.09	0.09
Mangrove swamp forest												
Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Means	19.61	19.9	18.58	17.59	16.26	14.14	12.54	12.84	13.23	14.64	16.88	18.7
COV	0.13	0.13	0.14	0.15	0.16	0.2	0.21	0.21	0.19	0.18	0.16	0.14

employed. These are the coefficient of determination (R^2), mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE). The MBE, RMSE, and MPE are all in MJ/m²/day. These are defined by [29] as follows:

(i) r

$$= \frac{\sum_{i=1}^n (H_{\text{NASA}} - \bar{H}_{\text{NASA}})(H_{\text{LAND}} - \bar{H}_{\text{LAND}})}{\left\{ \left[\sum_{i=1}^n (H_{\text{NASA}} - \bar{H}_{\text{NASA}})^2 \right] \left[\sum_{i=1}^n (H_{\text{LAND}} - \bar{H}_{\text{LAND}})^2 \right] \right\}^{1/2}},$$

(ii) $\text{MBE} = \left[\frac{1}{n} \sum_{i=1}^n (H_{\text{NASA}} - H_{\text{LAND}}) \right], \quad (1)$

(iii) $\text{RMSE} = \left[\frac{1}{n} \sum_{i=1}^n (H_{\text{NASA}} - H_{\text{LAND}})^2 \right]^{1/2},$

(iv) $\text{MPE} = \frac{\left[\sum_{i=1}^n (H_{\text{LAND}} - H_{\text{NASA}}) / (H_{\text{LAND}} \times 100) \right]}{n},$

where H_{NASA} = mean monthly satellite global solar irradiance, H_{LAND} = mean monthly ground truth global solar irradiance, $\bar{H}_{\text{NASA}}$ = overall mean monthly satellite global solar irradiance, $\bar{H}_{\text{LAND}}$ = overall mean monthly ground truth global solar irradiance, and N is the total number of observations.

The RMSE allows a term-by-term comparison of the actual deviation between the satellite and land measured values of the global solar irradiance and therefore provides information on the short-term performance of the satellite derived values. The RMSE is always positive: however a zero value is ideal. On the other hand, the test on MBE provides information on the long-term performance of the satellite data. A positive MBE value gives the average amount of overestimation in the satellite values and vice versa.

In general, a low MBE is desirable [29, 30]. The correlation coefficient (r) is a test of the linear relationship between the satellite and land values.

These error analyses were performed for each of the sixteen stations in relation to the land and satellite measured mean monthly values of the global solar irradiance.

3. Results and Discussions

The daily frequency of occurrence (%) of global solar irradiance over the climatic zones plotted on an annual basis is as depicted in Figure 2.

Clearly, for each climatic zone, the pattern of daily global solar irradiance is fairly evenly distributed with peaks of 15.01–20.01 MJ/m²/day intervals for the tropical rainforest and Mangrove swamp forest. This means that, on average, 46.88% and 40.6% of the total number of days (9794) have total irradiation within the range of 15.01–20.01 MJ/m²/day as presented in Figure 2, respectively, for each of the two zones. Within this modal group and for the tropical rainforest, Benin and Enugu, respectively, have higher frequencies of 49.06% and 48.99%. Uyo and Ikom in the Mangrove swamp forest also have higher frequencies of 46.35% and 46.21%, respectively, within the same group. Furthermore, the frequency distribution of the daily global solar irradiance shows that the occurrence of irradiance at intervals of 0.01–5.01, 5.01–10.01, 10.01–15.01, and 25.01–30.01 MJ/m²/day is lower for the tropical rainforest with average values of 1.29%, 5.74%, 16.43%, and 0.51% and also lower at the same irradiance intervals for the Mangrove swamp forest with average values of 3.39%, 10.66%, 20.34%, and 0.35%. However for the above two climatic zones, no irradiance data is seen to fall within the radiation group of 30.01–35.01 MJ/m²/day. A comparison

FIGURE 2: Percentage frequency distribution of the daily global solar irradiance over the climatic zones.

of the percentage frequency distribution of daily global solar irradiance between both climatic zones as seen in Figure 2 clearly shows that more global irradiance is received at the tropical rainforest due to less cloudy skies over the zone as compared with the Mangrove swamp forest.

Over the Guinea, Sahel, and Sudan savannahs, 46.19%, 55.84%, and 58.53% of the total number of days, respectively, for the zones have total irradiation within the modal radiation group of 20.01–25.01 MJ/m²/day. Locations such as Ibi and Minna in the Guinea savannah have higher frequencies of 53.35% and 54.11%. Maiduguri, Potiskum, and Damaturu in the Sahel savannah have higher frequencies of 59.38%, 56.81%, and 56.83% while Bauchi and Yola in the Sudan savannah have higher frequencies of 62.95% and 62.3% within the above modal radiation group. The percentage frequency of occurrence of global irradiance at intervals of 0.01–5.01, 5.01–10.01, 10.01–15.01, and 15.01–20.01 MJ/m²/day with average values of 0.5%, 3.26%, 11.05%, and 37.08% is the highest over the Guinea savannah as compared to the other two zones. The average values (0.33%, 1.26%, 3.26%, and 22.04%) at these same intervals are the lowest over the Sahel savannah except for an average of 0.33%, higher than 0.27% which falls under the insolation interval of 0.01–5.01 MJ/m²/day for the Sudan savannah. For the radiation group of 20.01–25.01 MJ/m²/day, the highest average percentage frequency of occurrence of global insolation of 58.53% which is slightly higher than that of the Sahel savannah's 55.84% is in the Sudan savannah. Within the same irradiance interval, the lowest value of 46.19% is found in the Guinea savannah. The average percentage frequency of occurrence of global insolation for the radiation range of 25.01–30.01 MJ/m²/day is the highest over the Sahel savannah with a value of 17.3% and lowest in the Guinea savannah with a value of 1.92%. Furthermore, global solar irradiance data within the radiation group of 30.01–35.01 MJ/m²/day is seen only for the Sudan and Sahel savannah. The average percentage frequency of occurrence of global insolation within this group is almost negligible and higher over the Sudan savannah with a minute difference of 0.04% between the Sudan (0.06%) and Sahel savannah (0.02%). The above discussion of global solar insolation over the Guinea, Sahel, and Sudan savannahs clearly indicates that its influx is most pronounced over the Sahel savannah and least pronounced over the Guinea savannah as the Sahel savannah is of clearer skies than the other two climatic zones.

Table 3 presents the monthly means and coefficient of variation of daily global irradiance over the climatic zones. In each climatic zone, the months of July and August have relatively high monthly average coefficient of variation. The range is between 0.0980 (Sahel savannah) and 0.2097 (Mangrove swamp forest) among the 5 climatic zones. Also, the least coefficient of variation ranging between 0.0755 (Sudan) and 0.1307 (Mangrove swamp forest) is found in the months of March and February among the climatic zones under study. For the global irradiance, least values are found in the months of July and August in all the climatic zones. This is most pronounced in the Mangrove swamp forest (12.54 MJ/m²/day) and least pronounced in the Sahel savannah (19.19 MJ/m²/day). Over the Mangrove swamp forest,

tropical rain forest, and Guinea savannah, global irradiance has peak values ranging between 19.86 and 18.69 MJ/m²/day, 20.37 and 19.37 MJ/m²/day, and 21.73 and 20.55 MJ/m²/day around February and December, respectively, for the zones. Peak values are found around March and April in the range of 24.48 and 24.64 MJ/m²/day and 23.73 and 23.55 MJ/m²/day in the Sahel and Sudan savannah.

The contour maps of the averaged daily and seasonal global solar irradiance and clearness index for the locations are as shown in Figure 3.

Averaged global solar irradiance ranges between a maximum of 22.06 MJ/m²/day in Nguru, a location at the North-eastern part of Nigeria, and a minimum of 15.23 MJ/m²/day in Port Harcourt, a location in the Southern part of Nigeria. Spatial distribution of global solar irradiance is almost zonally symmetrical with an increase in the receipt of solar radiation northwards. As regards the distribution of global solar irradiance during the summer months (June–September), global solar irradiance is seen to range between 21.63 MJ/m²/day and 11.95 MJ/m²/day for all the locations. Higher values of global solar irradiance are observed around Nguru, Bursari, Kano, Potiskum, Damaturu, Maiduguri, and Sokoto while lower values can be seen in locations like Port Harcourt, Uyo, Calabar, Warri, Benin, and Ikom. The situation in the winter months (November–February) is a bit different from the summer months. Higher values ranging between 21.56 MJ/m²/day and 20.85 MJ/m²/day are seen in locations close to the middle belt such as Ibi, Bauchi, Makurdi, and Yola. Lower values are seen around Port Harcourt, Calabar, Uyo, and Warri.

The averaged daily clearness index ranges between 0.63 and 0.43 for all the locations. It was found to be zonally symmetrical with peak values at the Northern part of Nigeria in areas like Sokoto, Kano, Nguru, Bursari, Potiskum, Damaturu, and Maiduguri. There is a southward decrease in clearness index values to locations like Port Harcourt, Calabar, Warri, and Uyo where it has low values. This is expected as cloudiness also increases in that direction. During the dry and wet months, distribution of the clearness index decreases southwards with an almost zonally symmetric spatial pattern but for an area band around Bauchi during the winter months. In order of magnitude, the winter months have higher values of the clearness index and this justifies the scattering effects of clouds on incoming radiation during summer months.

4. Conclusion

This paper has presented the use of a 26-year (1984–2009) daily global solar irradiance data measured from satellite over 25 locations in Nigeria to carry out a frequency distribution of global solar irradiance and to observe the coefficient of variation and means of global solar irradiance over the five major climatic zones in Nigeria. Also, the contour maps of the distribution of averaged daily global solar irradiance and clearness index with their seasonal values have been generated across the locations.

FIGURE 3: Contour maps of the (a) averaged daily global solar irradiance, (b) clearness index for the year, and wet season (JJAS) and dry season (NDJF) for the locations.

On average, 46.88% and 40.6% of the total number of days (9794) over the tropical and Mangrove swamp forest have total irradiation within the modal radiation group of 15.01–20.01 MJ/m²/day. Furthermore, for the Guinea, Sahel, and Sudan savannahs, 46.19%, 55.84%, and 58.53% of the total number of days have total irradiation within the modal radiation group of 20.01–25.01 MJ/m²/day. Across the climatic zones, the coefficient of variation of global solar irradiance is high in the months of July and August and low in January and December. Also, low mean values of global solar irradiance are generally observed in July and August in all the zones and high values are observed in February and December in the tropical rainforest, Guinea savannah, and Mangrove swamp forest and also in March and April in the Sahel and Sudan savannahs.

Lastly, the contour maps of the averaged daily global solar irradiance and clearness index over the locations displayed that their spatial pattern is almost horizontally symmetric but with an obvious North-South variation. Peak global solar irradiance and clearness index are seen at the Northern horn of the maps with steady decrease in surface receipt southwards. Not much spatial variation in surface irradiance and clearness index were however observed between the seasons but little differential changes in magnitude were observed in Northern and Southern Nigeria. For the seasons (summer: JJAS and winter: NDJF), lower values of surface irradiance and clearness index were observed when compared with the average annual spatial pattern. The North-South differential spatial pattern could be traced to seasonality in cloudiness and solar angle of the study areas.

Symbols

H :	Global solar irradiance
H_o :	Extraterrestrial irradiance
mL:	Milliliter
MJ/m ² /day:	Megajoule per meter square per day
R^2 :	Coefficient of determination
MBE:	Mean bias error
RMSE:	Root mean square error
MPE:	Mean percentage error
JJAS:	June, July, August, and September
NDJF:	November, December, January, and February.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors sincerely acknowledge the support of the National Aeronautics and Space Administration (NASA) and the Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation, Oshodi Lagos, Nigeria, in the provision of the data sets used for this paper.

References

- [1] A. Mellit, M. Benghanem, and M. Bendekhis, "Artificial neural network model for prediction solar radiation data: application for sizing stand-alone photovoltaic power system," in *Proceedings of the IEEE Power Engineering Society General Meeting*, vol. 1, pp. 40–44, June 2005.
- [2] D. H. W. Li and T. N. T. Lam, "Determining the optimum tilt angle and orientation for solar energy collection based on measured solar radiance data," *International Journal of Photoenergy*, vol. 2007, Article ID 85402, 9 pages, 2007.
- [3] M. Engin, "Sizing and simulation of PV-wind hybrid power system," *International Journal of Photoenergy*, vol. 2013, Article ID 217526, 10 pages, 2013.
- [4] E. C. Okogbue, *Broad-Band solar irradiance and photometric illuminance at the tropical station, Ile-Ife [Ph.D. thesis]*, Obafemi Awolowo University, Ife, Nigeria, 2007.
- [5] E. C. Okogbue, J. A. Adedokun, and B. Holmgren, "Hourly and daily clearness index and diffuse fraction at a tropical station, Ile-Ife, Nigeria," *International Journal of Climatology*, vol. 29, no. 8, pp. 1035–1047, 2009.
- [6] A. A. Osinowo and E. C. Okogbue, "Investigation of the sky optical conditions over selected stations in the major vegetation zones of Nigeria," *International Journal of Sustainable Energy*, vol. 33, no. 2, pp. 357–366, 2014.
- [7] S. D. Al-Aruri, "The empirical relationship between global radiation and global ultraviolet (0.290–0.385) μm solar radiation components," *Solar Energy*, vol. 45, no. 2, pp. 61–64, 1990.
- [8] B. Pinty, T. Laverne, T. Kaminski et al., "Partitioning the solar radiant fluxes in forest canopies in the presence of snow," *Journal of Geophysical Research: Atmospheres*, vol. 113, no. 4, Article ID D04104, 2008.
- [9] M. Noia, C. F. Ratto, and R. Festa, "Solar irradiance estimation from geostationary satellite data: I. Statistical models," *Solar Energy*, vol. 51, no. 6, pp. 449–456, 1993.
- [10] H. Bulut and O. Büyükalaca, "Simple model for the generation of daily global solar-radiation data in Turkey," *Applied Energy*, vol. 84, no. 5, pp. 477–491, 2007.
- [11] J. D. Tarpley, "Estimating incident solar radiation at the surface from geostationary satellite data," *Journal of Applied Meteorology*, vol. 18, no. 9, pp. 1172–1181, 1979.
- [12] S. Studer, R. Stöckli, C. Appenzeller, and P. L. Vidale, "A comparative study of satellite and ground-based phenology," *International Journal of Biometeorology*, vol. 51, no. 5, pp. 405–414, 2007.
- [13] A. Hammer, J. Kühnert, K. Weinreich, and E. Lorenz, "Short-term forecasting of surface solar irradiance based on meteosat-SEVIRI data using a nighttime cloud index," *Remote Sensing*, vol. 7, no. 7, pp. 9070–9090, 2015.
- [14] C. Schillings, R. Meyer, and H. Mannstein, "Validation of a method for deriving high resolution direct normal irradiance from satellite data and application for the Arabian Peninsula," *Solar Energy*, vol. 76, no. 4, pp. 485–497, 2004.
- [15] Y. Eissa, M. Korany, Y. Aoun et al., "Validation of the surface downwelling solar irradiance estimates of the HelioClim-3 database in Egypt," *Remote Sensing*, vol. 7, no. 7, pp. 9269–9291, 2015.
- [16] P. Illera, A. Fernández, and A. Pérez, "A simple model for the calculation of global solar radiation using geostationary satellite data," *Atmospheric Research*, vol. 39, no. 1–3, pp. 79–90, 1995.
- [17] G. López, M. A. Rubio, M. Martínez, and F. J. Batlles, "Estimation of hourly global photosynthetically active radiation

- using artificial neural network models,” *Agricultural and Forest Meteorology*, vol. 107, no. 4, pp. 279–291, 2001.
- [18] G. López and F. J. Batlles, “Estimate of the atmospheric turbidity from three broad-band solar radiation algorithms: a comparative study,” *Annales Geophysicae*, vol. 22, no. 8, pp. 2657–2668, 2004.
- [19] A. I. Kudish, V. Lyubansky, E. G. Evseev, and A. Ianetz, “Inter-comparison of the solar UVB, UVA and global radiation clearness and UV indices for Beer Sheva and Neve Zohar (Dead Sea), Israel,” *Energy*, vol. 30, no. 9, pp. 1623–1641, 2005.
- [20] M. A. Rubio, G. López, J. Tovar, D. Pozo, and F. J. Batlles, “The use of satellite measurements to estimate photosynthetically active radiation,” *Physics and Chemistry of the Earth*, vol. 30, no. 1–3, pp. 159–164, 2005.
- [21] R. S. Eckman and P. W. Stackhouse Jr., “CEOS contributions to informing energy management and policy decision making using space-based Earth observations,” *Applied Energy*, vol. 90, no. 1, pp. 206–210, 2012.
- [22] M. J. Isabelle, L. Laurent, G. Marie-Line, and W. Lucien, “On the applicability of the Heliosat-2 method to assess surface solar irradiance in the Intertropical Convergence Zone, French Guiana,” *International Journal of Remote Sensing*, vol. 34, no. 8, pp. 3012–3027, 2013.
- [23] A. K. Yadav, H. Malik, and S. S. Chandel, “Selection of most relevant input parameters using WEKA for artificial neural network based solar radiation prediction models,” *Renewable and Sustainable Energy Reviews*, vol. 31, pp. 509–519, 2014.
- [24] P. Ineichen, “Long term satellite global, beam and diffuse irradiance validation,” *Energy Procedia*, vol. 48, pp. 1586–1596, 2014, Proceedings of the 2nd International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2013).
- [25] C. Voyant, P. Haurant, M. Muselli, C. Paoli, and M.-L. Nivet, “Time series modeling and large scale global solar radiation forecasting from geostationary satellites data,” *Solar Energy*, vol. 102, pp. 131–142, 2014.
- [26] L. Nonnenmacher, A. Kaur, and C. F. M. Coimbra, “Verification of the SUNY direct normal irradiance model with ground measurements,” *Solar Energy*, vol. 99, pp. 246–258, 2014.
- [27] P. Wang, M. Snee, J. P. Veefkind, P. Stammes, and P. F. Levelt, “Evaluation of broadband surface solar irradiance derived from the ozone monitoring instrument,” *Remote Sensing of Environment*, vol. 149, pp. 88–99, 2014.
- [28] A. Linares-Rodríguez, J. A. Ruiz-Arias, D. Pozo-Vázquez, and J. Tovar-Pescador, “Generation of synthetic daily global solar radiation data based on ERA-Interim reanalysis and artificial neural networks,” *Energy*, vol. 36, no. 8, pp. 5356–5365, 2011.
- [29] M. Iqbal, *An Introduction to Solar Radiation*, Academic Press, New York, NY, USA, 1983.
- [30] N. Halouani, C. T. Nguyen, and D. Vo-Ngoc, “Calculation of monthly average global solar radiation on horizontal surfaces using daily hours of bright sunshine,” *Solar Energy*, vol. 50, no. 3, pp. 247–258, 1993.