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Estimation of global and diffuse solar radiations for selected cities in Nigeria

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ABSTRACT

In this study, estimation of global and diffuse solar radiations of selected cities in Nigeria was carried out to assess the feasibility of solar energy utilization. The results of this work show the variation of direct and diffuse component of solar radiation in summer and winter months. The contribution of diffuse solar radiation is high during the monsoon months whereas sky conditions are clear during winter months. From the estimated values it was found that solar energy can be utilized very efficiently throughout the year in Sokoto and Ilorin. The clearness index which is availability of global solar radiation varies with geographical location and period of the year. Clearness index in the cities studied varies from 0.303 to 0.683. The least clearness index is in Port- Harcourt (0.303) in the month of July and the highest value is 0.683 in Sokoto in the month of March. The values of the global solar radiation estimated in the selected cities vary from 12.67 - 20.72 $MJm^{-2}day^{-1}$ in Abeokuta, 15.17 - 22.90 $MJm^{-2}day^{-1}$ in Ilorin, 10.75 - 19.03 $MJm^{-2}day^{-1}$ in Port Harcourt and 19.08 - 25.71 $MJm^{-2}day^{-1}$ in Sokoto. The data reveal that there is an evident increase of the value of the global solar radiation from south to north. This was expected as the radiation should increase as one move to the equatorial line. This study shows that the availability of solar energy in the selected cities varies and generation of electric power from solar energy in Nigeria is viable.

Keywords

Solar radiation, sunshine hours, relative humidity, cloudiness index, diffuse and global radiation

1. Introduction

With the rapid depletion of fossil fuel reserves, we will likely find them harder to attain. This is a matter of concern for the developing countries whose economy heavily leans on its use of energy. Under this circumstance it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the ever increasing energy demand (Aklaque et al, 2009).

For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. It has been found that there is an estimated 3,000 h of annual sunshine (Augustine and Nnabuchi, 2010) and average solar radiation received in Nigeria per day is as high as 20MJ/m^2 depending on the time of the year and location (Offiong, 2003). Despite this abundant availability of solar energy, Nigeria with over 97,000 rural communities, her population is characterized with deprivation from conventional energy, arising from poor supply of infrastructure. About 18% only of the rural population had access to electricity by 1991/1992(FOS, 1996). Where conventional energy is available, its supply is unreliable. The readily available and widely utilized energy in the rural areas is renewable energy type, particularly fuel wood, agricul-

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tural and animal wastes, wind energy and solar energy; which are mainly used for cooking, cottage industrial applications, winnowing and open-to-sun drying process.

Solar energy occupies one of the most important places among the various possible alternative energy sources for both urban and rural areas. An accurate knowledge of the solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performance (Chegaar and Chibani, 2000). Unfortunately, for many developing countries solar radiation measurements are not easily available. This is due to inability to afford the measurement equipment and techniques involved. Therefore, it is rather important to elaborate methods to estimate the solar radiation on the basis of more readily meteorological data.

Solar radiation data may be considered as an essential requirement to conduct feasibility studies for solar energy systems. The knowledge of solar energy preferably gained over a long period should be useful not only to the locality where the radiation data is collected but for the wider world community (Augustine and Nnabuchi, 2010).

In some developing countries, the facility for global radiation measurement is available at a few places while bright sunshine hours are measured at many locations. Some cannot even afford the equipment and techniques involved.

In Nigeria only few stations have been measuring daily solar radiation on a consistent basis, while diffuse solar radiation is not observed experimentally in any meteorological station of the country. Therefore, it is rather important to develop method to estimate the global and diffuse solar radiations using climatological parameters such as sunshine hours, relative humidity, maximum and minimum temperature, cloud cover and geographical location.

Several empirical formulas have been developed to calculate the global solar radiation using various parameters. These parameters include: the sunshine hours (Angstrom, 1924; Black et al, 1954); the relative humidity and sunshine hours (Gopinathan, 1988); the decination angle and the latitude (Liu and Jordan, 1960); sunshine duration, relative humidity, maximum temperature, latitude, altitude and location (Sabbagh et al, 1977) and the total precipitation, turbidity and surface albedo (Hoyt, 1978).

In Nigeria, a number of correlations involving global solar radiation and sunshine duration for different locations have been studied by different researchers. For example, Okogbue and Adedokun (2002), estimated the global solar radiation at Ondo, Nigeria; Okundamiya and Nzeako (2010), developed empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria; Agbo et al (2010) developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Nigeria; Medugu and Yakubu (2011), used angstrom model to estimate mean monthly global solar radiation in Yola, Nigeria; Burari et al (2001) developed a model for estimation of global solar radiation in Bauchi with regression coefficients a = 0.24 and b = 0.46; Akpabio and Etuk (2008) developed a relationship between global solar radiation and sunshine duration for Onne, with regression coefficients a = 0.23 and b = 0.38.

All these earliest researchers developed their models based on correlation of global solar radiation with sunshine hours for some selected cities in Nigeria. Based on the available literatures, there is little or no study carried out on global and diffuse radiations in Nigeria cities. This is partly due to the fact that, information is scarce on the distribution of diffuse radiation in the country.

The prime objectives of this study include (i) examining the selected models for estimating the mean monthly global and diffuse solar radiations of some selected cities in Nigeria (ii) to establish linear regression models using both sunshine hour's data and other climatogical parameters (maximum temperature, cloudiness index and relative humidity).

2. Materials and method

The monthly mean daily sunshine duration, maximum temperature, cloud cover and relative humidity used for this study, were obtained from the Archives of the Nigerian Meteorological Agency, Oshodi, Lagos. The four cities being studied lie on the latitudes and longitudes (lat. 4.4^{o}N, long. 7.1^{o}E) for Port Harcourt, (lat. 7.0^{o}N, long. 4.0°E) for Abeokuta, (lat. 9.7°N, long. 4.5°E) for Ilorin and (lat. 13.0°N, long.5.0°E) for Sokoto respectively. The data obtained covered a period of six years (2000-2005).

To develop the models, the global solar radiation data measured in $Kwhm^{-2}day^{-1}$ was converted to $MJm^{-2}day^{-1}$ using a factor of 3.6 (Igbal, 1983).

Various climatic parameters have been used in developing empirical relations for predicting the monthly average global solar radiation. In this work, the simple model used to estimate monthly average daily global solar radiation on horizontal surface is the modified form of the Angstrom – type equation.

The original Angstrom type regression equation related monthly average daily radiation to clear day radiation at the location in question and average fraction of possible sunshine hours (Angstrom, 1924). Page (1961) and others have modified the method to base it on extraterrestrial radiation on horizontal surface rather than on clear day radiation (Duffie and Beckman, 1991):

$$H_m/H_o = a + b\,(n/N) \quad (1)$$

Where H is the monthly average daily global radiation, H_o is the monthly average extraterrestrial radiation, n is the monthly average daily hours of bright sunshine, N is the monthly average day length, and a and b are climatologically determined regression constants. n/N is often called the percentage of possible sunshine hour.

Regression coefficients a and b have been obtained from relationship given as (Tiwari and Sangeeta, 1977) and also confirmed by Frere et al method (Frere et al, 1980):

$$a = -0.110 + 0.235\cos\Phi + 0.323\,(n/N)$$

$$b = 1.449 - 0.553\cos\Phi - 0.694\,(n/N) \quad (2)$$

Where

Φ is the latitude of the site and

N is the possible daily maximum number of hours of insolation (monthly average day length) is given as (Igbal, 1983):

$$N = 2/15\omega_s \quad (3)$$

Where

$$\omega_s = Cos^{-1}(-tan\emptyset tan\delta) \quad (4)$$

Where

$$\delta = 23.45Sin\left[\frac{360(284+n)}{365}\right] \quad (5)$$

The monthly average daily extraterrestrial radiation on a surface (H_o) can be computed from the following equation (Duffie and Beckman, 1991):

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033cos\frac{360n}{365}\right]\left[cos\emptyset cos\delta sin\omega_s + \frac{\pi}{180}\omega_s sin\emptyset sin\sigma\right] \quad (6)$$

Where I_{sc} is the solar constant ($=1367Wm^{-2}$),Φ is the latitude of the site, δ is the solar declination, ω_s is the mean sunrise hour angle for the given month and n is the number of days of the year starting from first of January.

The solar radiation reaching the earth's surface is made up of two components, direct and diffuse. Direct radiation is part which travels unobstructed through space and atmosphere to the surface and diffuse radiation is the part scattered by atmospheric components such as gases molecules, aerosols, dusts and clouds (Safari and Gasore, 2009).

2.1. Prediction of diffuse solar radiation (H_d)

The diffuse solar radiation H_d can be estimated by an empirical formula which correlates the diffuse solar radiation component H_d to the daily total radiation H. The correlation equation which is widely used is given as (Page, 1961):

$$H_d/H = 1.00 - 1.13K_T \quad (7)$$

Where H_d is the monthly mean of the daily diffuse solar radiation and $K_T = H/H_o$ is the clearness index.

Another commonly used correlation formulated by Liu and Jordan (1960) and developed by Klein (Klein, 1977) is given as:

$$H_d/H = 1.390 - 4.027K_T + 5.53(K_T)^2 - 3.108\,(K_T)^3 \quad (8)$$

3. Data analysis

Other regression models were obtained by the modification of the modified Angstrom model of equation (1).

The various meteorological data are related to global solar radiation. Multiple linear regression and correlation analysis of five parameters (H/H_o, n/N, T_M, c/C and RH) were employed to estimate the global solar radiation. Where H/Ho is the clearness index, n/N is the fraction of sunshine duration, T_M is the maximum temperature, c/C is the cloudiness index and RH is the relative humidity. Microsoft Excel Software Program was used in evaluating model parameters.

The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE). The RMSE (MJm^{-2}), MBE (MJm^{-2}) and MPE (%) for the five variables are:

$$\text{MBE} = \left[\sum\left(H_{pred} - H_{obs}\right)\right]/n \quad (9)$$

$$\text{RMSE} = \left[\sum\left(H_{pred} - H_{obs}\right)^2/n\right]^{\frac{1}{2}} \quad (10)$$

$$\text{MPE} = \left[\sum\left(\frac{H_{obs} - H_{pred}}{H_{obs}} X\ 100\right)\right]/n \quad (11)$$

RMSE and MBE statistical indicators are solar commonly used in comparing the models of radiation predictions. Low values of RMSE are desirable, but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE values at the same time a small MBE or vice versa. The use of RMSE and MBE statistical indicators are not adequate for the evaluation of models performance, hence, MPE is used in addition to RMSE and MBE so as to give more reliable result (Falayi, et al, 2008). The MPE test gives long term performance of the examined regression equations.

A positive MPE values provide the averages amount of overestimation in the calculated values, while a negative value gives the underestimation. A low value of MPE is desirable (Akpabio and Etuk, 2003).

The values of the meteorological data and global solar data for the four cities are presented in Tables 1 – 4.

4. Results and discussion

4.1. Global solar radiation

The input parameters for the estimation of monthly average daily global solar radiation at the four selected cities are shown in Tables 1-4.

From these it is observed that sunshine duration varies with location and period of the year. It is very high in Sokoto (80.7% maximum in December and 49.1% minimum in August), next to this is Ilorin (71.1% maximum in December and 30.4% minimum in August), Abeokuta (49.9% maximum in February and 22.6% minimum in August) and the least is in Port Harcourt (43.6% maximum in December and 14.2% minimum in July). In general, sunshine duration in Nigeria is very high from November to April and low in July to August.

Table 1. Meteorological data and global solar radiation for Abeokuta

	T_M(°C)	c/C	R/100	n/N	H_M($MJm^{-2}day^{-1}$)	H_O($MJm^{-2}day^{-1}$)	$K_T=H_M/H_O$
JAN	30.23	0.5978	0.6042	0.4495	19.87	33.35	0.5958
FEB	29.90	0.5714	0.6647	0.4995	20.28	35.43	0.5725
MAR	28.72	0.5552	0.8068	0.4933	20.72	37.24	0.5563
APR	28.16	0.4935	0.8483	0.4483	18.62	37.64	0.4947
MAY	28.01	0.4804	0.8491	0.4694	17.75	36.79	0.4825
JUN	26.80	0.4292	0.8581	0.3468	15.56	36.03	0.4318
JUL	25.91	0.3695	0.8644	0.2521	13.46	36.25	0.3712
AUG	25.79	0.3416	0.8622	0.2264	12.67	37.06	0.3419
SEPT	26.46	0.3798	0.8634	0.2535	14.09	37.16	0.3792
OCT	27.42	0.4552	0.8499	0.4266	16.26	35.78	0.4545
NOV	28.23	0.5448	0.8222	0.4340	18.32	33.69	0.5437
DEC	29.20	0.5995	0.7164	0.4914	19.39	32.54	0.5958

Table 2. Meteorological data and global solar radiation for ilorin

MONTH	T_M(°C)	c/C	R/100	n/N	H_M($MJm^{-2}day^{-1}$)	H_O($MJm^{-2}day^{-1}$)	$K_T=H_M/H_O$
JAN	33.01	0.6378	0.3119	0.6103	20.62	32.12	0.6421
FEB	33.05	0.6195	0.4061	0.6587	21.59	34.54	0.6252
MAR	32.18	0.6174	0.5970	0.6094	22.90	36.89	0.6211
APR	29.73	0.5754	0.7892	0.5303	21.82	37.84	0.5765
MAY	29.40	0.5519	0.7934	0.5158	20.66	37.44	0.5519
JUN	28.02	0.4963	0.8161	0.5099	18.29	36.88	0.4959
JUL	27.02	0.4399	0.8347	0.3455	16.27	37.00	0.4396
AUG	27.12	0.4062	0.8266	0.3038	15.17	37.44	0.4051
SEPT	28.20	0.4714	0.8172	0.3603	17.44	36.00	0.4715
OCT	30.04	0.5481	0.7509	0.5334	19.31	35.06	0.5508
NOV	32.30	0.6344	0.5655	0.6772	20.81	32.55	0.6393
DEC	33.20	0.6748	0.3666	0.7114	21.18	31.22	0.6786

Table 3. Meteorological data and global solar radiation for Port-Harcourt

MONTH	T_M(°C)	c/C	R/100	n/N	H_M($MJm^{-2}day^{-1}$)	H_O($MJm^{-2}day^{-1}$)	$K_T=H_M/H_O$
JAN	27.42065	0.538925	0.790049	0.369341	18.60639	34.46856606	0.539807
FEB	27.57083	0.523134	0.809882	0.342467	19.02652	36.21708454	0.525346
MAR	27.35183	0.465054	0.841362	0.27869	17.49716	37.52446932	0.466287
APR	27.3955	0.428778	0.847084	0.33039	16.0362	37.36597912	0.429166
MAY	27.20968	0.40172	0.851638	0.396374	14.54594	36.09359979	0.403006
JUN	26.19733	0.315444	0.847088	0.255379	11.0988	35.13906839	0.315854
JUL	25.40699	0.302957	0.850761	0.141558	10.75355	35.44853712	0.303357
AUG	25.23462	0.330161	0.84756	0.182726	12.08342	36.61320323	0.330029
SEPT	25.51111	0.313556	0.858892	0.2604	11.6776	37.2324234	0.313641
OCT	25.99661	0.34043	0.85992	0.32667	12.41865	36.4052352	0.341123
NOV	26.02817	0.417	0.854188	0.438237	14.5072	34.72787047	0.417739
DEC	26.94167	0.512581	0.826805	0.43679	17.3069	33.75222632	0.512763

Table 4. Meteorological data and global solar radiation for Sokoto

MONTH	T_M(°C)	c/C	R/100	n/N	H_M($MJm^{-2}day^{-1}$)	H_O($MJm^{-2}day^{-1}$)	$K_T=H_M/H_O$
JAN	31.43505	0.638548	0.134965	0.767313	19.43323	30.55667046	0.635973
FEB	33.74843	0.671656	0.126083	0.762767	22.48087	33.35608005	0.673966
MAR	37.03806	0.679892	0.136668	0.595004	24.80652	36.30125197	0.683352
APR	38.51233	0.6745	0.310227	0.640216	25.7066	37.98699672	0.676721
MAY	37.02452	0.665323	0.408388	0.670996	25.48297	38.15412718	0.667896
JUN	33.08367	0.633722	0.581336	0.618287	24.076	37.84262013	0.636214

(Table 4. continue) Meteorological data and global solar radiation for Sokoto

MONTH	T_M(°C)	c/C	R/100	n/N	H_M($MJm^{-2}day^{-1}$)	H_O($MJm^{-2}day^{-1}$)	$K_T=H_M/H_O$
JUL	29.86892	0.582419	0.717197	0.528485	22.11271	37.84613448	0.584279
AUG	29.61011	0.524194	0.735231	0.490905	19.83174	37.81431217	0.524451
SEPT	31.71156	0.584611	0.667854	0.617757	21.4556	36.69198999	0.584749
OCT	35.68602	0.610645	0.369631	0.718111	20.83684	34.07828987	0.61144
NOV	35.38944	0.663667	0.168128	0.785116	20.6102	31.08225704	0.663086
DEC	32.735	0.65	0.135931	0.807486	19.0831	29.55054115	0.645778

Employing the parameters in Tables 1- 4 together with the corresponding latitudes for each location, the regression constants a and b were obtained using equations 2a and 2b as shown in Table 5. The values of the regression constants are found to be different from that obtained from the earliest researchers (Fagbenle, 1990; a= 0.31, b= 0.42; Turton, 1987; a = 0.30, b =0.40; Augustine and Nnabuchi, 2009; a = 0.295, b = 0.306 and Akpabio and Etuk, 2003; a = 0.23, b = 0.38). These differences suggested that regression coefficients are associated with sunshine hours and atmospheric conditions. The previous researchers developed correlations based on sunshine duration only for the locations studied.

Table 5. Regression constants for various stations

Location	Regression Constants	
	a	b
Sokoto	0.334	0.447
Ilorin	0.293	0.536
Abeokuta	0.252	0.623
Port Harcourt	0.225	0.680

4.2. Diffuse solar radiation

The diffuse solar radiation was estimated using Page and Liu &Jordan methods, as no station in Nigeria measures diffuse radiation. From the estimated results shown in Figures 1 – 4, it is seen that the contributions of diffuse solar radiation is very low throughout the year in all the cities selected with the exception of monsoon months (July – August). Also, from Figures 1 -4, it can be seen that the Liu and Jordan method predicts lower values than the Page correlation. In the absence of measured values of diffuse radiation, it is difficult to establish the superiority of one over the other. The contribution of diffuse radiation is below 25 percent in all the locations studied. From utilization point of view, the availability of direct solar radiation is very encouraging in all the cities studied. The transmission of H_d (diffuse radiation) in Extraterrestrial radiation varies from 19.94 to 22.10 percent (in April) in Port Har-court, 19.47 to 22.11 percent (in June) in Abeokuta,15.82 to 22.12 percent (in July) in Ilorin and 15.57 to 21.82 per cent (in August) in Sokoto. From the observation of clearness index and ratio of diffuse radiation to global radiation it can be concluded that the presence of cloud is very rare even in the monsoon months (July – August). Hence, condition for solar energy utilization in Nigeria is most favourable. Figures 1 – 4 present the plot of global solar radiation at selected locations with the sunshine hours and the diffuse solar radiation estimated by Liu & Jordan and Page methods. A dip is seen for the month of August for sunshine hours (n) and global solar radiation (H_m) in all the locations except for Port Harcourt that has dip in July. Figures 5 – 8 show the plot of monthly variation of clearness index K_T (transmission through atmosphere) along with the percent of diffuse radiation in global radiation for the selected cities. The dip in the values of K_T is in accordance with high value of H_d/H for the same month. There is dip in K_T and rise in H_d/H in the month of August in the cities selected except in Port Harcourt that has dip in K_T and rise in H_d/H in the months of July and September. The sky is fairly clear during winter months when solar radiation is in demand for utilization purpose.

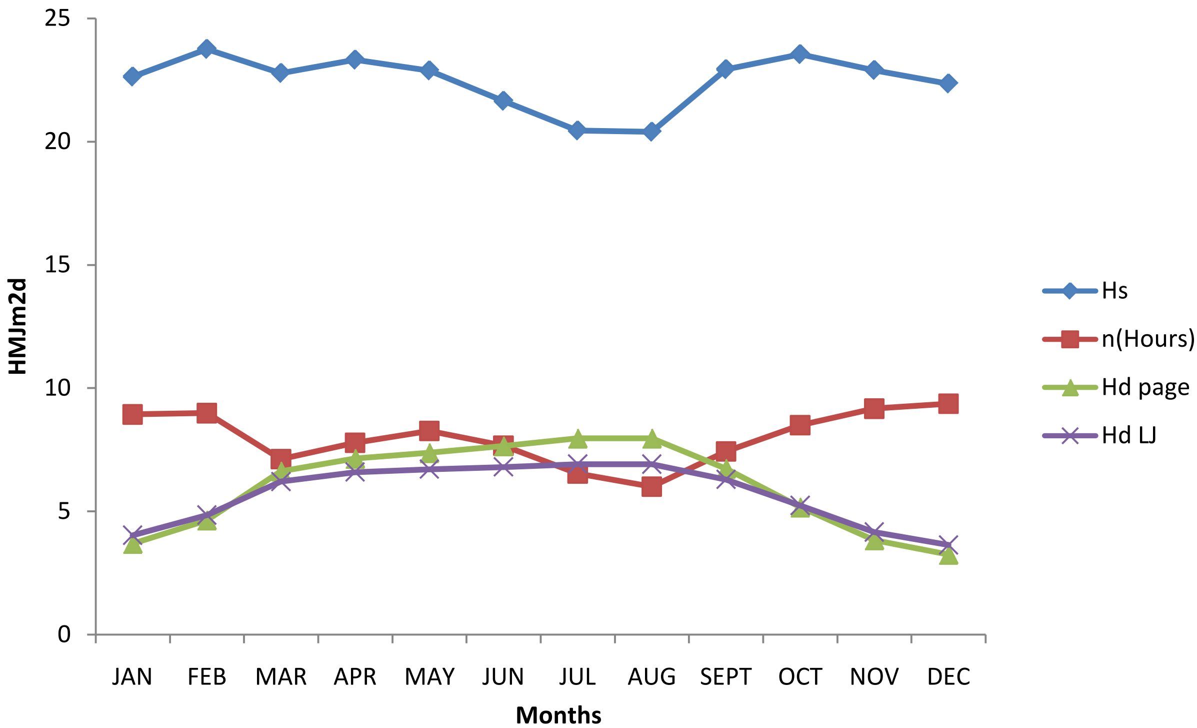

Fig. 1: Monthly variation of H_m, n, H_d (Page and Liu and Jorden method) for Sokoto

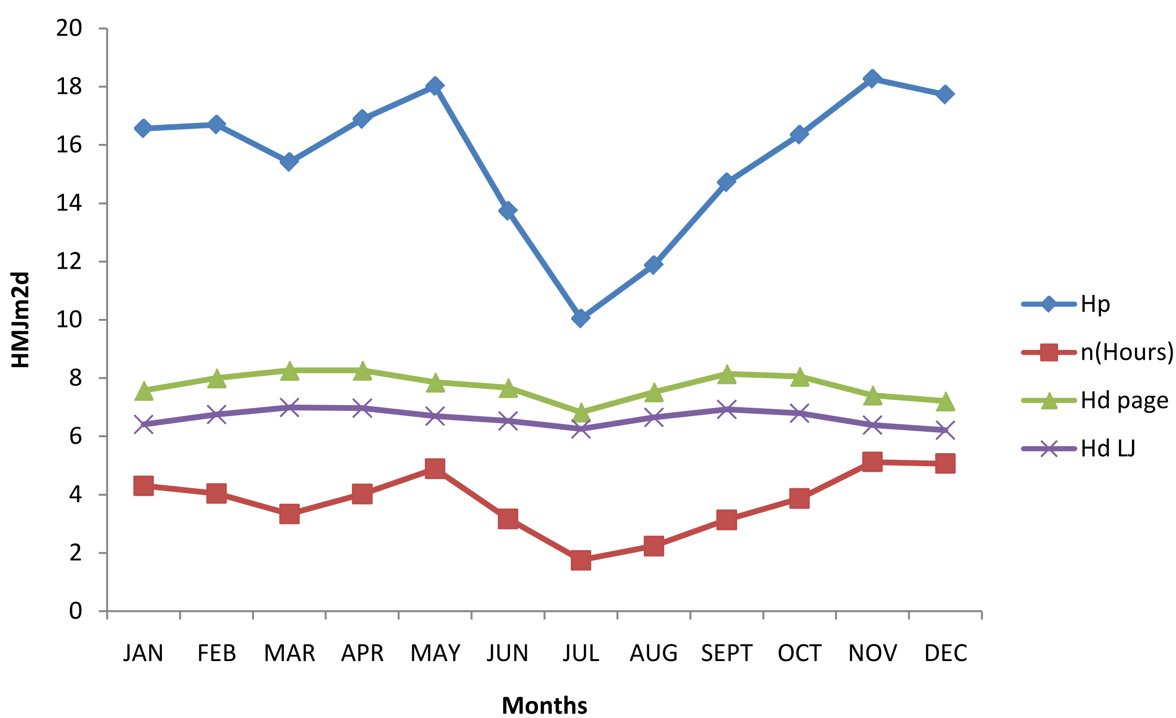

Fig. 2: Monthly variation of H_m, n, H_d (Page and Liu and Jorden method) for Port-Harcourt

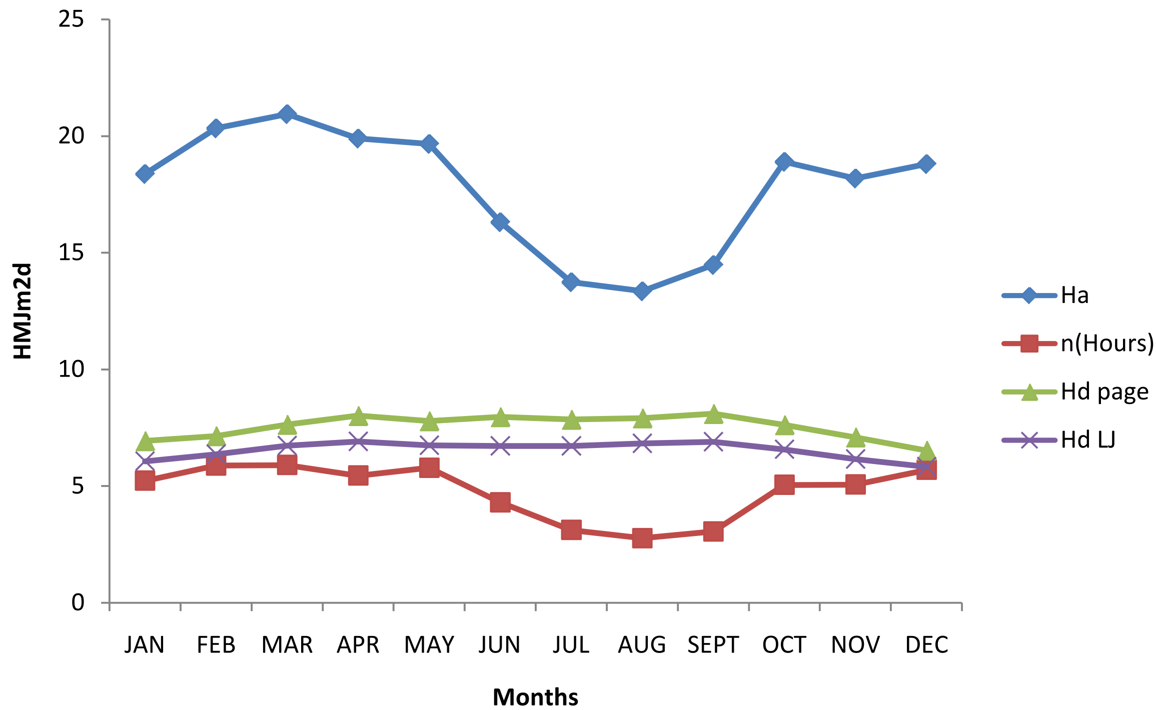

Fig. 3: Monthly variation of H_m, n, H_d (Page and Liu and Jordan method) for Abeokuta

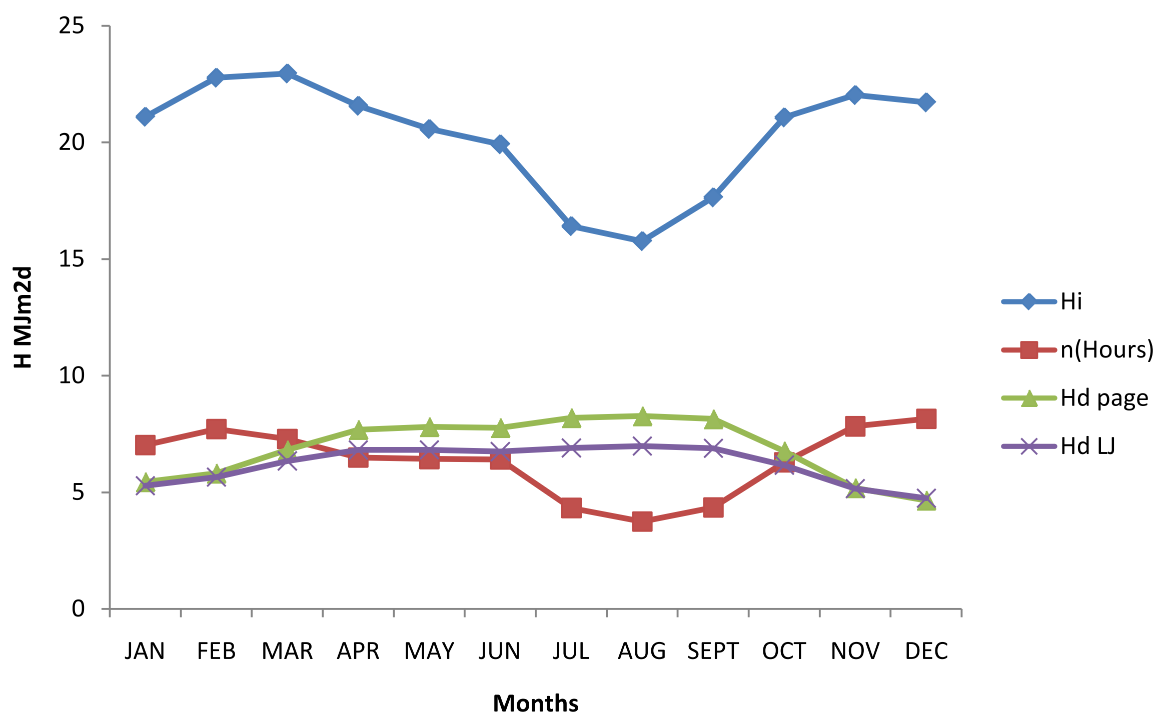

Fig. 4: Monthly variation of H_m, n, H_d (Page and Liu and Jordan method) for Ilorin

From Fig.5, the estimated value of H for Sokoto, K_T is calculated and it is very encouraging to note that the sky is very clear over Sokoto throughout the year as $K_T > 0.5$. Similarly, from Fig.6, K_T calculated for Ilorin shows that the sky is very clear over Ilorin almost throughout the year except in June – September where $K_T < 0.5$. K_T calculated for Abeokuta and Port Harcourt are shown in Fig.7 and 8 respectively. It can be seen from these figures that the sky is not very clear for these two locations as the value of K_T is less than 0.5 from April – October and March – November in Abeokuta and Port Harcourt respectively.

The transparency of the atmosphere is indicated by fraction of Extraterrestrial radiation that reaches the earth surface as global solar radiation. It is a measure of the degree of clearness of the sky (Akhlaque et al, 2009). Clearness index is given as $K_T = H_m/H_o$ where K_T is clearness index, H_m is the global solar radiation and Ho is the Extraterrestrial insolation. Clearness index K_T indicates the availability of global solar radiation. The values of KT are as shown in Tables 1 – 4, and it is very encouraging to note that the sky over Sokoto is very clear throughout the year as $K_T > 50$ per cent throughout the year. The highest K_T (0.683) is observed in March while lowest value (0.524) occurred in August. In Ilorin, highest K_T (0.678) is observed in December and lowest value (0.405) occurred in August. In Abeokuta, the highest value of K_T (0.596) occurred in January and December and lowest value (0.341) is observed in August. In Port Harcourt, the highest value of K_T (0.540) is observed in January and lowest value (0.303) occurred in July.

4.3. Monthly variation of direct and diffuse solar radiation

Modelization of global and diffuse solar radiation has many applications in the calculation of the design and performance of solar energy systems.

However, while the number of stations recording the different meteorological parameters has increased rapidly in recent years, experimental data on global and diffuse radiation are very rare. In the solar energy literature there have been numerous papers dealing with the evaluation and comparison of solar radiation estimation models (Mechlouch and Brahim, 2008).

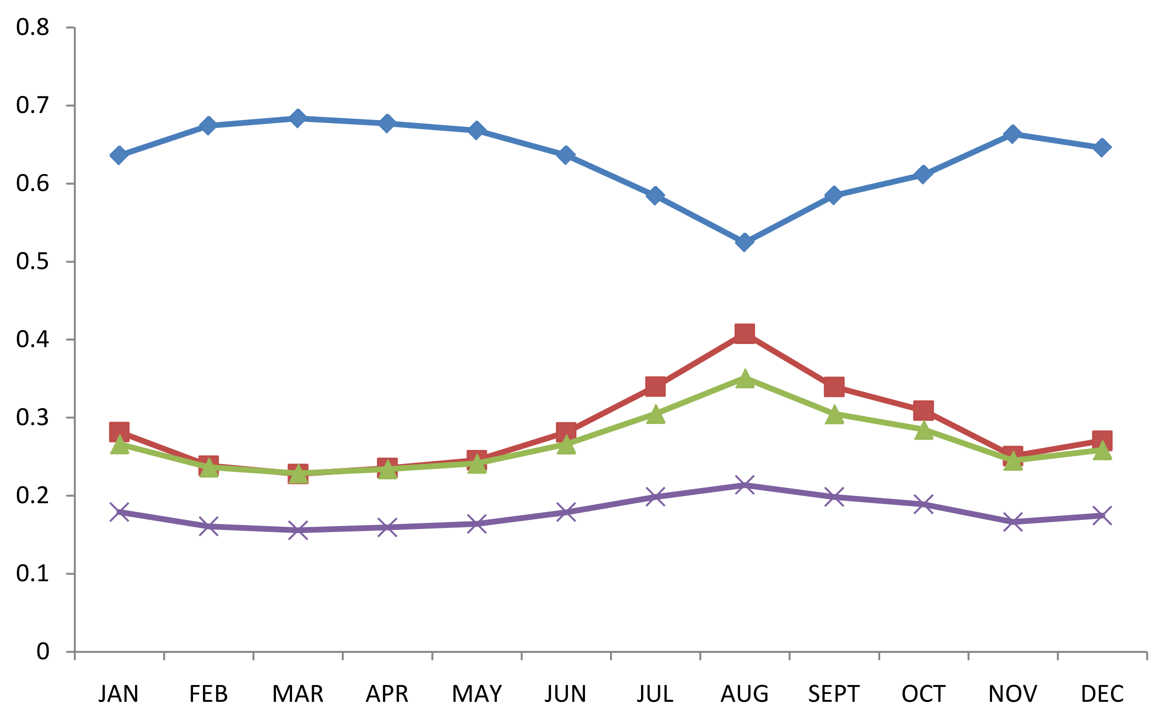

Fig. 5: Plot of monthly variation of clearness index K_T, H_d/H, (Page and LJ) and H_d/H_o for Sokoto.

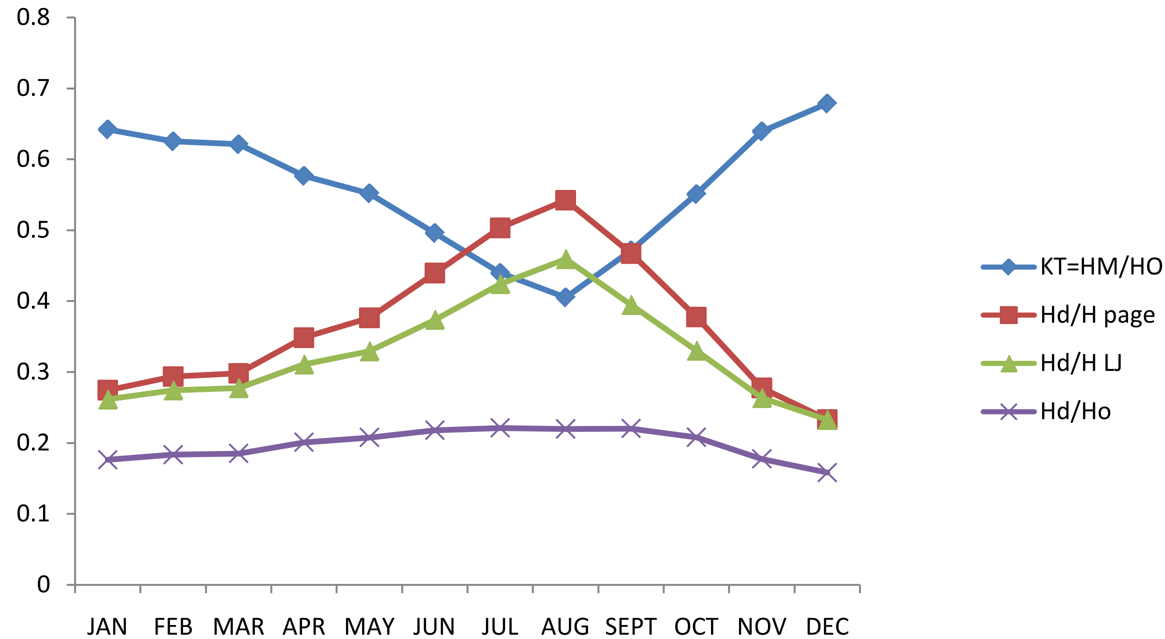

Fig. 6: Plot of monthly variation of clearness index K_T, H_d/H, (Page and LJ) and H_d/H_o for Ilorin

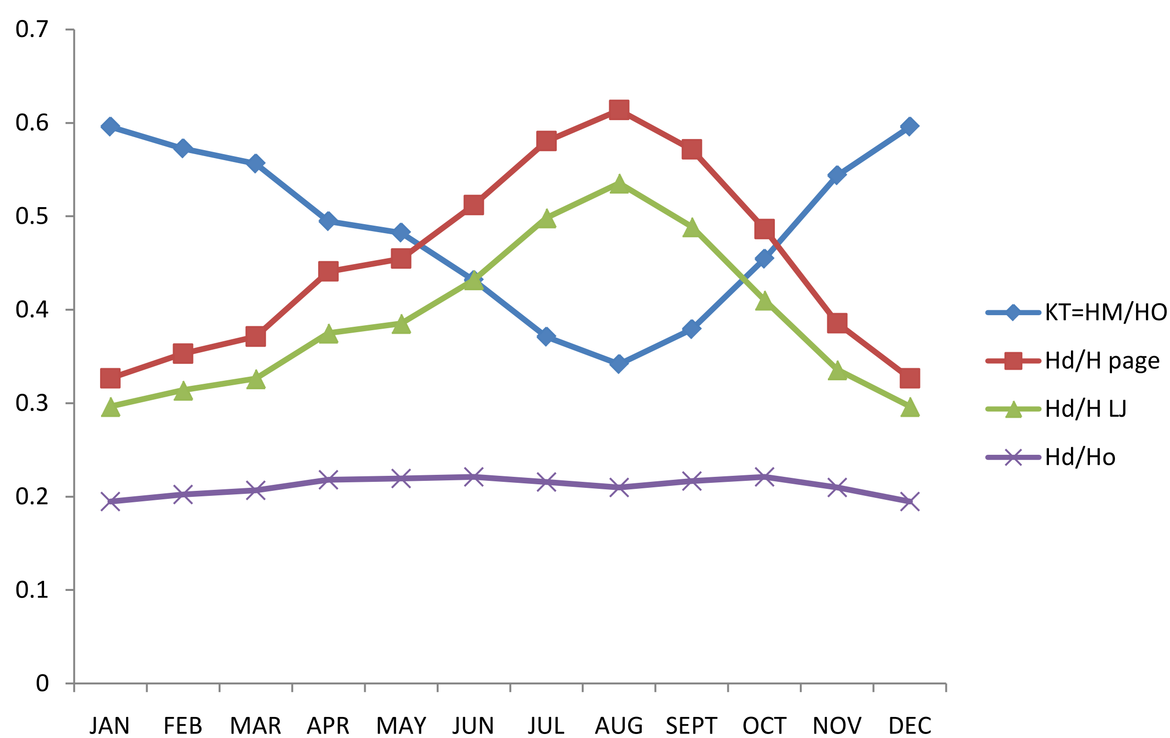

Fig. 7: Plot of monthly variation of clearness index K_T, H_d/H, (Page and LJ) and H_d/H_o for Abeokuta

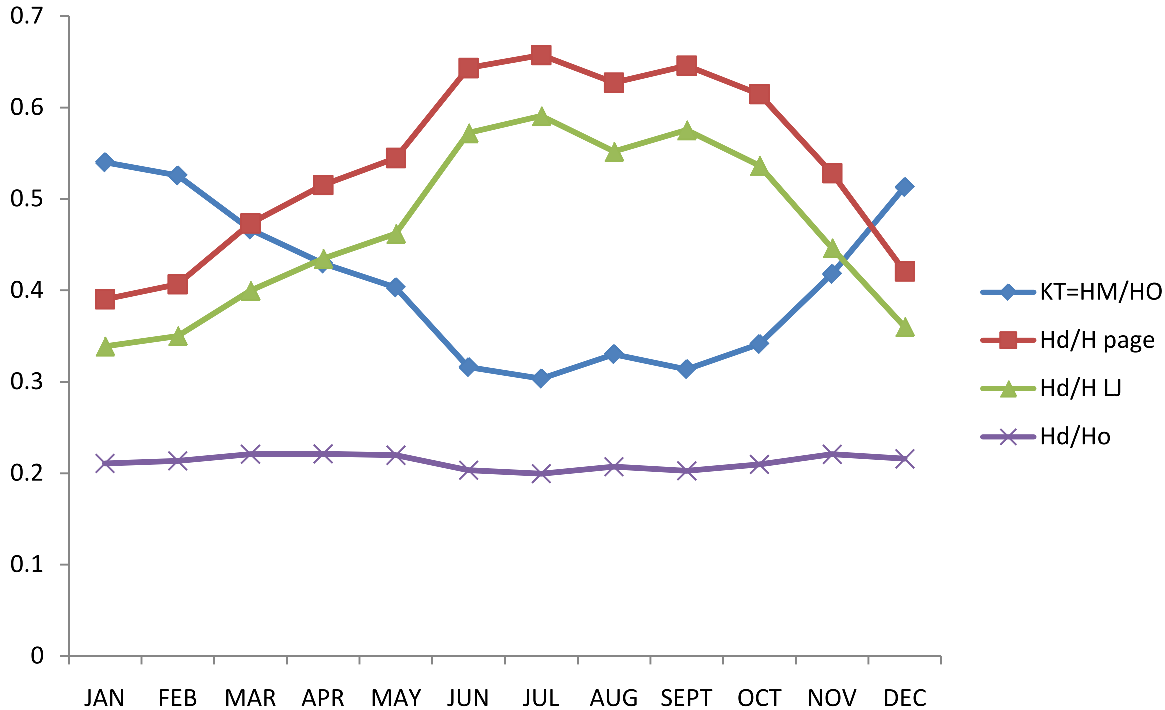

Fig. 8: Plot of monthly variation of clearness index K_T, H_d/H, (Page and LJ) and H_d/H_o for Port-Harcourt

Several empirical models have been developed to calculate global solar radiation using various climatic parameters. These parameters include extraterrestrial radiation, sunshine hours, mean temperature, maximum temperature, soil temperature, relative humidity, number of rainy days, altitude, latitude, total precipitation, cloudiness and evaporation (Jamil and Tiwari, 2010, Tahran and Sari, 2005, Bakirci, 2007,). The most commonly used for estimating global solar radiation is sunshine duration. Sunshine duration can be easily and reliably measured and data are widely available.

The design of a solar energy conversion system needs exact knowledge regarding the availability of global solar radiation. Sunshine hours are measured at many locations around the world, while global radiation is measured at selected locations only. In order to overcome this defectiveness, scientists have developed many empirical equations. Most of the sunshine based these equations built to estimate the monthly average daily global solar radiations are of modified Angstrom-type equation.

Important points can be drawn from the analysis of the data for this study. In all stations, the global solar radiation values increase from winter to summer. The regularity of the distribution of the solar radiation resources decreases as one move from south (Port Harcourt) to north (Sokoto). The data also revealed that there is an increase of the value of the global solar radiation from south (Port Harcourt) to north (Sokoto). This was expected, as the radiation should increase as one move to the equatorial line.

In this study, the diffuse component of solar radiation was obtained by calculation applying equations given by Page (1961) and Liu and Jordan (1960). In the cities studied, there is a large variation in the intensities of Direct and Diffuse radiation due to cloudiness. The results of the variation are shown in Figures 9 – 12 to exhibit the trend of percentage variation of direct and diffuse radiation. From Figures 9 and 10, the maxima of direct radiation for the months of February and December in Sokoto and Ilorin are quite appreciable. In these cities, the percentage contribution of diffuse radiation to global solar radiation is low during winter months (bright clear sky) and does not exceed 40 percent (in Sokoto) and 50% (in Ilorin) even in the worst sky condition. This is not the case for Abeokuta and

Port Harcourt. The percentage contribution of diffuse radiation exceeds 50% in Abeokuta and exceeds 60% in Port Harcourt in the months of July and August. The global solar radiation in the selected cities vary from 12.67 to 20.72 $MJm^{-2}day^{-1}$ in Abeokuta, 15.17 to 22.90 $MJm^{-2}day^{-1}$ in Ilorin, 10.75 to 19.03 $MJm^{-2}day^{-1}$ in Port Harcourt and 19.08 to 25.71 $MJm^{-2}day^{-1}$ in Sokoto. The highest value of global solar radiation was observed in Sokoto in May and the lowest in Port Harcourt in July.

The result of this study shows that there is greater availability of solar radiation in Sokoto than other locations studied. Also, solar energy devices will function successfully throughout the year in Sokoto.

The Angstrom model for determination of global solar radiation and Liu and Jordan model for estimation of diffuse radiation exhibit the validity of estimation for the locations under study.

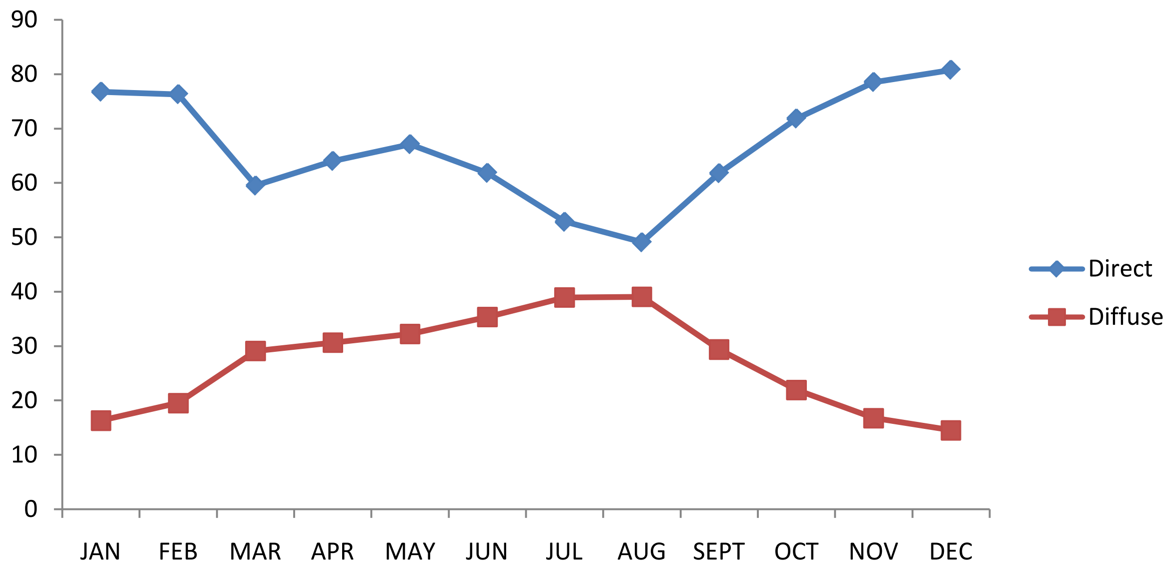

Fig. 9: Percentage variation of direct and diffuse radiation at Sokoto

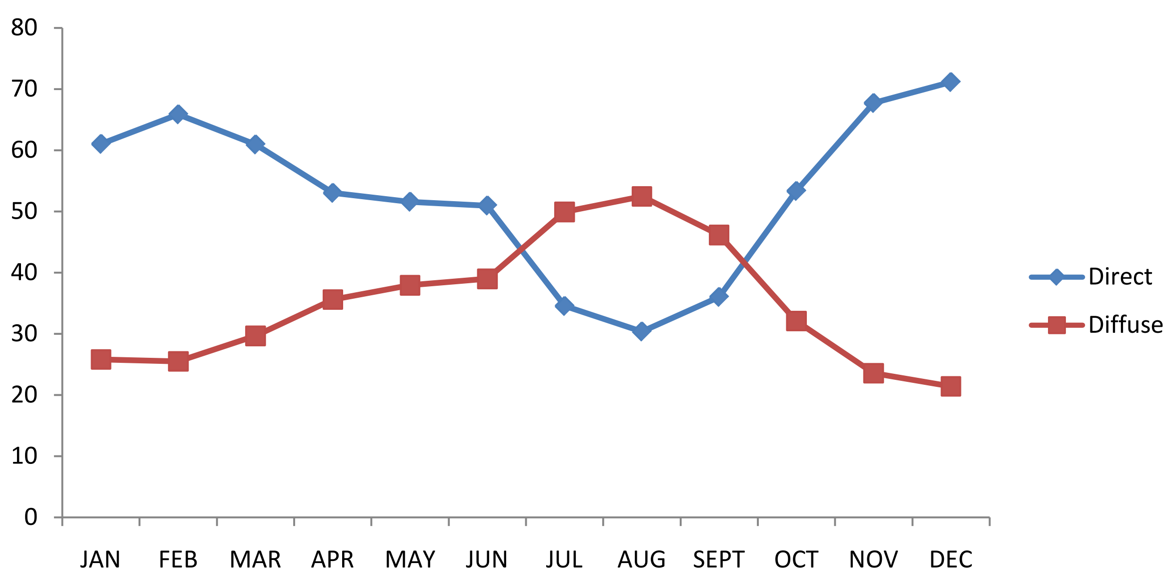

Fig. 10: Percentage variation of direct and diffuse radiation at ilorin

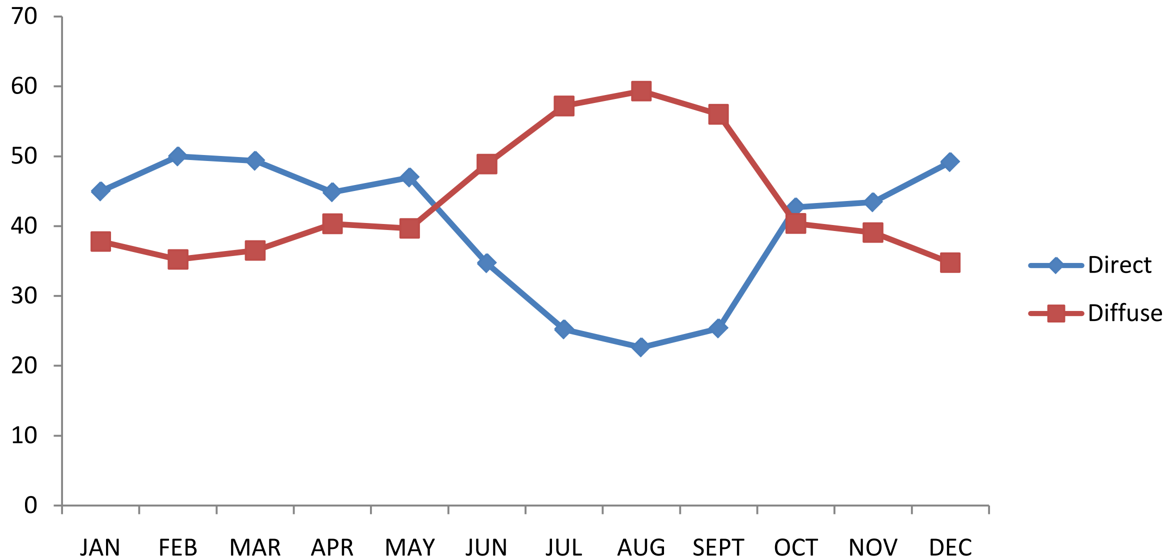

Fig. 11: Percentage variation of direct and diffuse radiation at Abeokuta

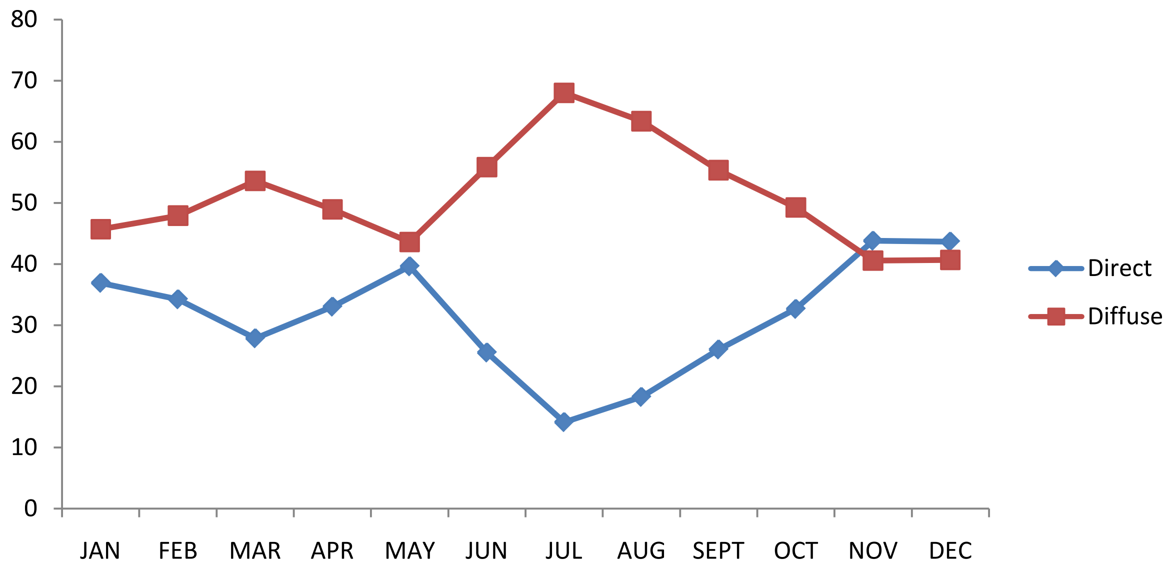

Fig. 12: Percentage variation of direct and diffuse radiation at Port Harcourt

4.4. Utilization of solar energy potential in Nigeria

As fossil fuel prices have risen and concerns over green house gases and global climate change have increased, alternative technologies for producing electricity have received greater attention (Yilmas, et al, 2009).

One of that is solar energy technology. The utilization of solar energy depends on its availability and appropriate technology (Nasir 2001). The idea of using the sun's power has held scientist in its grips for centuries. Given the finite element of the non-renewable resources the world is using, it was necessary to find renewable resources that would not get depleted.

In the beginning of this century, scientists and engineers began researching ways to use solar energy. The ability to use solar energy for heat was the first discovery. It was used to heat water and cook food (Anderson *et al.* 1983). Producing electricity from solar energy was the second discovery. This is applied in many machines and appliances today.

Solar energy has numerous applications when it is converted to heat, electricity or biomass. The technologies for conversion of solar energy into heat and electricity can be classified into solar thermal systems and photovoltaic (PV) or solar electricity respectively (Eze, 2004; Ilenikhena and Ezemonye, 2010; Yiew and Balbir, 2009,).

Nigeria has an important potential for renewable energy sources, especially solar energy. Solar energy systems have emerged as a viable source of renewable energy over the past two or three decades and are now widely used for variety of domestic and commercial applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy.

In general, the power developed in such applications depends fundamentally upon the amount of solar energy captured by the collector (Tamer, et al, 2009; Arzu and Gokhan, 2007).

The earth directly receives 0.0000000455% of the sun's output. The world's annual energy consumption is 9.262 10^{13} KWh/year.

$$\frac{N\times 100}{9.262\times 10^{13}} = 0.0000000455$$
$$N = \frac{9.262\times 10^{13}\times 0.0000000455}{100} = 42141.92$$
$$\cong 42000$$

This implies that one year of the sun's output that the earth receives is equivalent to 42,000 times the world's total annual energy consumption.

This indicates that solar energy is abundant. The extraterrestrial radiation received on earth was determined to be 1.729 x 10^{14}KW/m^2. 47% of this radiation reaches the earth's surface (Cliff 1990).

$$\frac{47}{100}\times 1.729\times 10^{14} = 81.263\times 10^{12}\ \text{kW/m}^2$$

Therefore, the energy reflected, absorbed and scattered is relatively not a significant energy loss. The terrestrial radiation on Nigeria's land area is 2.079 x 10^{15} KWh/year average annual consumption of all forms of energy in Nigeria is 2.4026 x 10^{11} and the electrical energy consumption in the year 2001 was 15 x 10^6KWh.

This implies that the solar energy on Nigeria's land area is about 9,000 times the average annual consumption of all form of energy and 139 million times the electrical energy consumption. Hence, solar energy is available in Nigeria.

A developing country like Nigeria where the power generated presently is insufficient and sunlight is usually abundant represents one of the biggest potentials for solar power generation. Solar power could be generated all year round but it works best when the sun is at its brightest.

Solar power generation can be adopted during the dry season when water level in the dams are low for sufficient hydro-power generation and there's high availability of solar radiation due to high sunshine hours compared with other seasons that are favorable for hydropower generation.

Moreover, given both the immediate and long-term harmful effects of power generation through the burning of fossil fuels, the dangers of nuclear power generation and the insufficiencies of hydropower renewable energy sources are the best answer. With independent breakthrough that advance the technology combined with governmental and industrial cooperation, solar power is poised to take an ever-expanding role in power generation.

Nigeria is situated in a belt of high sunshine. The solar radiation is fairly well distributed throughout the country. The annual average of total solar radiation varies from about 12.6 MJ/m^2/day (equivalent 3.5 KWh/m^2/day) in the coastal latitudes to about 25.2 MJ/m^2/day (equivalent 7.0 KWh/m^2/day) in the far North.

This equals an average annual solar energy intensity of 1,934.5 KWh/m^2/day. Thus, over a whole year, an average of 6,372,613 PJ/year (1,770 thousand TWh/year) of solar energy falls on the entire land area of Nigeria. The national average is 5.5 KWh/m^2/day and the average solar radiation time is 6 hours/day, which are favorable conditions for PV power generation. Considering the availability of solar energy in Nigeria, present technologies for the conversion of this energy into power and the economies of the power generated, the generation of power from solar energy in Nigeria is viable, especially in the North.

4.5. Linear regression analysis

Tables 6–9 contain summaries of various linear regression analyses obtained from the application of equation (1) to the monthly mean value for the five variables under study. It is clear that the correlation coefficient, R, coefficient of determination, R^2, MBE ($MJm^{-2}day^{-1}$), RMSE ($MJm^{-2}day^{-1}$) and MPE (%) vary from one variable to another variable.

Table 6 shows the regression equations and statistical indicators for Ilorin. It is observed that multiple regression equation with four variables gives the least values of RMSE (0.0191) and MPE (-0.00046) and highest value of coefficient of determinant, R^2.

Table 7 shows the regression equations and statistical indicators for Port Harcourt. There in, it is observed that the multiple regression equation with four variables gives the least values of MBE (-0.0000555), RMSE (0.0163) and MPE (-0.0000912) and highest value of R^2. Table 8 shows that the multiple regression equation with four variables gives the least values of MBE (-0.000412), RMSE (0.0443) and MPE (-0.00165) and highest value of R^2 for regression equation of Abeokuta.

Table 9 is the regression equations and statistical indicators for Sokoto. The multiple regression equation with four variables gives the highest value of R^2 (0.9994) and least values of MBE (-0.000396), RMSE (0.0374) and MPE(-0.000297).

It was observed that combination of sunshine hours, maximum temperature, cloudiness index and relative humidity gave better results. These results are shown in Table 10. The table shows remarkable agreement between the observed and predicted values of global solar radiation for the study locations.

In this study, two statistical tests: mean bias error (MBE) and root mean bias error (RMSE), and mean percent error (MPE) were used to evaluate the accuracy of the correlation developed. For better analysis, the developed correlation will be considered that has high value of correlation coefficient R and coefficient of determination R^2 with least values of MBE, RMSE and MPE. From Tables 6 – 9, based on the highest values of correlation coefficient, coefficient of determination and least values of MBE, RMSE and MPE, the following equations:

$$H_m/H_o = -0.0451 + 0.00704n/N + 0.9686c/C + 0.001935T_m + 0.00348R/100$$

$$H_m/H_o = -0.0121 + 0.000473n/N + 0.9997c/C + 0.000528T_m + 0.0011R/100$$

$$H_m/H_o = -0.0378 + 0.0145n/N + 0.9568c/C + 0.0016T_m + 0.00904R/100$$

$$H_m/H_o = -0.0189 + 0.0168n/N + 1.0355c/C + 0.00021T_m + 0.00367R/100$$

are considered the best regression equations suitable for estimating global solar radiation in Ilorin, Port Harcourt, Abeokuta and Sokoto respectively.

Table 6. Regression equations and statistical indicators for Ilorin

Equations	R	R^2	MBE	RMSE	MPE
$H_m/Ho = 0.219 + 0.638(n/N)$	0.9703	0.9415	0.00523	0.7306	-0.1399
$H_m/Ho = -0.525 + 0.0358Tm$	0.9658	0.93275	-0.00342	0.8007	-0.219
$H_m/Ho = -0.0113 + 1.024(c/C)$	0.9999	0.9998	0.000617	0.0386	0.000736
$H_m/Ho = 0.803 - 0.372(R/100)$	0.838	0.7022	0.00204	1.6823	-0.869
$H_m/Ho = -0.154 + 0.351(n/N) + 0.0174Tm$	0.9853	0.9707	-0.00374	0.5271	-0.0928
$H_m/H0 = -0.00936 + 0.00642(n/N) + 1.0143(c/C)$	0.9999	0.9998	0.000581	0.038	0.000831
$H_m/H0 = 0.321 + 0.545(n/N) - 0.0789(R/100)$	0.9762	0.953	-0.00431	0.672	-0.1354
$H_m/H0 = -0.0316 + 0.00769(n/N) + 0.974(c/C) + 0.00146Tm$	0.9999	0.9999	0.0000132	0.0201	-0.00087
$H_m/H0 = -0.423 + 0.301(n/N) + 0.0725(R/100) + 0.0256Tm$	0.9869	0.9739	0.000804	0.4861	-0.0747
$H_m/H0 = 0.000856 + 0.00814(n/N) - 0.00561(R/100) + 1.00095(c/C)$	0.9999	0.9998	-0.0000368	0.03071	-0.00071
$H_m/H0 = -0.04511 + 0.00704(n/N) + 0.9686(c/C) + 0.00193Tm + 0.00348(R/100)$	0.9999	0.9999	0.000212	0.0191	-0.00046

Table 7. Regression equations and statistical indicators for Port Harcourt

Equations	R	R^2	MBE	RMSE	MPE
Hp/Ho = 0.211 + 0.629(n/N)	0.6692	0.4478	0.00213	2.2451	-2.2092
Hp/Ho = -1.829 + 0.0843Tm	0.8463	0.7161	0.028	1.5831	-1.1194
Hp/Ho = -0.000975 + 1.00411(c/C)	0.9999	0.9999	-0.000185	0.0182	-0.000575
Hp/Ho = 3.245 - 3.376(R/100)	0.8139	0.6624	-0.00334	1.7453	-1.7086
Hp/Ho = -1.501 + 0.241(n/N) + 0.0691Tm	0.8711	0.7588	0.01766	1.474	-0.8873
Hp/H0 = -0.000968 - 0.000337(n/N) + 1.0043(c/C)	0.9999	0.9999	-0.000177	0.0182	-0.000667
Hp/H0 = 2.622 + 0.441(n/N) - 2.798(R/100)	0.9289	0.8628	-0.0172	1.1407	-0.6777
Hp/H0 = -0.0113 - 0.000597(n/N) + 1.000083(c/C) + 0.000523Tm	0.9999	0.9999	0.06152	0.0636	-0.4381
Hp/H0 = 1.164 + 0.294(n/N) - 2.0997(R/100) + 0.0346Tm	0.9564	0.9147	-0.004608	0.879	-0.3987
Hp/H0 = -0.00490 - 0.000773(n/N) + 0.00429(R/100) + 1.0055(c/C)	0.9999	0.9999	-0.0001504	0.0181	-0.000468
Hp/H0 = -0.0121 - 0.000487(n/N) + 0.999(c/C) + 0.000528Tm - 0.0011(R/100)	0.9999	0.9999	-0.0000555	0.0163	-0.0000912

Table 8. Regression equations and statistical indicators for Abeokuta

Equations	R	R^2	MBE	RMSE	MPE
H_m/Ho = 0.163 + 0.806(n/N)	0.9138	0.835	0.0389	1.224	-0.4314
H_m/Ho = -1.160 + 0.0590Tm	0.9661	0.9333	0.0124	0.7708	-0.2548
H_m/Ho = 0.00476 + 0.991(c/C)	0.9998	0.9997	-0.3419	0.3479	2.0268
H_m/Ho = 1.114 - 0.786(R/100)	0.775	0.6006	0.0154	1.965	-1.5699
H_m/Ho = -0.839 + 0.247(n/N) + 0.0439Tm	0.9752	0.9509	0.0168	0.6637	-0.1441
H_m/H0 = 0.00689 + 0.0221(n/N) + 0.968(c/C)	0.9999	0.9998	-0.000674	0.0452	0.00144
H_m/H0 = 0.555 + 0.616(n/N) - 0.395(R/100)	0.9699	0.9407	0.01397	0.7338	-0.185
H_m/H0 = -0.00806 + 0.0219(n/N) + 0.957(c/C) + 0.000735Tm	0.9999	0.9998	-0.000521	0.0446	-0.00201
H_m/H0 = -0.834 + 0.248(n/N) - 0.00131(R/100) + 0.0438Tm	0.9752	0.9509	0.0169	0.664	-0.1446
H_m/H0 = 0.0110 + 0.246(n/N) - 0.00329(R/100) + 0.963(c/C)	0.9999	0.9998	3.151	3.238	-18.055
H_m/H0 = -0.0378 + 0.0145(n/N) + 0.958(c/C) + 0.00165Tm + 0.00904(R/100)	0.9999	0.9998	-0.000412	0.0443	-0.00165

Table 9. Regression equations and statistical indicators for Sokoto

Equations	R	R^2	MBE	RMSE	MPE
H_m/Ho = 0.450 + 0.274(n/N)	0.5867	0.3443	-0.03493	1.3591	-0.3625
H_m/Ho = 0.196 + 0.0130Tm	0.785	0.6162	0.0471	0.9877	-0.2274
H_m/Ho = -0.00410 + 1.00764(c/C)	0.9989	0.9978	-0.00565	0.0697	-0.000591
H_m/Ho = 0.691 - 0.157(R/100)	0.7977	0.6364	-0.04372	1.009	-0.2113
H_m/Ho = 0.138 + 0.182(n/N) + 0.011Tm	0.8694	0.7559	-0.00209	0.8042	-0.1398
H_m/H0 = -0.00811 - 0.0228(n/N) + 1.038(c/C)	0.9996	0.9993	-0.000993	0.0409	-0.000521
H_m/H0 = 0.749 - 0.0728(n/N) - 0.181(R/100)	0.8031	0.6449	-0.0375	1.0047	-0.209

(Table 9. continue) Regression equations and statistical indicators for Sokoto

Equations	R	R^2	MBE	RMSE	MPE
$H_m/H0 = -0.00866 - 0.0208(n/N) + 1.0247(c/C) + 0.000228Tm$	0.9997	0.9993	-0.000761	0.0396	-0.00054
$H_m/H0 = 0.376 + 0.0129(n/N) - 0.10001(R/100) + 0.00842Tm$	0.9078	0.8241	-0.0116	0.7017	-0.1064
$H_m/H0 = -0.0192 - 0.0182(n/N) + 0.00395(R/100) + 1.0485(c/C)$	0.9997	0.9993	-0.000581	0.0386	-0.00026
$H_m/H0 = -0.0190 - 0.0168(n/N) + 1.0355(c/C) + 0.000210Tm + 0.00367(R/100)$	0.9997	0.9994	-0.000396	0.0374	-0.000297

Table 10. Comparison between measured solar radiation and calculated solar radiation for the locations studied

Month	Location							
	Sokoto		Ilorin		Abeokuta		Port Harcourt	
	H_M	H_C	H_M	H_C	H_M	H_C	H_M	H_C
January	19.433	19.448	20.623	20.614	19.871	19.830	18.606	18.616
February	22.481	22.391	21.591	21.581	20.284	20.196	19.027	18.991
March	24.807	24.806	22.897	22.909	20.718	20.626	17.497	17.524
April	25.707	25.710	21.817	21.800	18.621	18.580	16.036	16.064
May	25.483	25.486	20.664	20.687	17.755	17.695	14.546	14.536
June	24.076	24.066	18.287	18.293	15.557	15.443	11.099	11.104
July	22.113	22.108	16.266	16.225	13.445	13.357	10.754	10.747
August	19.832	19.834	15.168	15.268	12.671	12.648	12.083	12.091
September	21.456	21.470	17.444	17.436	14.091	14.102	11.678	11.681
October	20.837	20.793	19.309	19.288	16.264	16.298	12.419	12.408
November	20.610	20.611	20.808	20.782	18.322	18.268	14.507	14.494
December	19.083	19.146	21.183	21.192	19.389	19.399	17.307	17.329

H_M – Measured solar radiation in $MJm^{-2}day^{-1}$
H_C – Calculated solar radiation in $MJm^{-2}day^{-1}$

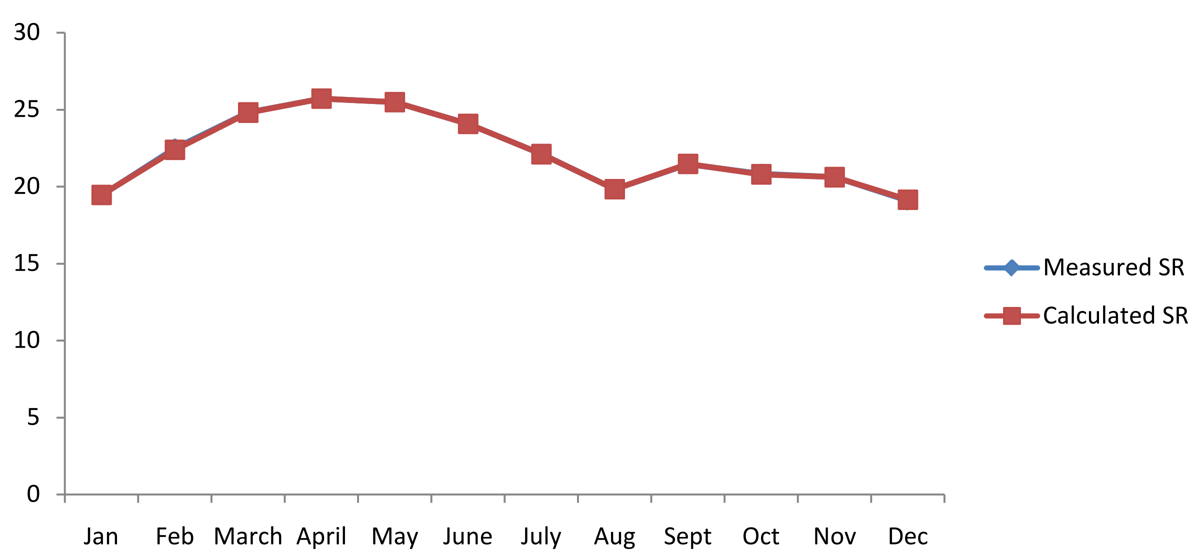

Fig. 13: Comparison between the measured and calculated global solar radiation for Sokoto

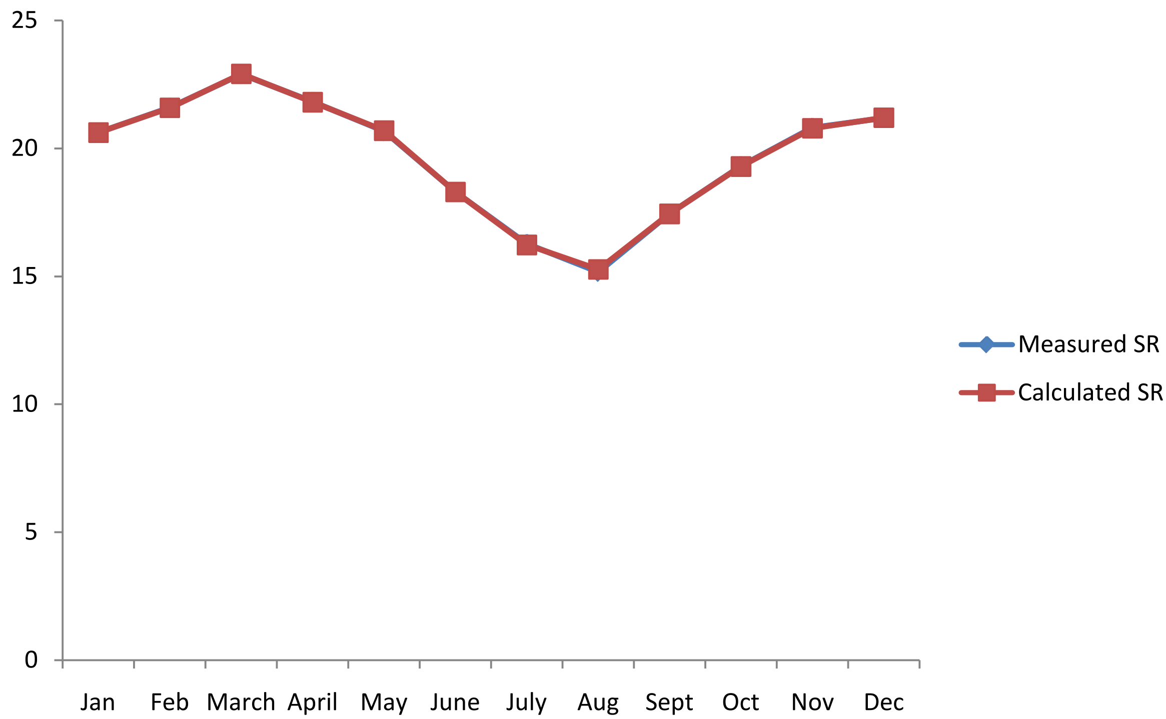

Fig. 14: Comparison between the measured and calculated global solar radiation for Ilorin

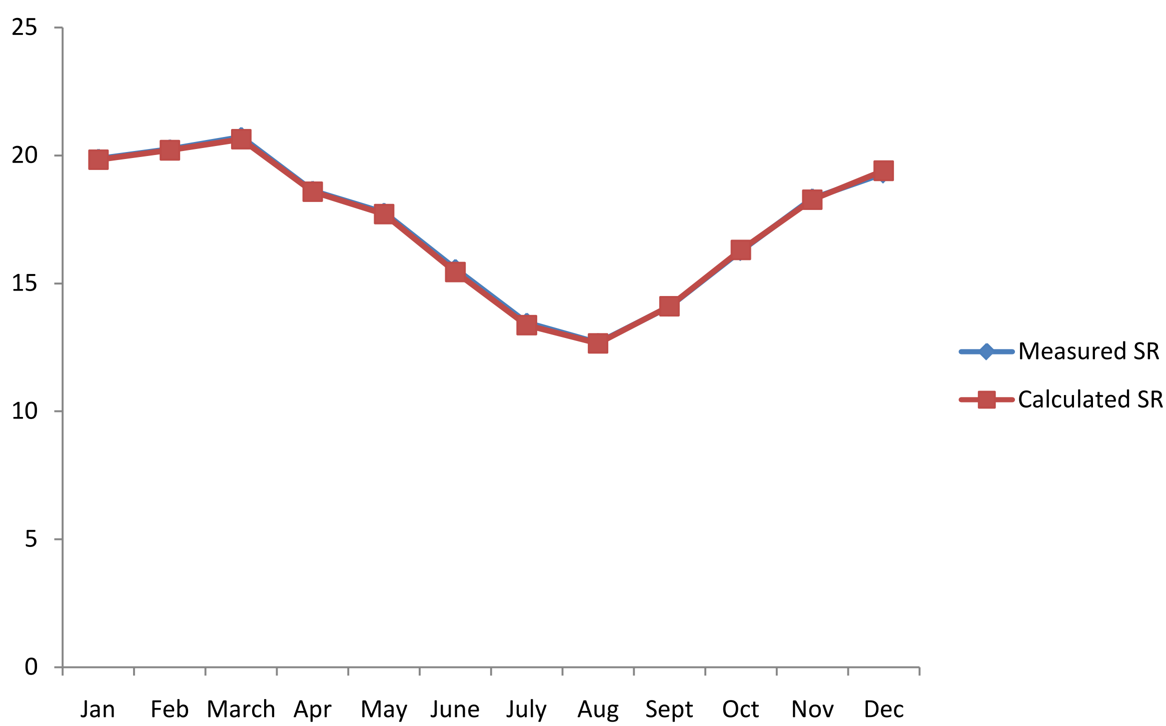

Fig. 15: Comparison between the measured and calculated global solar radiation for Abeokuta

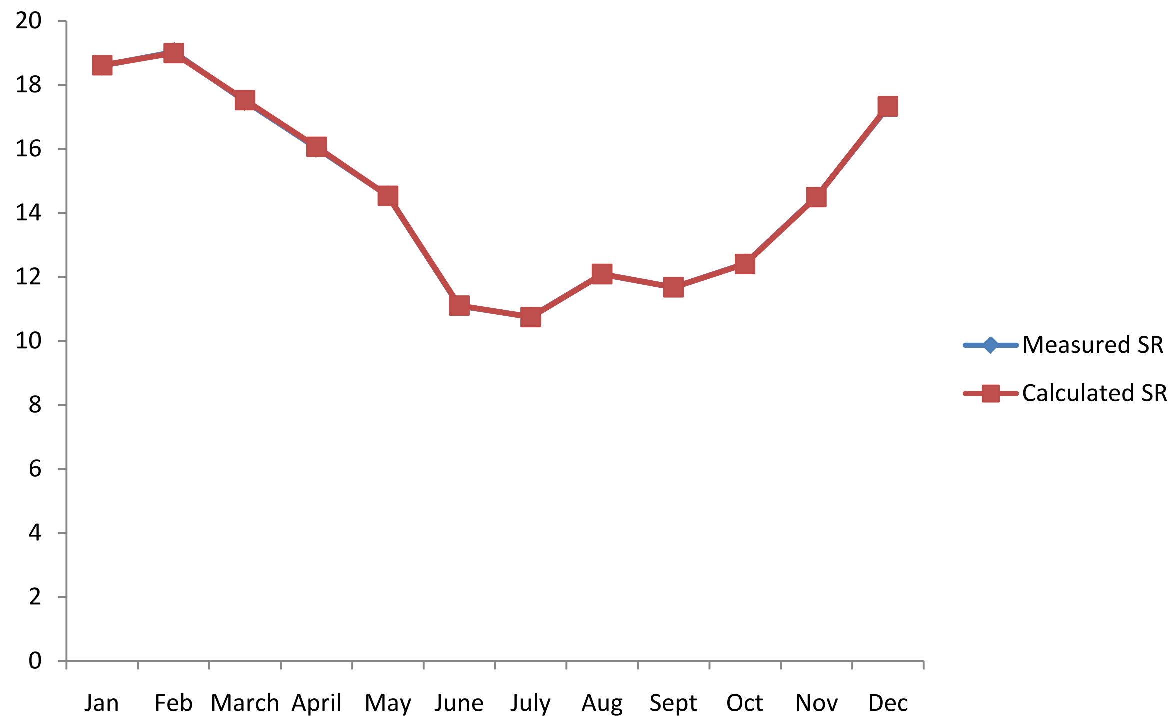

Fig. 16: Comparison between the measured and calculated global solar radiation for Pot Harcourt

5. Conclusion

The monthly mean daily global solar radiation, fraction of sunshine duration, maximum temperature, cloudiness index and Relative Humidity have been employed in this study to develop several correlation equations. It was observed that combination of sunshine hours, maximum temperature, cloudiness index and relative humidity gave better results. These results are shown in Table 10. The table shows remarkable agreement between the observed and predicted values of global solar radiation for the study locations. The error variation domain between the measured solar radiation and calculated solar radiation is narrow. This leads to the conclusion that the proposed model estimates in a high manner the real solar radiation. It should be noted that accurate empirical method strongly depends on the quality and quantity of the measured data used, and is a tool for generating global solar radiation at locations where measured data are not available.

Although the models used in this work are simple from a mathematical point of view, and these are easy to use in practice, they have the disadvantage of a limited area of applicability, these being specific to a particular area. The existent empirical models should be developed based on the specific measured data specific to a geographic area (solar radiation, temperature, humidity, etc.). In other words, for a mathematical estimation of the solar radiation accordingly to the reality (and implicitly of the direct and diffuse one) it is recommendable to take into consideration both the climatic and geographical characteristics of every site, and the influence of the urban environment over the meteorological parameters that intervene in the radiation expression.

Although this work was based on data of limited duration and on limited number of stations, representative of the four main regions (Southern, Western, Middle belt and Northern) of the country, some important conclusions can nevertheless be drawn. The country has substantial solar energy resources. The global solar radiation in the selected cities vary from 12.67 - 20.72 $MJm^{-2}day^{-1}$ in Abeokuta, 15.17 - 22.90 $MJm^{-2}day^{-1}$ in Ilorin, 10.75 - 19.03 $MJm^{-2}day^{-1}$ in Port Harcourt and 19.08 - 25.71 $MJm^{-2}day^{-1}$ in Sokoto. The highest value of global solar radiation was observed in Sokoto in May and the lowest in Port Harcourt in July. The data reveal that there is an evident increase of the value of the global solar radiation from south to north. This was expected as the radiation should increase as one moves to the equatorial line. This result correlates with that of previous researchers (Akpabio and Etuk, 2003; Augustine and Nnabuchi, 2010; Chukwuemeka and Nnabuchi, 2009).

The result of this study shows that there is greater availability of solar radiation in Sokoto compared to other locations studied. Also, solar energy devices will function successfully throughout the year in Sokoto.

The derived data and correlation developed will provide a useful source of information in the design and estimation of performance of solar application systems which is gaining attention in Nigeria.

The work reported in this paper indicates that the solar energy utilization has bright prospects in Sokoto and Ilorin when compared to other locations (Abeokuta and Port Harcourt). The estimated values of global and diffuse solar radiations reveal that solar radiation can be very efficiently used to compensate for energy deficit in Nigeria.

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