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# Evaluation of various global solar radiation models for Nigeria

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**ABSTRACT**

This study assessed the performance of six solar radiation models. The objective was to determine the most accurate model for estimating global solar radiation on a horizontal surface in Nigeria. Twenty-two years meteorological data sets collected from the Nigerian Meteorological agency and the National Aeronautics and Space Administration for the three regions, covering the entire climatic zones in Nigeria were utilized for calibrating and validating the selected models for Nigeria. The accuracy and applicability of various models were determined for three locations (Abuja, Benin City, and Sokoto), which spread across Nigeria using seven viable statistical indices. This study found that the estimation results of considered models are statistically significant at the 95% confidence level, but their accuracy varies from one location to another. However, the multivariable regression relationship deduced in terms of sunshine ratio, air temperature ratio, maximum air temperature, and cloudiness performs better than other relationships. The multivariable relationship has the least root mean square error and mean absolute bias error, not exceeding 1.0854 and 0.8160 MJ $m^{-2}$ $day^{-1}$, respectively, and monthly relative percentage error in the range of ± 12% for the study areas.

**KEYWORDS**

Empirical models; meteorological parameters; model calibration; Nigeria; regression coefficients; solar radiation

## Introduction

The knowledge of the availability of global irradiation and its components for a given area is essential in order to utilize the available solar energy economically and efficiently. The long-term average daily global irradiation is a commonly used parameter for the design, optimization, and performance evaluation of solar energy systems for any particular area. The amount of global solar radiation at any site is best determined through the installation of measuring instruments, such as the pyranometer, at that particular place for monitoring and storing of its day-to-day recording, but this is a very tedious and costly exercise (Katiyar and Pandey 2010). A common practice for regions like Nigeria, where surface measurements (of solar radiation) are sparse, is to rely on available methods of estimations as well as to develop new methods.

There are various methods for estimating the monthly average daily global solar radiations (Maghrabi 2009; Almorox, Hontoria and Benito 2011; Besharat, Dehghan and Faghih, 2013). These methods based their estimation on meteorological data. The meteorology of a geographical region influences the availability of solar radiation at that location. Although the latitude of Nigeria falls within the tropical zone, its climatic conditions are not entirely tropical in nature. These vary in most parts of the country. For example, the climatic condition is arid in the north, tropical at the centre and equatorial in the south (Okundamiya, Emagbetere and Ogujor 2014).

The variation of commonly used methods of estimation with geographical locations called for the need to evaluate models and verify their suitability based on the local environmental conditions before application for the design and installation of solar energy systems. Okundamiya and Nzeako (2010) suggested a simple method based on air temperature for estimating the global solar radiation on a horizontal surface for the six geopolitical zones in Nigeria. Results showed that the accuracy of estimates from proposed model could improve if additional meteorological parameters are included in the proposed model. Moreover, the behavior of air temperature-based model may be influenced by site-specific characteristics. Correct prediction of the solar energy potential of a given place depends on the accurate determination of the intensity of solar radiation at that location. The determination of an accurate method for estimating the daily global solar radiation on a horizontal surface using available parameters has motivated this study.

This paper calibrates and evaluates the performance of six models to identify patterns of characteristic behavior of solar radiation estimates for Nigerian terrain. The objective was to determine the most accurate model for estimating the monthly average daily global solar radiation on a horizontal surface in Nigeria.

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## Studied models

The number of correlations published and tested to estimate global solar radiations is relatively high, which makes it difficult to select the best method for a particular site and purpose. Besharat, Dehghan, and Faghih (2013) classified various global solar radiation models into four categories (sunshine-based, cloud-based, temperature-based, and other or hybrid-parameter-based models). Sunshine-based models are commonly used probably for the ease of obtaining reliable sunshine data that are widely available at most weather stations (Angstrom 1924; Prescott 1940; Page 1961; Rietveld 1978; Akpabio, Udo, and Etuk 2005; El-Metwally 2005). In the absence of sunshine data, cloud-based models can be a useful alternative but are sensible to human biasing (Supit and Van Kappel 1998; Badescu 1999). The temperature-based models can be a convenient way if calibrated for a particular location (Hargreaves and Samani 1982; Allen 1997; Chen et al. 2004; Okundamiya and Nzeako 2010; Almorox, Hontoria, and Benito 2011). The hybrid-parameter-based model is reported to predict the solar radiation on a horizontal surface with a high degree of accuracy (Supit and Van Kappel 1998; Menges, Ertekin, and Sonmete, 2006), but most of their input parameters are not readily available at most locations of interest (Besharat, Dehghan, and Faghih 2013).

The selection of studied models is on the basis of the model prediction accuracy and the ease of obtaining input parameters. In addition, only models believed to be universally applicable and those that can be easily calibrated for the study locations are selected. A model is selected from the cloud-based, two models from the sunshine-based and three models from hybrid-parameter-based models. The six models considered are as follows.

## Angstrom–prescott model

Angstrom (1924) proposed the first relation for estimating the monthly average daily global solar radiation. The proposed relation was deduced based on a correlation between the ratios of average daily global radiation to the corresponding value on an entirely clear day. Prescott (1940) modified the Angstrom relation with a view to resolving the ambiguity characterizing the definition of the clear sky global solar radiation. The modified Angstrom-type (Angstrom–Prescott-type) relation is of the form:

$$K_T = a + b\, S_R. \tag{1}$$

where, $K_T$ is the ratio of the monthly average daily global solar radiation ($H$) to the monthly average daily extraterrestrial radiation ($H_o$) both on a horizontal surface and expressed in MJ $m^{-2}$ $day^{-1}$. $S_R$, on the other hand, is the ratio of the monthly average sunshine duration ($S$) to the monthly average daylight duration ($S_o$), both expressed in h.

Several studies applied the Angstrom–Prescott-type model for estimating the monthly average daily global radiation on a horizontal surface for different regions of the world by determining the empirical constants (*a, b*) of Equation (1) using the meteorological parameters of the given location of study. Among the Angstrom–Prescott-type models, those calibrated by Page (1961) and Rietveld (1978) claimed to be universally applicable. Notwithstanding, Falayi and Rabiu (2005), and Akpabio, Udo, and Etuk (2005) calibrated the sunshine-based models for estimating monthly average daily global radiation on a horizontal surface for different locations in Nigeria. The results showed a higher level of accuracy in the calibration sites as compared to previously published models that claimed to be universally applicable.

## Swartman–ogunlade model

Swartman and Ogunlade (1967) expressed global solar radiation in terms of the relative sunshine and relative humidity as:

$$K_T = a + b\ S_R + cRH, \tag{2}$$

where, $RH$ is the monthly average daily relative humidity (%). Chegaar and Guechi (2009) applied Equation (2) to estimate the global solar radiation on a horizontal surface, using meteorological parameters collected, for different stations in Algeria. Results showed that the agreement between the measured and the computed values for study locations is remarkable. The study further recommends the use of Equation (2) for any location in Algeria or station with similar climate.

## Badescu model

Badescu (1999) proposed a cloud-based model based on a correlation between the clearness index and the average total cloud cover during daytime observations of the form:

$$K_T = a + b\ C, \tag{3}$$

where, $C$ is average total cloud cover during daytime observations (octa). The calibration results of the Badescu model for Yard city showed a high degree of accuracy (Besharat, Dehghan, and Faghih 2013).

## Chen et al. model

Hargreaves and Samani (1982) first proposed a relation for predicting the global solar radiation on a horizontal surface in terms of the difference between the maximum and minimum air temperatures. Allen (1997) modified the Hargreaves model suggesting a self-calibrating coefficient in terms of the relative atmospheric pressure. The proposed self-calibrating model for the coefficient estimation performed poorly for sites having an elevation above 1500 m. Chen et al. (2004) observed based on a comparison study that the Hargreaves and Allen models are not suitable for estimating the daily global solar radiation in China. They suggested a non-linear relationship for improving the estimation accuracy in terms of the air temperature difference ($\Delta T$) and relative sunshine ($S_R$) of the form:

$$K_T = a + b\ \ln \Delta T + c\ {S_R}^d, \tag{4}$$

where, $\Delta T$ (= $T_{\max}$ – $T_{\min}$) is the temperature difference (°C), $T_{\min}$ and $T_{\max}$ are the monthly average daily minimum and

Table 1. Main characteristics of studied models.

| Model | Category | Relation | Accuracy | Restrictions |
|---|---|---|---|---|
| Angstrom–Prescott | Sunshine | $K_T = a + b\, S_R$ | High | – |
| Swartman–Ogunlade | Hybrid | $K_T = a + b\, S_R + c\, RH$ | High | – |
| Badescu | Cloud | $K_T = a + b\, C$ | High | Sensible to human biasing |
| Chen et al. | Hybrid | $K_T = a + b \ln \Delta T + c\, {S_R}^d$ | High | Suitable for tropical climate |
| El-Metwally | Sunshine | $K_T = a^{\frac{1}{S_R}}$ | High | – |
| Okundamiya | Hybrid | $K_T = a + b\, S_R + c\, T_R + d\, T_{\max} + e\, C$ | High | – |

maximum air temperatures (°C), respectively. Wu et al. (2007) assessed the performance of nine models using meteorological data for Nanchang station, China. Simulation results showed that the Chen model of Equation (4) is the most accurate for estimating the monthly average daily solar radiation.

### El-Metwally model

El-Metwally (2005) proposed a non-linear relation between $K_T$ and $S_R$ of the form:

$$K_T = a^{\frac{1}{S_R}}. \quad (5)$$

In addition, Besharat, Dehghan, and Faghih (2013) assessed the predictive performance of various solar radiation estimation techniques for Yard city. Simulation results showed that the El-Metwally sunshine-based model of Equation (5) is the most accurate for estimation of the monthly average daily values.

### Okundamiya model

Okundamiya (2014) developed correlations between global solar radiation and other meteorological parameters based on monthly average daily data sets collected for different locations in Nigeria and proposed a relation of the form:

$$K_T = a + b\, S_R + c\, T_R + \mathrm{d}\, T_{\max} + e\, C \quad (6)$$

The applicability of Equation (6) was tested by a comparison with the simple temperature-based model previously proposed (Okundamiya and Nzeako 2010). Results showed that Equation (6) compares more favorably with observed data for considered locations in Nigeria (Okundamiya 2014). It is noteworthy that the input data of Equation (6) are easily measured at Nigerian stations. Table 1 shows the main characteristics of the studied models.

## Simulations

### Study locations

This study considers three areas as shown in Figure 1, for assessing the performance of studied models. The areas considered are selected each from the northern, central, and southern region of Nigeria. A comprehensive description of the meteorology of these locations is available in the literature (Okundamiya and Nzeako 2013).


Figure 1. Map of Nigeria showing the study sites.

### Data and methods

The monthly average daily meteorological data sets used were obtained from two data sources for the study sites. The first part was downloaded from the archives of the National Aeronautics and Space Administration (NASA). These data sets consist of monthly average daily records of global solar radiation on a horizontal surface, cloud cover, relative humidity, and maximum and minimum air temperatures for a period of 22 years (1984–2005). NASA derives these data sets from a variety of earth-observing satellites and reanalysis research programs that provide reliable meteorological resource data over regions where surface measurements are scarce or non-existent (NASA 2013). The second part collected from the archives of the Nigerian Meteorological (NIMET) agency, Oshodi, Lagos (Nigeria) for same locations, is made of the average daily sunshine duration data for 22 years (1991–2012). Table 2 shows the geographical coordinates of selected areas and the characteristics of the day-to-day recordings of the sunshine data while Figure 2 shows the observed long-term (22 years) average daily meteorological data sets collected.

The daily data sets were divided into two sub-data sets. The first sub-data set (sub-data set 1), which consists of 17-years records were used to calibrate the considered models, i.e., Equations (1)–(6). Linear, multiple-linear, and non-linear regressions are carried out between the monthly average observed clearness index and other meteorological parameters using sub-data set 1 to obtain the values of regression

**Table 2.** Geographical coordinates of study locations and characteristics of sunshine data.

| | Geographical coordinates | | | | Characteristics of sunshine data (NIMET 2013) | | |
|---|---|---|---|---|---|---|---|
| Regions | Locations | Latitude (°N) | Longitude (°E) | Elevation (m) | Instrument used | Measurement range | Recording resolution |
| Central | Abuja | 9.08 | 7.53 | 484 | Campbell stokes sunshine recorder | 0–24 h | 0.1 h |
| Southern | Benin City | 6.34 | 5.63 | 135 | | | |
| Northern | Sokoto | 13.06 | 5.25 | 331 | | | |

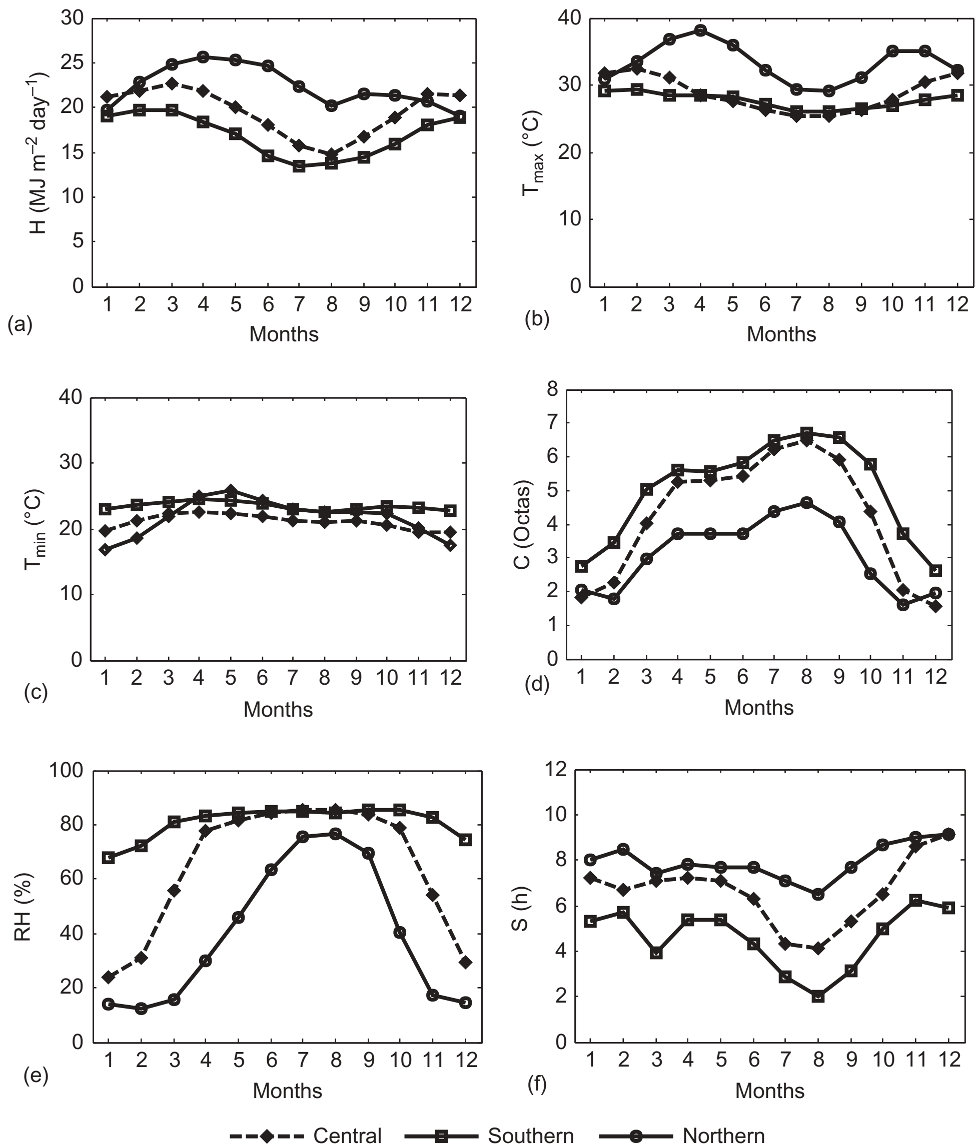


**Figure 2.** Long-term (22 years) monthly average daily data sets for Nigeria (a) global solar radiation, (b) maximum air temperature, (c) minimum air temperature, (d) cloudiness, (e) relative humidity, and (f) sunshine duration.

coefficients of the studied models as shown in Table 3. The methods employed are similar to those described in the previous study (Okundamiya and Okpamen 2013). The second sub-data set, which contains 5-year records were used for performance evaluation and validation.

## *Statistical analysis*

The accuracy and applicability of studied models were determined based on analysis of different statistical indicators. These are the coefficient of correlation ($r$), coefficient of determination ($R^2$), mean bias error ($MBE$), mean absolute bias error ($MABE$), root mean square error ($RMSE$), relative percentage error ($RPE$), and the $t$-statistic ($t$-stat) test indicators.

The $r$-value defines the linear relationship between the observed and predicted values of global solar radiations. The $R^2$ statistic gives the percentage variation of the dependent variable in connection with the explanatory (independent) variables while $MBE$, $MABE$, $RMSE$, and $RPE$ are common error terms often used in comparing models. For better data modeling, these error indicators should be closer to zero, but $r$ and $R^2$ should

**Table 3.** Calibration results of studied models along with $R^2$ and *t-stat* for Nigeria.

| | | | Statistics | | Regression coefficients | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | Site | Model | $R^2$ | *t*-stat | *a* | *b* | *c* | *d* | e |
| Central | Abuja | Equation 1 | 0.8059 | 0.0380 | 0.2195 | 0.6143 | 0 | 0 | 0 |
| | | Equation 2 | 0.9467 | 0.3312 | 0.4171 | 0.4252 | −0.0015 | 0 | 0 |
| | | Equation 3 | 0.7936 | 0.0543 | 0.7506 | −0.0455 | 0 | 0 | 0 |
| | | Equation 4 | 0.9598 | 0.0770 | −6.8739 | 0.1167 | 7.3102 | 0.0237 | 0 |
| | | Equation 5 | 0.8145 | 0.0718 | 0.7349 | 0 | 0 | 0 | 0 |
| | | Equation 6 | 0.9793 | 0.3298 | −0.1832 | 0.2790 | 0.1704 | 0.0179 | −0.0128 |
| Southern | Benin City | Equation 1 | 0.6677 | 0.0270 | 0.2361 | 0.6213 | 0 | 0 | 0 |
| | | Equation 2 | 0.8874 | 0.4260 | 0.6700 | 0.4381 | −0.0046 | 0 | 0 |
| | | Equation 3 | 0.8456 | 0.0462 | 0.7374 | −0.0528 | 0 | 0 | 0 |
| | | Equation 4 | 0.9532 | 0.0344 | −5.3448 | 0.2396 | 5.4894 | 0.0172 | 0 |
| | | Equation 5 | 0.6707 | 0.0038 | 0.7649 | 0 | 0 | 0 | 0 |
| | | Equation 6 | 0.9750 | 0.0067 | −0.5700 | 0.1158 | 0.4513 | 0.0285 | -0.0345 |
| Northern | Sokoto | Equation 1 | 0.6702 | 0.0616 | 0.4785 | 0.2465 | 0 | 0 | 0 |
| | | Equation 2 | 0.8332 | 0.1498 | 0.7561 | −0.0829 | −0.0014 | 0 | 0 |
| | | Equation 3 | 0.8133 | 0.1042 | 0.7231 | −0.0265 | 0 | 0 | 0 |
| | | Equation 4 | 0.8154 | 0.1028 | −13.090 | 0.1149 | 13.439 | −0.0041 | 0 |
| | | Equation 5 | 0.7573 | 0.0684 | 0.7496 | 0 | 0 | 0 | 0 |
| | | Equation 6 | 0.9087 | 0.1465 | 0.5741 | −0.3053 | 0.1922 | 0.0097 | −0.0577 |

approach unity as closely as possible. Although these tools are commonly used indicators, the *t*-stat (determined in terms of *MBE* and *RMSE*) has satisfactory accuracy for analyzing solar radiation data as it determines whether a model's estimate is statistically significant at a particular confidence level (considered in this study as 95%). To determine whether the model's estimate is statistically significant, one has to determine the critical *t*-stat at α level of significance and ($m$ − 1) degree of freedom (where $m$ refers to the 12 months of the year) from standard statistical tables. A model's estimate is statistically significant if the calculated *t*-stat lies between the intervals defined by the critical *t*-stat (acceptance region under the reduced normal distribution curve). Standard equations available in Okundamiya and Nzeako (2010), Khatib et al. (2011), Besharat, Dehghan, and Faghih (2013) were used to calculate all the necessary parameters such as $H_o$ and $S_o$, and values of $r$, $R^2$, *RMSE, MBE, MABE, RPE*, and *t*-stat.

## Results and discussion

Tables 3 and 4 show the calibration and validation results of studied models for different regions in Nigeria.

There is a significant variation of the $R^2$ values, shown in Table 3, for considered models, but Equations (2), (4), and (6) have higher $R^2$ values compared to Equations (1), (3), and (5). The result shows that the accuracy of hybrid-parameters-based solar radiation models is better, compared to single-parameter-based models. Nevertheless, the *t*-stat of considered models, computed at the 95% confidence level, is significantly lower than the corresponding $t_c$-stat (1.96). The variation of regression coefficients of considered models from one location to the other shows the dependence of solar radiation on site meteorology. Based on the established coefficients shown in Table 3, the monthly average daily solar radiations for each city selected from various regions in Nigeria were estimated as shown in Figure 3.

**Table 4.** Validation results of studied models for different regions in Nigeria using sub-data Set 2.

| | | | Statistics | | | |
|---|---|---|---|---|---|---|
| | | | | Error terms (MJ $m^{-2}$ $day^{-1}$) | | |
| Region | Location | Model | *r*-value | RMSE | MBE | MABE |
| Central | Abuja | Equation 1 | 0.8987 | 1.3055 | 0.3464 | 1.1711 |
| | | Equation 2 | 0.9785 | 0.9159 | 0.1930 | 0.7494 |
| | | Equation 3 | 0.8867 | 1.4682 | 0.3156 | 1.2301 |
| | | Equation 4 | 0.9668 | 0.8273 | 0.2044 | 0.6164 |
| | | Equation 5 | 0.8888 | 1.3134 | 0.3596 | 1.1127 |
| | | Equation 6 | 0.9867 | 0.6796 | 0.2736 | 0.5705 |
| Southern | Benin City | Equation 1 | 0.6670 | 1.7513 | -0.0630 | 1.4471 |
| | | Equation 2 | 0.7367 | 1.6891 | -0.8809 | 1.2665 |
| | | Equation 3 | 0.8600 | 1.1254 | -0.0932 | 0.9256 |
| | | Equation 4 | 0.8362 | 7.5463 | -7.4307 | 7.4307 |
| | | Equation 5 | 0.6414 | 3.1778 | -0.0697 | 2.5651 |
| | | Equation 6 | 0.8774 | 1.0854 | 0.0089 | 0.8160 |
| Northern | Sokoto | Equation 1 | 0.7731 | 1.4324 | 0.2990 | 1.1706 |
| | | Equation 2 | 0.9128 | 1.0715 | 0.5119 | 0.7433 |
| | | Equation 3 | 0.8535 | 1.2878 | 0.2823 | 1.0614 |
| | | Equation 4 | 0.9109 | 1.2158 | 0.7757 | 0.8920 |
| | | Equation 5 | 0.8329 | 1.3866 | 0.2945 | 1.2025 |
| | | Equation 6 | 0.9377 | 0.9202 | 0.5192 | 0.6282 |

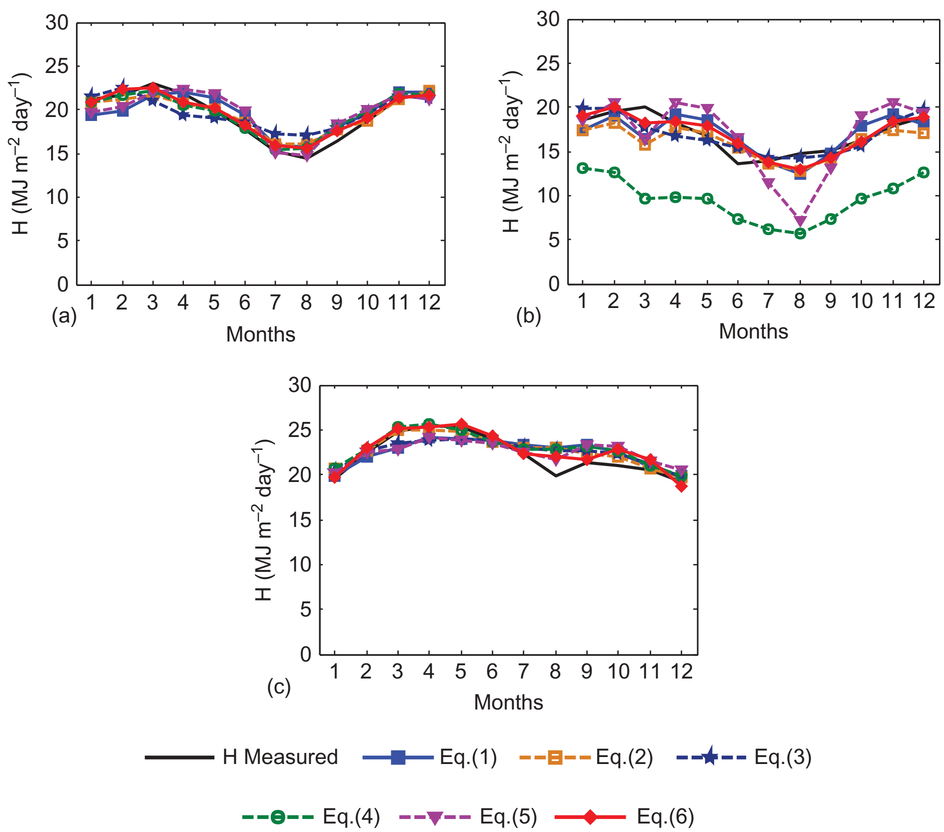


**Figure 3.** Comparison of the measured (22 years) and estimated monthly average daily global solar radiations for study locations: (a) Abuja, (b) Benin City, and (c) Sokoto; in Nigeria.

As noticed, the calculated values of error indices of studied models (shown in Table 4) vary from one place to another. The difference is perhaps due to seasonal variations of the solar radiation caused apparently by the degree of cloud cover, presence of water vapor and Ozone, and atmospheric dust in the atmosphere that differs from one place to another. The highest RMSE values (1.4324, 1.4682, and 7.5463 MJ $m^{-2}$ $day^{-1}$) are produced respectively by Equations (1), (3), and (4) for the northern, central and southern parts of the country (Nigeria), but Equations (6) provides the lowest range (0.6796–1.0854 MJ $m^{-2}$ $day^{-1}$) throughout the studied locations. The MBE values vary between under-estimation and over-estimation. The MBE achieved in this study, except for Equations (4) with considerable under-estimation in the southern region, are in the acceptable range. As mentioned earlier, the climatic conditions change in most parts of Nigeria. Although, small MBE values are desirable, over-estimation of an individual observation may cancel under-estimation in a separate observation. Hence, the test of MABE provides a more reliable error index compared to MBE. According to the MABE index, Equation (6) has the best long-term performance with values in the range 0.5705–0.8160 (MJ $m^{-2}$ $day^{-1}$).

A thorough study of validation results presented in Table 4 shows that the use of single-parameter-based techniques, i.e., Equations (1), (3), and (5), for estimating solar radiations could achieve a considerable degree of accuracy for the different areas in Nigeria. However, the estimation errors tend to increase towards humid sites (southern Nigeria). The hybrid-parameter-based model of Equation (2), which includes relative humidity as additional input parameter, gives a modest improvement on the estimation accuracy of Equation (1). The improvement is perhaps due to the greater range of relative humidity within studied locations. On the other hand, the inclusion of air temperature according to Chen et al. model of Equation (4) has a significant impact on the accuracy of sunshine-based technique of Equation (1). Although, Equation (4) tends to give a modest improvement in the estimation accuracy of Equation (1) for areas with high-temperature difference such Sokoto and Abuja, the error indices are unreasonably large for regions such as Benin City with low-temperature difference. The disparity indicates that temperature-based estimations are more applicable in areas with greater temperature range. The results of Equation (6) shows that the inclusion of cloud cover, to sunshine duration and air temperatures as input parameters, further improves the accuracy of global solar radiation models in Nigeria. It is noteworthy that cloud plays an important role in the transfer of energy between the surface and the atmosphere.

Based on the results presented in Table 4, and Figure 3, Equations (1)–(3) and (6) can be used for estimating the monthly average global solar radiation on a horizontal surface for Nigeria with a high degree of accuracy, but Equation (6) has the overall best mapping accuracy. A comparison of the relative percentage error of the observed and estimated global solar radiations is shown in Figure 4. The systematic deviations of estimates of the southern area (Benin City) for the months March and August, especially, perhaps is as a result of seasonal change (onset and peak of the rainy season, respectively). Moreover, vapor is one of the most important meteorological

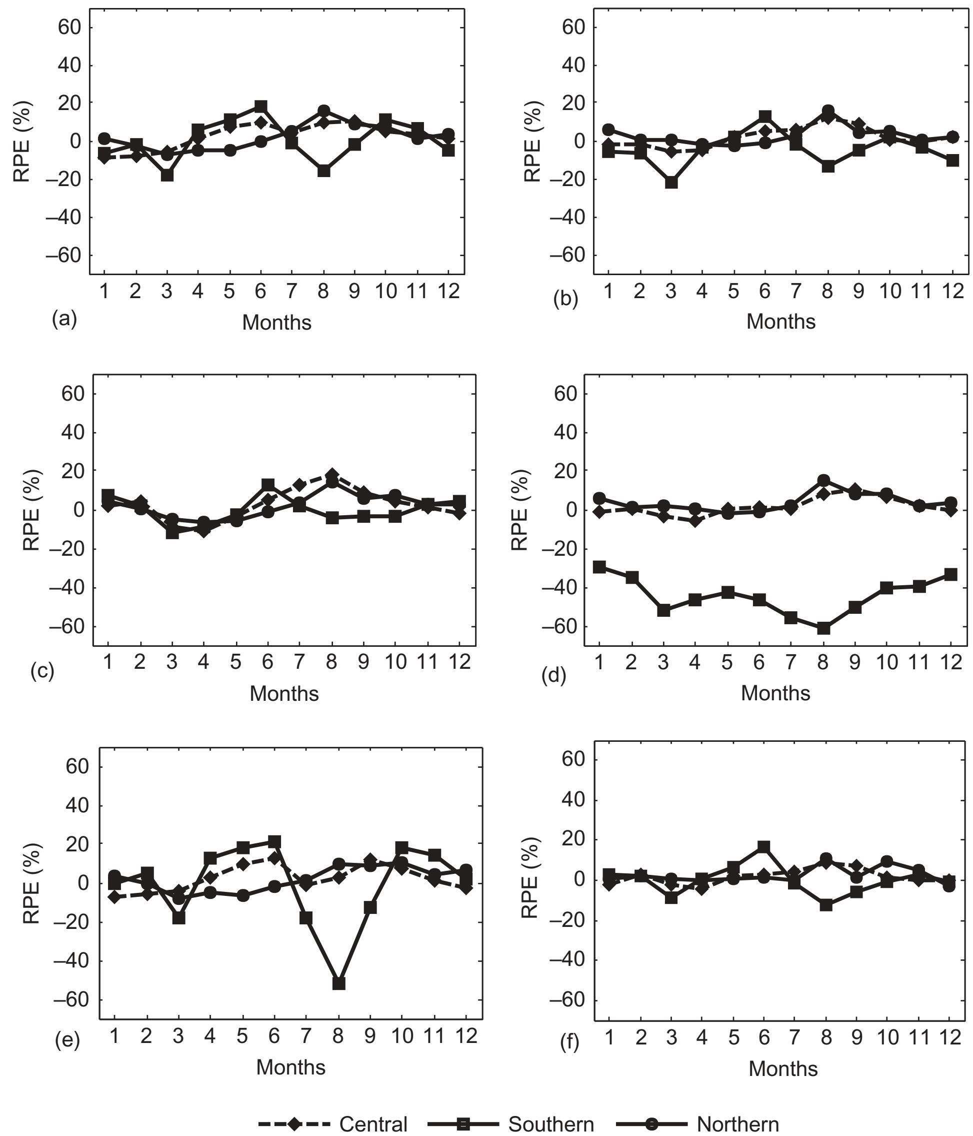


**Figure 4.** Comparison of the monthly relative percentage error of average daily global solar radiations (22 years) for studied models: (a) Angstrom–Prescott (1940), (b) Swartman and Ogunlade (1967), (c) Badescu (1999), (d) Chen et al. (2004), (e) El-Metwally (2005), and (f) Okundamiya (2014); in Nigeria.

factors seriously influencing the transmission of solar radiation (Liu et al. 2012). The relative percentage error for each month produced by Equation (6) rarely exceeds ± 10%, but Equations (1)–(5) fall within ± 20% except for the southern region where Equations (4) and (5) give significant underestimation. The results justify the suggestion made by Muneer and Munawwar (2006) for improving the prediction accuracy of radiation models. This further confirmed the excellent agreement between the measured and predicted global solar radiations produced by Equation (6). This study, therefore, recommends the use of the multivariable regression model defined by Equation (6) for estimating the monthly average daily global solar radiations on a horizontal surface in Nigeria and for other areas with similar climatic conditions.

## Conclusion

This study clearly shows the significance of the calibration and assessment of solar radiation models before application for the design and development of solar systems. Six global solar radiation models, based on commonly measured meteorological parameters such as sunshine, temperature, cloudiness, and relative humidity, were calibrated and assessed for Nigeria. The long-term meteorological data sets utilized for the study were collected for three areas, which spread across the entire climate of Nigeria.

The conclusions drawn from the discussion of results presented in the foregoing section as well as from the experience gained in the course of this study are as follows.

- The estimates of studied models are statistically significant at the 95% confidence level, but their accuracy varies considerably from one location to another.
- The highest under-estimation, observed in the southern part of Nigeria, was produced by the Chen et al. model, with monthly relative percentage error exceeding 60%.
- The error terms of Angstrom and Prescott (1940), Swartman and Ogunlade (1967), Badescu (1999) and

Okundamiya (2014) models are within the acceptable range, and can estimate daily solar radiation with a high degree of accuracy for study sites.

- Okundamiya (2014) model, i.e., Equation (6) has the overall best accuracy with the least RMSE and MABE ($\leq$ 1.0854 and 0.8160 MJ $m^{-2}$ $day^{-1}$ respectively), and least monthly relative percentage error ($< \pm$ 12%) for the entire sites.
- Equation (6) is recommended for estimating the monthly average daily global solar radiations on a horizontal surface in Nigeria and other locations with similar climatic conditions.
- The inclusion of cloud cover as input parameter improves the accuracy of solar radiation models in Nigeria.

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