Assessment of Six Daily Diffuse Solar Radiation Models for Nigeria

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Keywords: Cloud cover, diffuse solar radiation, estimation model, meteorological parameter, solar energy.

Abstract. Lack of available diffuse solar radiation data in Nigeria and the variation of commonly used estimation methods with site meteorology called for the need to evaluate models and verify their suitability based on the local environmental conditions before application for the design and development of solar energy systems. This study assesses the performance of six models for estimating the monthly average daily diffuse solar radiation over Nigeria. The models considered utilize clearness index, cloud cover, relative sunshine duration or a combination of these parameters as input, for estimating diffuse solar radiations on a horizontal surface. The performance evaluation of estimation models used data sets for 37 cities with varying meteorology, which spread across the six geopolitical zones in Nigeria, for a period of 22-years. The applicability of considered methods of estimation was determined based on the coefficient of correlation, coefficient of determination, mean bias error, root mean square error (RMSE), mean absolute bias error (MABE) and relative percentage error (RPE). This study finds that the multivariable regression relationship, which uses clearness index and cloud cover as input parameters, performs best in the estimation of diffuse solar radiations on a horizontal surface for Nigeria. It gives the lowest range of error terms, with RMSE (0.0778–0.1981 MJ/m^2), MABE (0.0663–0.1623 MJ/m^2) and monthly RPE of ± 6%.

Introduction

Global solar radiation is one of the most commonly used parameters for the design, optimization and performance evaluation of solar energy systems for any given location. Complete and accurate solar radiation data are of considerable significance for research and applications in agriculture, agrology, architecture, ecology, environment, hydrology, limnology and oceanography [1]. Global solar radiation consists of the direct normal irradiation, which is required for concentrating solar power projects, as well as the diffuse solar radiation on a surface.

The diffuse solar radiation is the prime parameter, which directs the quality of both global solar radiation and direct normal irradiation [2]. It gives a view of the atmospheric changes that affect the available solar radiation, such as clouds, smoke, dust or pollen [3]. In addition, knowledge of the long-term average daily diffuse fraction and its contributions to the global solar radiation is of fundamental importance as it enables the efficient and economic utilization of solar energy systems on a tilted plane [4]. In spite of the significance of diffuse radiation, ground-based measured data are not readily available in Nigeria [5]. For such regions where surface measurements (of diffuse solar radiation) are sparse or nonexistent, a common practice is to rely on available methods of estimations as well as to develop new methods.

Several methods in [2], [4], [6]–[11] have been proposed for estimating the daily average diffuse solar radiation on a horizontal surface. A commonly used approach is on the basis of meteorological parameters, correlating the diffuse solar radiation as a function of either the clearness index or cloud cover (also referred to as cloud fraction or cloud amount). The advantage of using this approach is that only one observed or measured input (i.e., global solar radiation or cloud cover) is required [10].

A second-order polynomial model deduced in [4] was used for estimating the daily diffuse solar radiations on a horizontal surface for three sites, each selected from the northern, central and southern part of Nigeria. The results indicate the significance of model calibration for a given location.

In this study the daily meteorological data sets of 37 cities, which spread across the six geopolitical zone of Nigeria, for a period of 22-years were applied to:

- calibrate and validate five existing diffuse solar radiation models;
- develop a new multivariable regression model to estimate daily diffuse solar radiations from clearness index and cloud cover; and
- compare estimates from the newly developed and five existing radiation models with the measured values.

The objective is to determine the most suitable model for estimating the average daily diffuse solar radiation on a horizontal surface for Nigeria. A better estimation tool will ensure a more accurate prediction of future or past values of daily diffuse solar radiations on a horizontal surface in Nigeria and other regions with similar climatic conditions.

Methodology

Site Meteorology and Data. The meteorology of a geographical region influences the solar irradiation at that location. Nigeria has a total area of 923,768.00 km^2 (910,768 km^2 of land and 13,000 km^2 of water), which is located within the Equator and the Tropic of Cancer, on main latitude and longitude of 10°N and 8°E respectively. There are six geopolitical zones in Nigeria, which consists of 37 sites. These areas are made up of the 36 states and the Federal Capital Territory (FCT), Abuja as shown in Fig. 1. Although the latitude of Nigeria falls within the tropical zone, its climatic conditions are not entirely tropical in nature [12]. The Nigerian climate varies from being arid in the northern to tropical at the central and equatorial in the southern part of the country [13].

Fig. 1. Map of Nigeria showing the 36 states and FCT [14]

The meteorological datasets used in this study were collected from two data sources for 37 sites in Nigeria. The capital city of each state and Abuja were considered. The first part was downloaded from the archives of the National Aeronautics and Space Administration (NASA), accessed from the internet (http://eosweb.larc.nasa.gov/; accessed on Nov. 20, 2013). These data consist of the monthly average daily cloud cover, and the corresponding global and diffuse solar radiations on a horizontal surface, for a period of 22-years (1984–2005). NASA satellite-derived data sets provide reliable meteorological resource data over regions where surface measurements are scarce or nonexistent. The second part was collected from the archives of the Nigerian Meteorological (NIMET) agency, Oshodi, Lagos State, Nigeria, for same locations. It contains the monthly average daily measurements of sunshine duration for a period of 22-years (1991–2012). The sunshine duration data contains some missing record (sunshine duration data), which were removed. The main characteristics of the sunshine data collected from NIMET are shown in Table 1.

Table 1: The Main Characteristics of Sunshine Duration Data for Nigerian Station [15]

Items	Description
Instrument	Campbell Stokes Sunshine Recorder
Measurement range	0 - 24 h
Recording resolution	0.1 h

The retained sunshine data set and those collected from NASA were integrated to form the final data sets used in this study. The final data sets for the 37 sites considered are classified into two groups. Firstly, the site is randomly chosen from each of the six geopolitical zones. The data sets from the remaining (31) sites were combined for each geopolitical zone to form *group-1* data sets. The combined (*group-1*) data sets were used for calibration of model parameters as well as to develop generalized correlations, which can be used for estimating the daily diffuse solar radiation on a horizontal surface for each of the six zones in Nigeria. Thereafter, the individual data sets randomly selected from each geopolitical zone (referred to as *group-2* data sets) were used for performance evaluation and validation of various solar radiation models for the six geopolitical zones in Nigeria. Table 2 gives a summary of the geographical classification of Nigeria, indicating the coordinates of the 31 sites (cities) used for model development or calibration and the six randomly selected sites (*highlighted in bold fonts*) used for evaluating the developed and existing radiation models discussed in the following section.

Methods. The five existing diffuse solar radiation models, which are believed to be universally applicable, considered for estimating the daily diffuse solar radiation on a horizontal surface are as follows.

1. *Page model:* Page in 1964 developed a linear relationship for estimating daily diffuse solar radiation on a horizontal surface using clearness index [6]. The performance of the Page type model shown in (1) has been demonstrated in [3] and [7] but the results suggest different values of regression coefficients compared to those initially proposed in [6]. The Page-type model is widely calibrated for different locations as:

$$K_D = a_o + a_1 K_T , \tag{1}$$

where K_D (= H_D/H) is the monthly average daily diffuse fraction, K_T (= H/H_o) is the monthly average daily clearness index, while H, H_D and H_o are the monthly average daily global, diffuse and extraterrestrial radiations respectively, on a horizontal surface (MJ/m^2). The parameters of model (1) are commonly estimated using regression techniques.

2. *Liu–Jordan model:* Liu and Jordan [8] developed a correlation, expressed by Klein [9] in the form of a third-order polynomial relationship as:

$$K_D = a_0 + a_1 K_T + a_2 K_T^2 + a_3 K_T^3 \ . \tag{2}$$

The performance of the model (2) was verified using experimental measurements while the parameters were estimated using partial regression analysis.

3. *Butt et al. model:* The relationship between cloud cover and diffuse fraction of solar radiation was investigated by Butt *et al.* [10], and proposed a linear regression model as:

$$K_D = a_0 + a_1 C, \tag{3}$$

where C is the average total cloud cover during daytime observations (Octa). The regression coefficients were determined using both ground-based and satellite-derived data collected for two contrasting rainforest sites in western and eastern Amazonia. Prediction results showed good agreement with the observed values, but with a seasonal weakness that seems to be aligned with dry season anthropogenic activity, such as biomass burning.

4. *Karakoti et al. model:* Karakoti *et al.* [11] analyzed a group of relations by first correlating the diffuse fraction with clearness index and relative sunshine duration, and then the diffuse coefficient with relative sunshine, using experimental data on global radiation, diffuse radiation and sunshine

hours reported in [16] for Indian stations. Based on the analysis, the cubic relationship of (4) was proposed for estimating the diffuse radiation on a horizontal surface over India. The predictive efficiency of the model (4), in estimating diffuse solar radiations on a horizontal surface, was compared with the widely used Page-type relation of (1) for 12 Indian locations. The results showed that error terms from Page-type relation are higher compared to the cubic relation for all Indian sites studied.

$$K = a_0 + a_1 S_R + a_2 S_R^2 + a_3 S_R^3 \ , \tag{4}$$

where $K\ (=H_D/H_o)$ is the monthly average daily diffuse coefficient and S_R is the ratio of the monthly average sunshine duration (h) to the monthly average daylight duration (h).

5. *Okundamiya-Nzeako model:* A second-order polynomial relationship for estimating the average daily diffuse radiation was deduced in [4] as:

$$K_D = a_0 + a_1 K_T + a_2 K_T^2 \ . \tag{5}$$

In order to determine the best model for estimating the diffuse solar radiation on a horizontal surface over Nigeria, besides the established methods, defined by models (1) – (5), the newly developed multivariable relationship of (6), deduced in terms of clearness index and cloud cover [17], was also considered. The inclusion of cloud cover could significantly improve the accuracy of diffuse radiation estimates from (6) as suggested in [18].

$$K_D = a_0 + a_1 K_T + a_2 C \ . \tag{6}$$

Table 2: The Geographical Classification and Coordinates for Selected Sites in Nigeria [17]

S/N	Geopolitical zone	Site	Latitude (°N)	Longitude (°E)	Altitude (m)
1.	North-western (NW)	Birnin Kebbi	12.46	4.20	271
2.		Dutse	11.70	9.34	480
3.		Gusau	12.16	6.67	415
4.		Kaduna	10.50	7.35	575
5.		Kano	12.03	8.50	457
6.		Katsina	12.99	7.61	492
7.		**Sokoto**	**13.06**	**5.25**	**331**
8.	North-eastern (NE)	Bauchi	10.31	9.85	559
9.		Damaturu	11.75	11.96	397
10.		Gombe	10.28	11.17	416
11.		Jalingo	8.90	11.37	476
12.		**Maiduguri**	**12.00**	**13.33**	**313**
13.		Yola	9.20	12.50	430
14.	North-central (NC)	**Abuja**	**9.08**	**7.53**	**484**
15.		Ilorin	8.50	4.58	274
16.		Jos	9.93	8.88	587
17.		Lafia	8.49	8.52	374
18.		Lokoja	7.81	6.74	216
19.		Makurdi	7.73	8.54	249
20.		Minna	9.61	6.55	319
21.	South-western (SW)	Abeokuta	7.16	3.35	156
22.		Ado-Ekiti	7.63	5.22	233
23.		Akure	7.25	5.20	233
24.		Ibadan	7.37	3.97	183
25.		**Ikeja**	**6.58**	**3.33**	**73**
26.		Oshogbo	7.77	4.56	223
27.	South-eastern (SE)	Abakaliki	6.33	8.10	277
28.		Awka	6.21	7.07	183
29.		**Enugu**	**6.50**	**7.50**	**183**
30.		Owerri	5.48	7.03	176
31.		Umuahia	5.53	7.48	176
32.	South-south (SS)	Asaba	6.2	6.73	159
33.		**Benin City**	**6.34**	**5.52**	**135**
34.		Calabar	4.95	8.33	246
35.		Port Harcourt	4.67	7.17	117
36.		Uyo	5.05	7.93	176
37.		Yenagoa	4.93	6.26	83

The parameters (model coefficients) of the six studied diffuse radiation models of (1) to (6) were calibrated by linear, multi-linear, or partial regression methods using *group-1* (combined) data sets for the six geopolitical zones in Nigeria. The performance of these radiation models was evaluated on the basis of six statistical indicators using *group-2* data sets for the various zones. The indicators selected are coefficient of correlation (r), which can be used to determine the linear relationship between the observed and predicted values; coefficient of determination (R^2), which gives the percentage of variation of the dependent variable in connection with the explanatory (independent) variables; while the root mean square error ($RMSE$), mean bias error (MBE), mean absolute bias error ($MABE$), and relative percentage error (RPE), are common error terms often used in comparing models. Standard equations available in [5], [11], and [19] were used to calculate all the necessary parameters such as H_o, and S_o, and values of R, R^2, $RMSE$, MBE, $MABE$, and RPE.

Simulation Results

The results derived from the calibration of the six studied diffuse radiation models (using *group-1* data sets) along with the corresponding R^2 values (computed based on *group-2* data sets), and the magnitude of estimation errors (validation results) for the six geopolitical zones in Nigeria are shown in Tables 3 and 4 respectively. A comparison of the monthly relative percentage error (RPE) from estimates of studied models is shown in Fig. 2 for six sites selected across Nigeria.

Discussion

A thorough study of results of the six diffuse solar radiation models, shown in Table 3, shows that the estimated regression coefficients (model parameters) vary from one zone to the other. The variation

Table 3: Derived Regression Relationships between Diffuse Radiations and Meteorological Correlation Variables for Nigeria

Geopolitical zone	Site	Model type	Regression relationships				R^2
			a_o	a_1	a_2	a_3	
North-western	Sokoto	Page [6]	1.0658	-1.2566	0.0000	0.0000	0.9019
		Liu-Jordan [8]	2.1699	-6.9082	9.5925	-5.4009	0.8950
		Butt *et al.* [10]	0.1505	0.0439	0.0000	0.0000	0.7134
		Karakoti *et al.* [11]	0.6923	-1.4582	1.2132	-0.2869	0.6680
		Okundamiya-Nzeako [2]	1.1198	-1.4433	0.1600	0.0000	0.9066
		Present study [Model (6)]	0.8169	-0.9347	0.0154	0.0000	**0.9934**
North-eastern	Maiduguri	Page [6]	1.0600	-1.2526	0.0000	0.0000	0.8968
		Liu-Jordan [8]	7.3138	-35.4344	61.7977	-36.9520	0.7385
		Butt *et al.* [10]	0.1202	0.0528	0.0000	0.0000	0.8253
		Karakoti *et al.* [11]	0.6226	-1.2632	1.0499	-0.2354	0.8549
		Okundamiya-Nzeako [2]	0.7087	-0.0103	-1.0845	0.0000	0.8619
		Present study [Model (6)]	0.8189	-0.9401	0.0149	0.0000	**0.9901**
North-central	Abuja	Page [6]	1.0506	-1.2461	0.0000	0.0000	0.9860
		Liu-Jordan [8]	2.7317	-11.3465	19.9398	-12.9301	0.9902
		Butt *et al.* [10]	0.1052	0.0614	0.0000	0.0000	0.8418
		Karakoti *et al.* [11]	-0.1485	2.2775	-4.3429	2.4702	0.8640
		Okundamiya-Nzeako [2]	0.8994	-0.6644	-0.5466	0.0000	0.9874
		Present study [Model (6)]	0.8760	-1.0222	0.0121	0.0000	**0.9960**
South-western	Ikeja	Page [6]	1.0467	-1.2461	0.0000	0.0000	0.9698
		Liu-Jordan [8]	2.3663	-9.8575	18.4150	-12.9072	0.9866
		Butt *et al.* [10]	0.0792	0.0706	0.0000	0.0000	0.8661
		Karakoti *et al.* [11]	-1.2813	13.4719	-39.3713	37.1341	0.8710
		Okundamiya-Nzeako [2]	0.9225	-0.7240	-0.5340	0.0000	0.9751
		Present study [Model (6)]	0.8700	-1.0309	0.0142	0.0000	**0.9903**
South-eastern	Enugu	Page [6]	1.0454	-1.2467	0.0000	0.0000	0.9775
		Liu-Jordan [8]	2.5887	-11.1174	20.7699	-14.3774	0.9781
		Butt *et al.* [10]	0.0888	0.0669	0.0000	0.0000	0.8157
		Karakoti *et al.* [11]	0.1179	0.7339	-1.5841	0.9322	0.7686
		Okundamiya-Nzeako [2]	0.9571	-0.8786	-0.3753	0.0000	0.9776
		Present study [Model (6)]	0.8490	-0.9989	0.0145	0.0000	**0.9915**
South-south	Benin City	Page [6]	1.0387	-1.2419	0.0000	0.0000	0.9739
		Liu-Jordan [8]	2.3880	-10.5426	21.0098	-15.5605	0.9701
		Butt *et al.* [10]	0.0761	0.0759	0.0000	0.0000	0.9155
		Karakoti *et al.* [11]	0.2015	0.0459	0.1159	-0.4154	0.8761
		Okundamiya-Nzeako [2]	0.9994	-1.0627	-0.1983	0.0000	0.9731
		Present study [Model (6)]	0.8285	-0.9784	0.0172	0.0000	**0.9871**

of regression coefficients of diffuse radiation models shows the dependence of solar radiation on site meteorology. The range of variation differs from one model to another. However, the variations of parameters from Page, Butt *et al.* and model (6) tend to be negligible. This implies that these models could be generalized for estimation of diffuse solar radiations over Nigeria.

The R^2-index is a necessary statistical tool used for determining the accuracy of the deduced model parameters for solar radiation estimation. For higher estimation accuracy, the computed R^2-values should approach unity as closely as possible. Based on the R^2-index, it is clear from the results (Table 3) that the newly developed multivariable regression model of (6) gives the overall best performance accuracy, with values in the range of 0.9870 – 0.9980, for all sites considered in the six geopolitical zones in Nigeria.

The test of correlation coefficient (see Table 4) shows that the newly developed diffuse radiations model of (6) gives the highest *r*-values in the range of (0.9935–0.9980) for the entire studied locations in Nigeria. This suggests that the model (6) give the best estimates of diffuse radiation on a horizontal surface in Nigeria.

It is noticed that the calculated values of error indices from studied models (see Table 4 and Fig. 2) vary from one zone to another. This is perhaps due to seasonal variations of the solar radiation caused apparently by the degree of cloud cover, atmospheric dust, and presence of water vapor and Ozone in the atmosphere which differs from one geographical zone to another. The magnitude of estimation errors are higher in the northern compared to the southern sites (Fig. 2). This perhaps is due to the presence of dusts particles, which affects diffuse fraction, that are higher in arid (northern) sites due to the influence of the Sahara desert. As earlier mentioned, the climatic conditions vary in most parts of Nigeria

Table 4: Validation Results of six studied Diffuse Radiations Models for Nigeria based on 22-Years (Group-2) Data Sets

Site (Zone)	Error terms (units)	Page [6]	Liu-Jordan [8]	Butt *et al.* [10]	Karakoti *et al.* [11]	Okundamiya-Nzeako [2]	Present study [Model (6)]	Range (Absolute value)	
								Min.	Max.
Sokoto (NW)	r	0.9497	0.9461	0.8446	0.8173	0.9521	**0.9967**	0.8173	0.9967
	RMSE (MJ/m^2)	0.4049	0.4219	0.8951	1.0711	0.3966	**0.1061**	0.1061	1.0711
	MBE (MJ/m^2)	-0.1652	-0.1832	0.5307	0.7989	-0.1575	**-0.0185**	0.0185	0.7989
	MABE (MJ/m^2)	0.3261	0.3434	0.6515	0.9239	0.3213	**0.0793**	0.0793	0.9239
Maiduguri (NE)	r	0.9470	0.8594	0.9085	0.9246	0.9284	**0.9950**	0.8594	0.9950
	RMSE (MJ/m^2)	0.3976	0.6884	0.7798	0.4401	0.4556	**0.1981**	0.1981	0.7798
	MBE (MJ/m^2)	-0.1506	-0.2523	-0.0831	**0.0467**	-0.1606	-0.1592	0.0467	0.2523
	MABE (MJ/m^2)	0.3269	0.5246	0.7136	0.3557	0.3629	**0.1623**	0.1623	0.7136
Abuja (NC)	r	0.9930	0.9951	0.9175	0.9295	0.9937	**0.9980**	0.9175	0.9980
	RMSE (MJ/m^2)	0.1727	0.2427	0.6918	0.5350	0.1802	**0.1109**	0.1109	0.6918
	MBE (MJ/m^2)	-0.0744	-0.1414	0.1298	0.1363	-0.0924	**-0.0461**	0.0461	0.1414
	MABE (MJ/m^2)	0.1182	0.1836	0.5151	0.4277	0.1461	**0.1000**	0.1000	0.5151
Ikeja (SW)	r	0.9848	0.9933	0.9307	0.9333	0.9875	**0.9951**	0.9307	0.9951
	RMSE (MJ/m^2)	0.1615	0.1857	0.7551	0.3119	0.1605	**0.1098**	0.1098	0.7551
	MBE (MJ/m^2)	**0.0370**	0.0662	-0.6056	-0.1614	0.0573	-0.0849	0.0370	0.6056
	MABE (MJ/m^2)	0.1395	0.1519	0.6550	0.2568	0.1392	**0.0913**	0.0913	0.6550
Enugu (SE)	r	0.9887	0.9890	0.9032	0.8767	0.9887	**0.9957**	0.8767	0.9957
	RMSE (MJ/m^2)	0.1348	0.1282	0.5029	0.4102	0.1289	**0.0778**	0.0778	0.5029
	MBE (MJ/m^2)	-0.0220	-0.0365	0.0973	-0.0216	-0.0237	**-0.0030**	0.0030	0.0973
	MABE (MJ/m^2)	0.1137	0.1018	0.4208	0.3241	0.1113	**0.0663**	0.0663	0.4208
Benin City (SS)	r	0.9869	0.9849	0.9568	0.9360	0.9865	**0.9935**	0.9360	0.9935
	RMSE (MJ/m^2)	0.1537	0.1471	0.5365	0.3942	0.1481	**0.1129**	0.1129	0.5365
	MBE (MJ/m^2)	-0.0599	-0.0781	**-0.0262**	0.0843	-0.0624	-0.0633	0.0262	0.0843
	MABE (MJ/m^2)	0.1197	0.1170	0.4814	0.2932	0.1162	**0.0955**	0.0955	0.4814

The root mean square errors computed for estimating the daily diffuse radiations on a horizontal surface over Nigeria vary from 0.0778 to 1.0711 (MJ/m^2) as shown in Table 4. The estimation errors produced by the Liu-Jordan, Butt *et al.* and Karakoti *et al.* models are higher compared to errors from

Page, Okundamiya-Nzeako and model (6). However, the newly developed multivariable regression model of (6) gives the lowest range of estimation errors from (0.0778 – 0.1981 MJ/m^2). Therefore, on the basis of the *RMSE* index, the newly developed multivariable regression model of (6) gives the best diffuse solar radiation estimates for Nigeria.

According to the *MBE* index, negative and positive *MBE* values indicate underestimation and overestimation respectively, of the individual term. Analysis of the *MBE* index shows that there are negligible estimation error for all sites considered, except for Butt *et al*. and Karakoti *et al*. estimates which tend to vary between high under-estimation and over-estimation for the south western and north-western part of Nigeria respectively.

The test of *MABE* provides information on the long-term performance of the solar radiation models. It gives a more reliable indices compared to *MBE*. This is because over-estimation of an individual observation may cancel under-estimation in a separate observation. According to the *MABE* index (Table 4), the newly developed multivariable regression model of (6) gives the lowest range of estimation error from 0.0663 – 0.1623 (MJ/m^2). This suggests that model (6) has the best long-term performance accuracy for estimating the daily diffuse solar radiation over Nigeria.

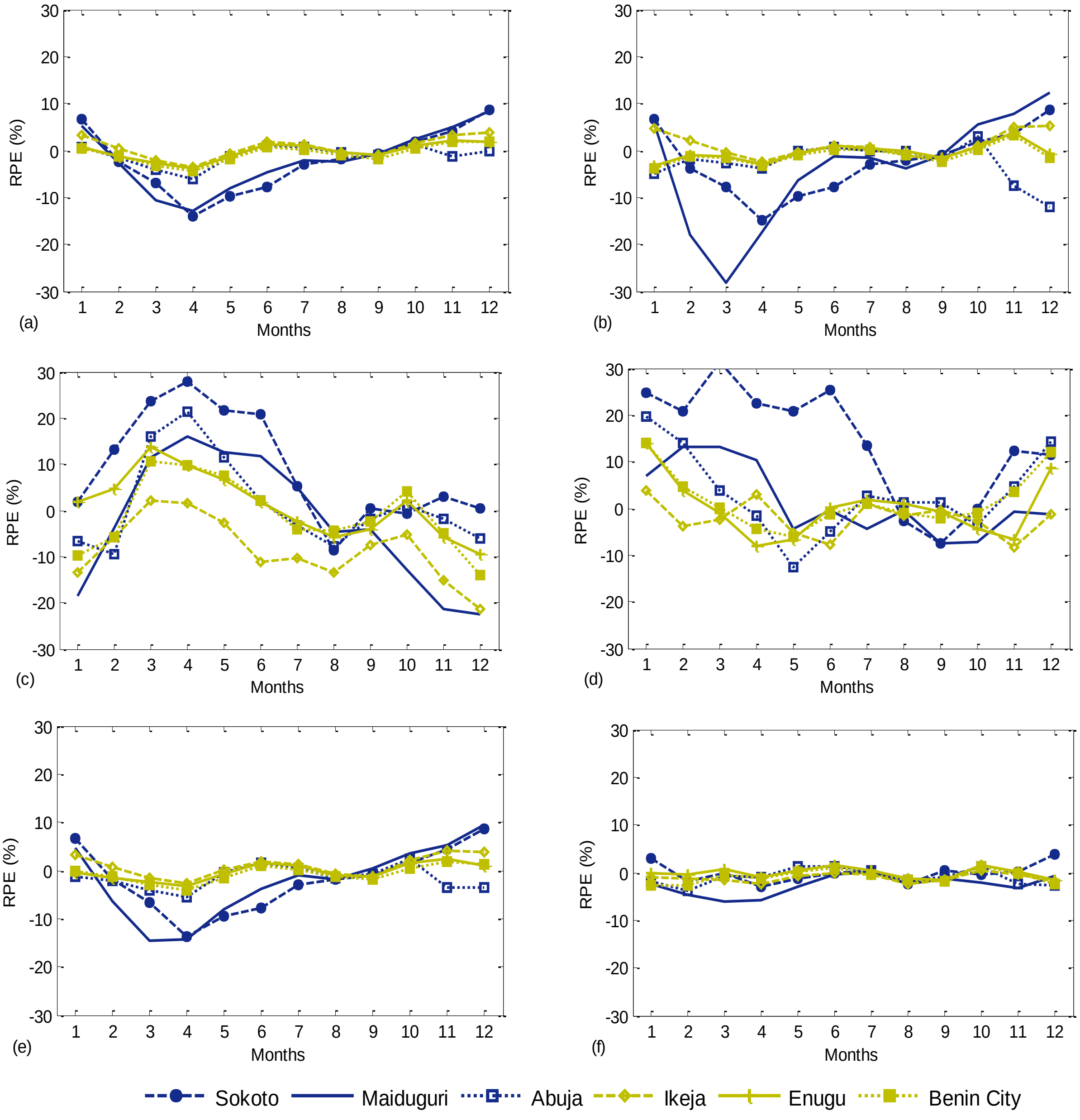

Fig. 2. Comparison of the monthly relative percentage error of diffuse solar radiation estimates from (a) Page [6], (b) Liu-Jordan [8], (c) Butt et al. [10], (d) Karakoti et al. [11], (e) Okundamiya-Nzeako [2], and (f) Present study [Model (6)]; in Nigeria

A comparison of the relative percentage error of the observed and estimated values of diffuse radiations for the six models (see Fig. 2), shows that the relative percentage error for each month produced by the newly developed multivariable regression model of (6) rarely exceeds ± 6%. The RPE values from the widely used Page-type model of (1), and the second-order polynomial model of (5) developed in previous study fall within ± 15%, but estimates from Liu-Jordan, Butt *et al.* and Karakoti *et al.* models of (2), (3), and (4) respectively, exceed the range of ± 20%. The *RPE* index further confirmed the excellent agreement between the measured and predicted value of daily diffuse solar radiations produced by the newly developed multivariable regression model of (6). This study therefore recommend the use of the newly developed multivariable regression model of (6), based on regression coefficients presented in Table 3, for estimating future or past values of the monthly average daily diffuse solar radiations on a horizontal surface over Nigeria, and for other regions with similar climatic conditions.

It is worth mentioning that the high performance accuracy of the newly proposed multivariable regression model of (6) for estimating the monthly average daily diffuse solar radiations over Nigeria could be traceable to the inclusion of cloud cover, to clearness index as input parameters. This is because cloud plays a crucial role in the transfer of energy between the surface and the atmosphere. The results justify the suggestion made in [18], " that the inclusion of cloud cover improves the prediction accuracy of radiation models."

Conclusion

The present study extends the previous work in [4] to a considerable number of sites, with varying meteorology covering the entire geographical zones in Nigeria. It considered six methods, which utilizes the clearness index, cloud cover, relative sunshine duration or the combination of two of these parameters as inputs, for estimating diffuse solar radiations on a horizontal surface over Nigeria.

A new multivariable regression model, which uses clearness index and cloud cover as inputs for estimating the monthly daily average diffuse solar radiations on a horizontal surface in Nigeria, was developed. The performance of deduced multivariable regression model was compared with five diffuse radiation models widely used the literature using 22-years meteorological data sets collected from NASA and NIMET. The results show that the methods proposed by Okundamiya-Nzeako [4], Page [6], and the multivariable regression model of (6) perform better than the methods proposed by Liu-Jordan [8], Butt *et al.* [10] and Karakoti *et al.* [11], but the proposed multivariable regression model of (6) has the best prediction accuracy (with relative percentage error of ± 6%). The conclusion is that the inclusion of cloud cover as input parameter improves the prediction accuracy of diffuse solar radiation models for Nigeria.

Acknowledgement

This work was supported in part by the Ambrose Alli University through the Education Trust Fund for Academic Staff Training and Development (ETF AST&D) Intervention under Grant AAU/REG/ETF.560/475.

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