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Assessment of Five Predictive Models for Solar Radiation in Southwest Nigeria

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Abstract

This study compares the accuracies of five predictive models for estimating solar radiation amongst other meteorological parameters in Southwest Nigeria. Twenty-one years of monthly averages of six measured meteorological parameters obtained from six stations in southwest Nigeria have been subjected to five mathematical models for prediction purposes. Solar radiation and sunshine hours have been modelled using the sum of two-Gaussians, the sum of two-Lorentzians, Fourier on four harmonics, sine wave and fourth-order polynomial functions. The fitting accuracies of these models were tested using performance indicators; mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), standard error (SE) and the correlation coefficient (R). An evaluation of the models showed that the Gaussian and Lorentzian models are in good agreement with the observed data. However, the Fourier on the fourth harmonics model had the lowest MBE, RMSE and MPE, consequently highest correlation coefficient values, indicating high model accuracy. Thus, the Fourier model has the best correlation with the observed data and is recommended for estimating these variables in the selected locations.

Keywords: Annual variation, meteorological variables, energy, performance indicator, statistical test.

1. Introduction

The design, optimisation, and performance evaluation of solar energy systems for a given location require an accurate global solar radiation estimation. An acceptable alternative to global solar radiation surface measurement is using predictive models with meteorological variables as inputs. Evaluation of models coupled with their suitability for a particular location is critical for designing and installing solar energy systems (Okundamiya et al., 2016). Solar radiation is considered dominant in determining the spatial-temporal variations of most meteorological variables. Several empirical models have been developed for the estimation of solar irradiance and other meteorological parameters at the earth?s surface in Nigeria. These models have been developed from records of databases archived by meteorological weather stations in different regions of the country. A majority of these predictive models are based on existing empirical models proposed and developed by individual researchers.

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2. Research Objectives

This study used sum of two-Gaussians, sum of two-Lorentzians, Fourier on fourth harmonic (Fourier FH), sine wave, and 4th order polynomial functions to estimating solar radiation. They were used to estimate the monthly average data points of solar radiation and sunshine hours across six states with monsoon and guinea savanna climates in the Southwest zone of Nigeria. The result is a set of monthly-predicted solar radiation and sunshine hours data as a function of the observed data input. The divergence of the models predictions from the observed data were evaluated using standard error analysis to test the accuracy of the functions. Mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) were used to validate the performance of the models to determine the best fit for the variables.

3. Solar Radiation

A network of solar monitoring stations equipped with pyranometers and data acquisition systems are established at the required locations to collect information on solar radiation (Hussein, 2012). However, solar irradiance data are not readily available in many parts of the world because there are very few weather stations that measure solar irradiance due to the measuring equipment's cost, maintenance, and calibration requirements. Given these shortcomings, different methods have been developed to estimate the solar irradiance on various surfaces using irradiative transfer models (Davies and McKay, 1982), empirical models (Majumdar et al., 1972), and mathematical models (Hussein, 2012). These models use meteorological data of the location under study. Accurate modelling is therefore dependent on the quality and quantity of the measured data used and is suitable for generating data for global solar radiation at locations where measured data are not available. Irradiative transfer models consider the interactions between direct solar irradiance and terrestrial atmosphere. However, these models are challenged by unavailability of some atmospheric parameters needed (Mubiru, 2011). The empirical models use various parameters, which include relative humidity, sunshine hours, sunshine duration, maximum temperature, and water vapour pressure (Rahoma and Hassan, 2007). Conversely, this approach tends to assume linearity in the prediction process. The potential solar radiation is computed based on latitude, slope aspect, topography, and season. Hourly solar radiation values enable the derivation of exact information about the performance of solar energy systems (Gopinathan and Soler, 1995; Gopinathan, 1992).

In Nigeria, solar radiation data have been repeatedly subjected to Angstrom-Prescott, Hargreaves, Garcia, and a host of other models. Some of which are in terms of maximum/minimum temperatures, clearness index, sunshine hour, extra-terrestrial radiation or relative humidity, soil temperature, latitude, elevation (Akinbobola et al., 2018; Okundamiya et al., 2016; Ajayi et al., 2014; Umoh et al., 2014; Kolebaje and Mustapha, 2012; Ogolo, 2010; El-Metwally, 2009; Augustine and Nnabuchi, 2010, 2009; Akpabio et al., 2005; Yang and Koike, 2002; A. and M., 2000; Togrul and Onat, 1999; Ododo and Usman, 1996; Fagbenle, 1993, 1992; Bindi and Miglietta, 1991; Balogun, 1981; Sabbagh et al., 1977). Furthermore, solar radiation has also been estimated in terms of location, solar declination, daily vapour pressure, precipitation, and evaporation (Hussein, 2012; Singh et al., 1996; Sezai and Tasdemiroglu, 1995; Reddy, 1971). Al-Salaymeh (2006) used four mathematical models, namely sine wave, Lorentzian, Gaussian, and fourth-order polynomial degree, to predict global solar radiation accurately. Rahoma and Hassan (2007) estimated probable values of horizontal daily global solar radiation at Helwan, Egypt, using the annual time function obtained from Fourier analysis. Okundamiya and Nzeako (2010) proposed a temperature-based model of the monthly mean of daily global solar radiation on horizontal surfaces for selected cities in Nigeria. Three statistical indicators, namely MBE, RMSE, and t-statistic (TS), validated the excellent performance accuracy of the proposed model by comparing the estimated and observed data. Ogolo and Adeyemi (2009)Ogolo and Adeyemi (2009) showed an annual decreasing trend of meteorological parameters that was not statistically significant, except for rainfall and relative humidity, which were increasing. On the other hand, Mann-Kendall (τ) and Spearman rho statistics showed that the result was statistically significant. Also, the annual variations of the parameter coincide with the north-south movement of the inter-tropical discontinuity (ITD). The movement and fluctuations ITD, which follow the sun, control the solar radiation and rainfall patterns of the location (Dairo and Kolawole, 2018; Ogolo and Adeyemi, 2009; Willoughby et al., 2002).

In particular, solar radiation and evaporation rates have a significant decreasing trend while increasing but lack significant statistical trends for other parameters. Moreover, the yearly data series of temperature and sunshine hour appeared similar to the global warming trends. The International Centre for Theoretical Physics (ICTP) Regional

Climate Model version 3 (RegCM3), with ECHAM5 GCM as the lateral boundary conditions, underestimated the global solar radiation over Nigeria with biases of 10% to 30% from NIMET and NASA observed data (Ohunakin et al., 2015; Ogolo, 2010).

4. Sunshine Hours

Sunshine hours is a climatological indicator measuring the duration of sunshine in a given period, usually a day or a year, for a given location, commonly expressed as an average of several years. The sunshine hours of a location indicate the cloudiness and thus differs from insolation, which measures the total energy obtained from the sun over a given period. The ready availability of sunshine hours data and its ease of measurement, ease of use, and relative reliability have made it the best alternative method of estimating solar radiation (Umoh et al., 2014). In addition, sunshine duration is used to determine the monthly average daily solar radiation on horizontal surfaces, which serves as input in some models to compute solar radiation (Augustine and Nnabuchi, 2009).

5. Methods

5.1. Data Acquisition

Long term averaged data of twenty-one years (1981-2012) from Nigerian Meteorological agency (NIMET) were used for this study. The southwestern states of Nigeria under consideration are shown in Figure 1 with their corresponding cities in Table 1. The average of these parameters were computed and used in the mathematical models.

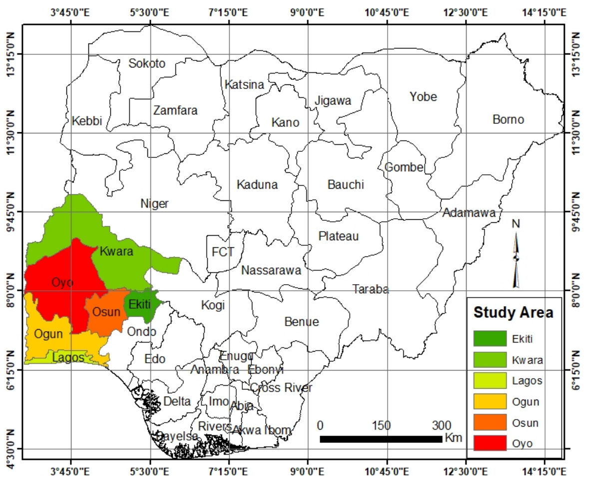

Figure 1. Map of the southwestern states of the study locations.

5.2. Prediction Models

Curve fitting models are mathematical functions that provide the best mathematical description or fit a set of data points. The function returns a set of estimated data based on observed or experimental data. For the model to be appreciably accurate, the deviations from the observed data points must be as minor as possible. A measure of deviation commonly used to test the exactness of the model is the minimum RMSE. To model the variables that appear to be exhibiting periodic variations, four model functions were applied to assess which variables best fit the observed data. Gaussian, Lorentzian, Fourier, sine, and polynomial functions, with their corresponding yield in coefficients, were utilised in this work. Gaussian and Lorentzian non-linear regression functions are the most widely used for fitting bell-shaped curves with peaks, although the Lorentzian has a more expansive 'tail' spread. However, due to the seasonal double maxima exhibited by rainfall, precipitable water, and relative humidity, the sum of two-Gaussians

Table 1. The parameters of study sites.

S/N	Sites	Geo. Coordinates	
		Lat	Lon
1	Abeokuta (Ogun)	7°9′ N	3 °21′ E
2	Ado-Ekiti (Ekiti)	7°37′ N	5 °13′ E
3	Ibadan (Oyo)	7°22′ N	3 °54′ E
4	Ikeja (Lagos)	6°35′ N	3 °20′ E
5	Ilorin (Kwara)	8°30′ N	4 °32′ E
6	Osogbo (Osun)	7°46′ N	4 °34′ E

and sum of two-Lorentzians functions were deemed more suitable for the curve fitting than the usual single Gaussian or Lorentzian distributions. The formalism of the predictive models used for estimating the parameters as a function of time were published by Willoughbya et al. (2019). FindGraph and GraphPad softwares were used as curve fitting and statistical analysis tools, respectively.

6. Results and Discussion

A perusal of the monthly plots, Figures 2 - 3, shows that both variables exhibit two peaks with a dip in mid-year over the annual period. In particular, the trends of irradiance and sunshine hours display a dip mid-year, indicating reduced mean values, usually between June and September.

6.1. Solar Radiation

The regression coefficient of each of the models was obtained for the atmospheric variables. Figures 2 (a)-(f) present the plots of the comparison between the modelled and observed global solar radiation for Abeokuta, Ado-Ekiti, Ibadan, Ikeja, Ilorin and Osogbo, respectively. The global solar radiation exhibits two seasonal variations, maintaining two peaks with the minimum in between them. The observed dip in global solar radiation is due to the high amount of rainfall during the period. This period is also characterised by an increase in the degree of cloudiness, which in effect diminishes the amount of solar radiation reaching the earth's surface. The graphs show that the estimated values of the Gaussian and Lorentzian models correlate reasonably well with the observed global solar radiation data, but the Fourier FH gives a much better prediction. The respective amplitudes, b and g for both former functions show that the height of the two-Lorentzian distribution is about double that of the two-Gaussians. Ikeja, being a coastal region and in the low latitudes exhibits lower values compared to the higher latitudes. The standard deviations, d and k for both functions display the same trend, i.e., two-Lorentzians values doubling those of the two-Gaussians. The sine model estimates the global solar radiation fairly accurately in each of the cities except in Ibadan where its values largely deviate from the observed data. The fourth order polynomial model is in poor agreement with the observed values for each city.

Tables 2 and 3 show the performance indicators of the models for solar radiation in each of the cities. In Abeokuta, the values presented show that Fourier FH has the least MBE, RMSE and MPE (%). It also has the least SE and highest correlation coefficient R of 0.037 and 0.997, respectively. This is followed by sine wave model, which has a correlation coefficient R of 0.816. The fourth order polynomial correlation formula has the highest standard error of 0.234. In Ado-Ekiti, Fourier FH also has the least MBE, RMSE, MPE (%) and the highest correlation coefficient R of 0.99. Sine wave, sum of two-Gaussians and sum of two-Lorentzians models show underestimation in MBE and MPE (%). On the other hand, fourth-order polynomial model shows overestimation in MBE and MPE (%) and has the highest standard error of 0.34. The assessments of the modelled performances in the other cities show that Fourier FH harmonics has the lowest values of MBE, RMSE and MPE (%).

This result indicates that the sum of two-Lorentzians, sum of two-Gaussians, and Fourier on fourth harmonics models give reasonable estimates of global solar radiation in each of the cities. However, the sine wave model gives a pretty good estimate. The polynomial model has the poorest fit for the estimation of this variable.

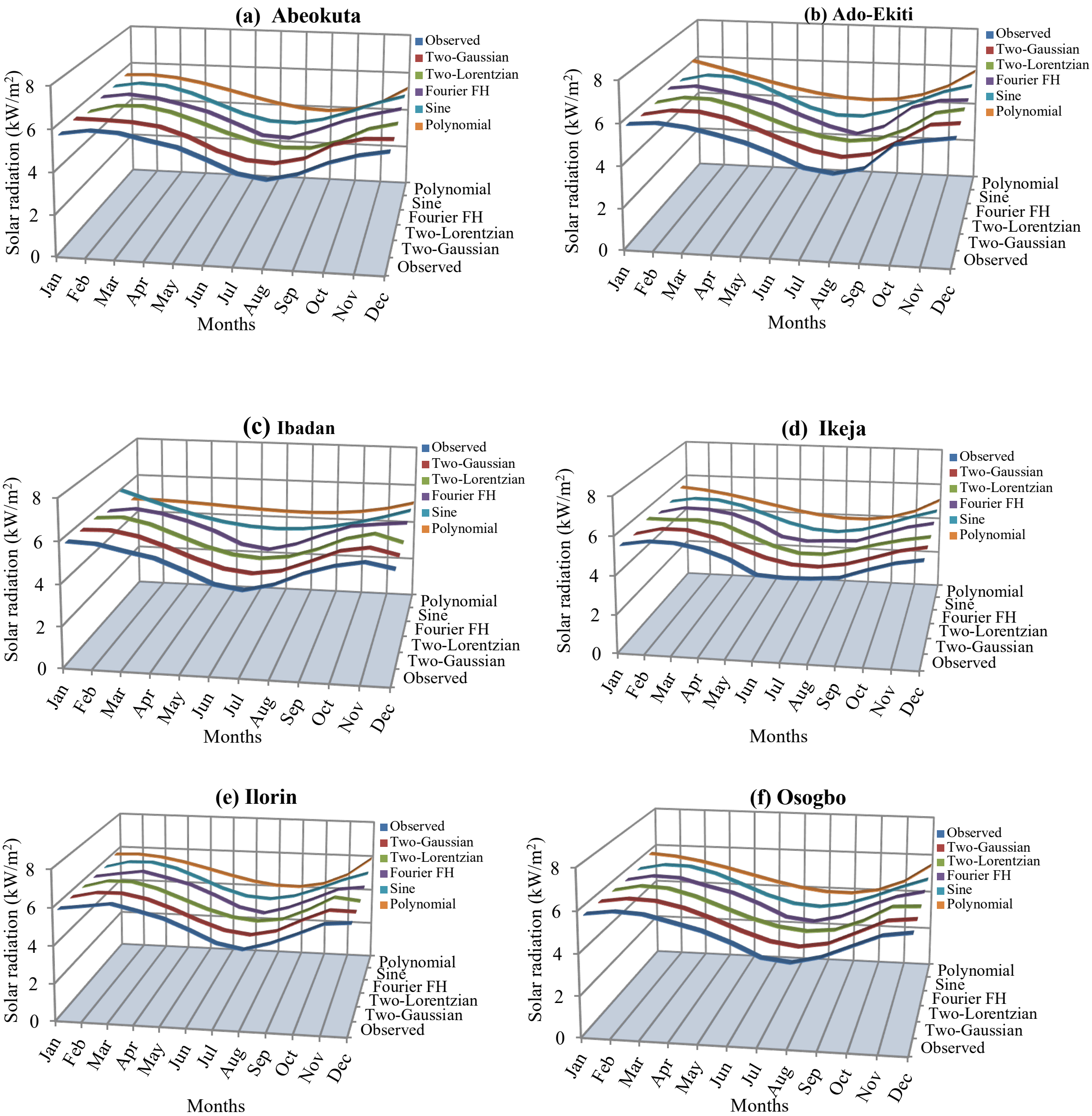

Figure 2. (a)-(f) Observed and modelled solar radiation for the stations

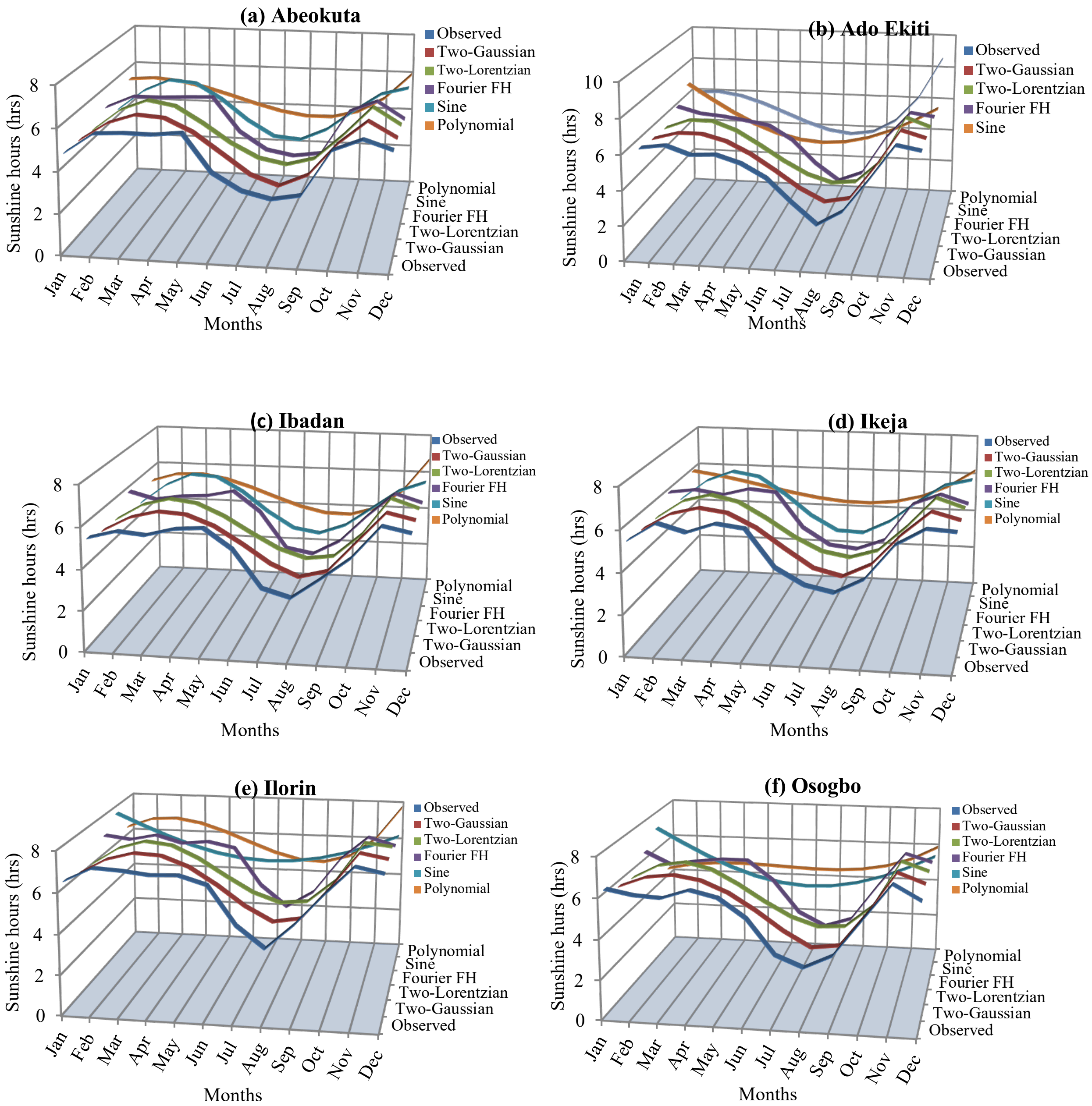

Figure 3. (a)-(f) Observed and modelled sunshine hours for the stations

Table 2. Regression coefficients for solar radiation at all the stations

<table>
<tr><th></th><th></th><th colspan="10">SOLAR RADIATION</th></tr>
<tr><th>Location</th><th>Models</th><th colspan="10">Regression Coefficients</th></tr>
<tr><th></th><th></th><th>a</th><th colspan="2">b</th><th>c</th><th colspan="2">d</th><th>g</th><th colspan="2">h</th><th>k</th></tr>
<tr><td rowspan="6">Abeokuta</td><td>Sum of two Gaussians</td><td>2.79</td><td colspan="2">2.92</td><td>2.53</td><td colspan="2">3.30</td><td>2.50</td><td colspan="2">11.80</td><td>1.93</td></tr>
<tr><td>Sum of two Lorentzians</td><td>0.05</td><td colspan="2">5.45</td><td>2.24</td><td colspan="2">5.71</td><td>3.91</td><td colspan="2">11.82</td><td>2.56</td></tr>
<tr><td>Sine wave</td><td>4.85</td><td colspan="2">0.89</td><td>5.19</td><td colspan="2">5.41</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order Polynomial</td><td>5.43</td><td colspan="2">0.30</td><td>-0.11</td><td colspan="2">0.01</td><td>2E-04</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="2">Fourier on 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>4.87</td><td>0.57</td><td>0.17</td><td>0.88</td><td>0.12</td><td>-0.1</td><td>-0.1</td><td>-0.05</td><td>-0.05</td><td>-0.05</td></tr>
<tr><td rowspan="6">Ado-Ekiti</td><td>Sum of two Gaussians</td><td>3.12</td><td colspan="2">2.68</td><td>2.25</td><td colspan="2">3.14</td><td>2.65</td><td colspan="2">11.44</td><td>1.59</td></tr>
<tr><td>Sum of two Lorentzians</td><td>0.69</td><td colspan="2">5.42</td><td>2.05</td><td colspan="2">5.29</td><td>4</td><td colspan="2">11.58</td><td>2.26</td></tr>
<tr><td>Sine wave</td><td>4.91</td><td colspan="2">-0.95</td><td>4.94</td><td colspan="2">5.08</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order Polynomial</td><td>6.33</td><td colspan="2">-0.28</td><td>-0.02</td><td colspan="2">8E-04</td><td>2E-04</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="2">Fourier on 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>4.97</td><td>0.40</td><td>0.57</td><td>0.87</td><td>0.24</td><td>-0.1</td><td>-.01</td><td>-0.1</td><td>-0.03</td><td>-0.07</td></tr>
<tr><td rowspan="6">Ibadan</td><td>Sum of two Gaussians</td><td>2.86</td><td colspan="2">2.84</td><td>1.62</td><td colspan="2">3.13</td><td>2.49</td><td colspan="2">10.97</td><td>2.06</td></tr>
<tr><td>Sum of two Lorentzians</td><td>0.19</td><td colspan="2">5.19</td><td>1.51</td><td colspan="2">4.83</td><td>4.2</td><td colspan="2">11.22</td><td>3.21</td></tr>
<tr><td>Sine wave</td><td>5.86</td><td colspan="2">1.61</td><td>1.25</td><td colspan="2">11.62</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order polynomial</td><td>4.93</td><td colspan="2">0.06</td><td>-0.03</td><td colspan="2">0.001</td><td>4.97</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="2">Fourier 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>4.83</td><td>0.57</td><td>0.56</td><td>0.62</td><td>-0.04</td><td>-0.18</td><td>-0.05</td><td>0.00</td><td>0.002</td><td>-0.04</td></tr>
<tr><td rowspan="6">Ikeja</td><td>Sum of two Gaussians</td><td>3.51</td><td colspan="2">2.05</td><td>2.39</td><td colspan="2">2.4</td><td>1.66</td><td colspan="2">12.18</td><td>2.18</td></tr>
<tr><td>Sum of two Lorentzians</td><td>5.7</td><td colspan="2">0.53</td><td>3.56</td><td colspan="2">1.4</td><td>1.92</td><td colspan="2">7.29</td><td>3.27</td></tr>
<tr><td>Sine wave</td><td>4.69</td><td colspan="2">-0.80</td><td>4.99</td><td colspan="2">5.44</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order polynomial</td><td>5.57</td><td colspan="2">0.03</td><td>-0.06</td><td colspan="2">0.00</td><td>1E-04</td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">Fourier on 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>4.70</td><td>0.57</td><td>0.25</td><td>0.77</td><td>-0.04</td><td>-0.07</td><td>0.04</td><td>0.03</td><td>-.002</td><td>-.07</td></tr>
<tr><td rowspan="6">Ilorin</td><td>Sum of two Gaussians</td><td>2.79</td><td colspan="2">3.2</td><td>2.69</td><td colspan="2">3.31</td><td>2.75</td><td colspan="2">11.68</td><td>1.83</td></tr>
<tr><td>Sum of two Lorentzians</td><td>0.81</td><td colspan="2">5.03</td><td>2.53</td><td colspan="2">5.04</td><td>3.73</td><td colspan="2">11.66</td><td>2.25</td></tr>
<tr><td>Sine wave</td><td>5.08</td><td colspan="2">-0.94</td><td>5.33</td><td colspan="2">5.22</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order Polynomial</td><td>5.52</td><td colspan="2">0.41</td><td>-0.12</td><td colspan="2">0.01</td><td>2E-04</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="2">Fourier 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>5.11</td><td>0.57</td><td>0.15</td><td>0.93</td><td>0.14</td><td>-.1</td><td>.01</td><td>-.1</td><td>.04</td><td>.02</td></tr>
<tr><td rowspan="6">Osogbo</td><td>Sum of two Gaussians</td><td>2.53</td><td colspan="2">3.22</td><td>2.28</td><td colspan="2">3.56</td><td>2.77</td><td colspan="2">11.79</td><td>1.89</td></tr>
<tr><td>Sum of two Lorentzians</td><td>0.64</td><td colspan="2">4.96</td><td>2.19</td><td colspan="2">5.29</td><td>3.64</td><td colspan="2">11.71</td><td>2.27</td></tr>
<tr><td>Sine wave</td><td>4.82</td><td colspan="2">-0.96</td><td>5.12</td><td colspan="2">5.45</td><td>-</td><td colspan="2">-</td><td>-</td></tr>
<tr><td>4th order Polynomial</td><td>5.75</td><td colspan="2">0.11</td><td>-0.08</td><td colspan="2">0.00</td><td>2E-04</td><td colspan="2">-</td><td>-</td></tr>
<tr><td rowspan="2">Fourier on 4 Harmonics</td><td>a</td><td>b</td><td>c_1</td><td>c_2</td><td>c_3</td><td>c_4</td><td>d_1</td><td>d_2</td><td>d_3</td><td>d_4</td></tr>
<tr><td>4.84</td><td>0.57</td><td>0.22</td><td>0.93</td><td>0.12</td><td>-.04</td><td>-.04</td><td>-.04</td><td>.03</td><td>-.01</td></tr>
</table>

Table 3. Regression coefficients for sunshine hours at all the stations

SUNSHINE HOURS

Location	Models	Regression Coefficients									
		a	b	c	d	g	h	k			
Abeokuta	Sum of two Gaussians	0.09	5.81	3.32	3.18	5.69	11.23	1.57			
	Sum of two Lorentzians	1.49	7.11	3.09	4.11	6.17	6.17	11.3			
	Sine wave	4.49	-1.48	5.5	4.32	-	-	-			
	4th order polynomial	4.98	0.52	-0.16	0.007	3E-04	-	-			
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		4.8	0.57	0.32	1.3	0.59	-0.5	0.11	-0.14	0.11	-0.4
Ado-Ekiti	Sum of two Gaussians	-0.77	7.1	2.52	4.32	7.16	11.5	1.4			
	Sum of two Lorentzians	-2.56	8.77	2.41	5.58	7.7	11.48	1.5			
	Sine wave	2.26	4.61	0.99	11.02						
	4th order polynomial	5.72	0.61	-0.2	0.007	6E-04					
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		5.0	0.57	0.56	1.7	0.9	-0.04	0.15	-0.2	0.06	-0.04
Ibadan	Sum of two Gaussians	0.99	6.98	3.28	3.98	6.67	11.55	1.62			
	Sum of two Lorentzians	4.53	10.17	2.99	6.01	7.87	11.52	1.94			
	Sine wave	4.79	-1.48	5.59	4.42	-	-	-			
	4th order Polynomial	4.41	1.08	0.25	0.009	4E-04	-	-			
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		4.9	0.57	0.26	1.3	0.8	-0.3	-0.04	-0.01	0.2	0.02
Ikeja	Sum of two Gaussians	0.35	6.62	3.15	3.52	6.54	11.45	1.81			
	Sum of two Lorentzians	2.36	8.71	2.87	4.93	7.45	11.47	2.25			
	Sine wave	4.94	-1.52	5.39	4.36	-	-	-			
	4th order Polynomial	5.96	-0.06	-0.06	0.004	8.63	-	-			
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		5.1	.57	.46	1.3	.58	-.46	.05	.00	.01	-.3
Ilorin	Sum of two Gaussians	0.55	7.75	3.23	4.16	7.26	11.5	1.55			
	Sum of two Lorentzians	2.82	9.69	2.96	5.67	7.8	11.49	1.89			
	Sine wave	7.6	-2.28	0.92	12.23	-	-	-			
	4th order Polynomial	5.56	1.15	-0.27	0.01	0.004	-	-			
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		6.1	0.57	0.32	1.4	0.87	-0.22	-.006	-0.31	0.15	0.05
Osogbo	Sum of two Gaussians	1.71	8.09	2.81	4.62	7.38	11.42	1.42			
	Sum of two Lorentzians	1.74	7.99	2.71	5.24	6.98	11.38	1.52			
	Sine wave	7.13	-2.86	0.92	12.38	-	-	-			
	4th order Polynomial	3.98	0.5	-0.09	0.004	1E-04	-	-			
	Fourier on 4 Harmonics	a	b	c_1	c_2	c_3	c_4	d_1	d_2	d_3	d_4
		5.2	0.57	0.42	1.5	0.9	-0.29	0.16	-0.05	0.15	-0.03

6.2. Sunshine Hours

The sunshine hours (or sunshine duration) variation curve is represented in Figures 3(a)-(f) for each location. Sunshine hours variation curve has a similar curve with the global solar radiation data in which there are two peaks. Both peaks are observed during the dry season, which is characterised by minimum cloud cover. The first peak lasts between January and May. Then there is a reduction in the sunshine hours, after which the curve rises gradually and hits a second peak between November and December. The Fourier FH, two-Gaussians and two-Lorentzians models exhibit good correlations with the observed data for the sunshine hours data. Sine model exhibits a poor correlation in Ilorin and Osogbo. The polynomial model gives the poorest fit as observed in each of the figures. The computed performance indicators for the models used to estimate sunshine hours for the locations are presented in Table 6. It is observed that polynomial model has the highest SE values in each city, varying between 0.67 in Ibadan and 1.26 in Osogbo. This is a validation of the inaccuracy of this model in predicting sunshine hours as discussed earlier. Fourier FH has the lowest SE values in each city, ranging from 0.12 in Osogbo to 0.23 in Ibadan, Ikeja and Ilorin. It also has the highest R value in each of the cities, indicating a good correlation with the observed data. The two-Gaussians and two-Lorentzians models have the highest RMSE in the estimation of sunshine hours in Abeokuta, Ibadan, and Osogbo. In Ikeja and Ilorin, the sine model gives the highest RMSE value, indicating low accuracy in estimating sunshine hours in those cities.

6.3. Statistical Test Results

The performance of each model was assessed statistically by computing the mean bias error (MBE), root mean square (RMSE) and mean percentage error (MPE). The standard error (SE) for each model is also presented. For accurate estimation, low values of MBE, RMSE, MPE, SE values, and a correlation coefficient R-value close to 1 are desirable. Table 4 presents the performance indicators of the models for solar radiation in each location. It is observed that for Abeokuta, Fourier FH has the lowest MBE, RMSE and MPE (%). Similarly, Fourier FH has the lowest standard error SE and highest correlation coefficient R of 0.04 and 1.00, respectively, for Abeokuta. This is followed by the sine wave model, which has SE and R of 0.11 and 0.82, respectively. The fourth-order polynomial correlation formula has the highest SE and lowest R of 0.23 and 0.07, respectively. Generally, Fourier FH has the lowest MBE, RMSE and MPE (%) for all the locations, which indicate the best fit with the observed data. In addition, Fourier FH has the lowest SE across all the locations except Ibadan. The statistical results are presented in Tables 2 - 4, showing a summary of the performance indicators for the models of global solar radiation and sunshine hours in each state. Figures 2 and 3 show that the estimated values of the models exhibit a good variation trend along with the observed data except for the fourth-order polynomial model, which shows a flawed agreement with the observed values. Table 4 summarises the results of the statistical indicators for the performance level of each of the models for solar radiation and sunshine hours in the selected locations. The Fourier model gives an excellent correlation for each location shown in Figures 2-3, except in January and December. The other models do not fit the observed data well; particularly, the sine and polynomial models exhibit the poorest curve.

Table 4. Statistical tests for solar radiation and sunshine hours at all the stations

		RADIATION					SUNSHINE HOURS				
Location	Models	MBE	RMSE	MPE (%)	SE	R	MBE	RMSE	MPE (%)	SE	R
Abeokuta	Sum of two Gaussians	-0.47	1.62	-0.80	0.10	0.07	-0.82	2.82	-1.44	0.25	0.00
	Sum of two Lorentzians	-0.47	1.62	-0.80	0.07	0.07	-0.82	2.82	-1.44	0.35	0.00
	Fourier on four harmonics	0.00	0.00	0.00	0.04	1.00	0.00	0.00	0.00	0.17	0.99
	Sine wave	-0.29	1.02	-0.50	0.11	0.82	-0.61	2.12	-1.09	0.39	0.22
	4th order Polynomial	0.00	0.00	0.00	0.23	0.07	-0.01	0.03	-0.02	0.76	0.22
Ado-Ekiti	Sum of two Gaussians	-0.49	1.68	-0.81	0.12	0.09	0.00	0.20	1.00	0.23	0.22
	Sum of two Lorentzians	-0.49	1.68	-0.81	0.17	0.09	0.00	1.40	0.20	0.37	0.96
	Fourier on four harmonics	0.00	0.00	0.00	0.05	0.99	0.00	0.20	0.20	0.18	0.99
	Sine wave	-0.27	0.92	-0.44	0.18	0.79	0.00	0.90	6.00	0.11	0.85
	4th order Polynomial	0.00	0.00	0.00	0.34	0.15	0.30	0.90	10.00	0.95	0.52
Ibadan	Sum of two Gaussians	-0.49	34.29	-0.83	0.07	0.20	-0.44	1.54	-0.74	0.32	0.01
	Sum of two Lorentzians	-0.49	34.29	-0.83	0.10	0.20	-0.44	1.54	-0.74	0.39	0.01
	Fourier on four harmonics	0.00	0.00	0.00	0.13	0.96	0.00	0.00	0.00	0.23	0.98
	Sine wave	-0.32	1.11	-0.55	0.29	0.89	-0.39	1.34	-0.65	0.46	0.09
	4th order Polynomial	-0.06	0.19	-0.09	0.49	0.04	-0.01	0.02	-0.01	0.67	0.47
Ikeja	Sum of two Gaussians	-0.48	1.64	-0.85	0.07	0.09	-0.45	1.56	-0.72	0.26	0.00
	Sum of two Lorentzians	-0.48	1.64	-0.85	0.09	0.09	-0.45	1.56	-0.72	0.34	0.00
	Fourier on four harmonics	0.00	0.00	0.00	0.01	0.99	0.00	0.00	0.00	0.23	0.96
	Sine	-0.31	0.44	-0.55	0.09	0.84	-0.72	2.49	-1.15	0.35	0.11
	4th order Polynomial	0.00	0.48	0.01	0.23	0.30	0.01	0.02	0.01	0.78	0.03
Ilorin	Sum of two Gaussians	-0.48	1.66	-0.77	0.06	0.04	-0.54	1.87	-0.73	0.33	0.00
	Sum of two Lorentzians	-0.48	1.66	-0.77	0.10	0.04	-0.54	1.87	-0.73	0.43	0.00
	Fourier on four harmonics	0.00	0.00	0.00	0.02	0.99	0.00	0.00	0.00	0.23	0.99
	Sine wave	-0.33	1.13	-0.53	0.12	0.83	-0.83	2.88	-1.13	0.97	0.01
	4th order Polynomial	0.01	0.02	0.01	0.28	0.18	-0.01	0.02	-0.01	0.73	0.16
Osogbo	Sum of two Gaussians	-0.47	1.64	-0.81	0.05	0.08	-0.53	1.82	-0.83	0.31	0.05
	Sum of two Lorentzians	-0.47	1.64	-0.81	0.09	0.08	-0.53	1.82	-0.83	0.44	0.05
	Fourier on four harmonics	0.00	0.00	0.00	0.04	0.99	0.00	0.00	0.00	0.12	0.99
	Sine wave	-0.37	1.29	-0.64	0.10	0.49	-0.48	1.68	-0.77	0.97	0.14
	4th order Polynomial	0.01	0.02	0.01	0.25	0.11	0.15	0.52	0.24	1.26	0.18

7. Conclusion

This study used five mathematical models to estimate the daily global solar radiation and sunshine hours of some cities in the southwest of Nigeria. The values of the modelled data were compared with the values of the observed data. The accuracies of the models were evaluated using the performance indicators: mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE), correlation coefficient R and standard error (SE). Generally, from the results of the performance indicators and the comparison between the observed and modelled data, it was observed that for most of the atmospheric variables at the selected locations, the polynomial model estimates exhibited the poorest correlations with the observed data. The sine model displayed reasonably good correlations in estimating global solar radiation and sunshine hours. This observation implies that the polynomial model is not suitable for predicting the atmospheric variables in the selected locations. The two-Gaussians and two-Lorentzians models demonstrated better correlation with some of the variables than the duo of sine and polynomial models and, thus, may be considered for estimating the atmospheric variables. However, the Fourier model possessed the least values of the errors when compared with the other models. Also, the Fourier model offered the highest correlation coefficient values, R, in each of the cities, ranging from 0.96 to 1, indicating high accuracy in the estimated data. Thus, from the summary of the results, the Fourier model is recommended as the most suitable model for estimating the daily global solar radiation and sunshine hours in the selected locations.

References

A., T.A., M., S.M.A., 2000. Correlation of global solar radiation with meteorological parameters over egypt. Renewable Energy 21, 297–308.

Ajayi, O.O., Ohijeagbon, O.D., Nwadialo, C.E., Olasope, O., 2014. New model to estimate daily global solar radiation over Nigeria. Sustainable Energy Technologies and Assessments 5, 28–36.

Akinbobola, A., Okogbue, E.C., Ayansola, A.K., 2018. Statistical Modelling of Monthly Rainfall in Selected Stations in Forest and Savannah Eco-climatic Regions of Nigeria. J. Climatol. Weather Forecasting 6, 226. doi:https://doi.org/10.4172/2332-2594.1000226.

Akpabio, L.E., Udo, S.O., Etuk, S.E., 2005. Modeling Global Solar Radiation for a Tropical Location: Onne, Nigeria. Turkish Journal of Physics 29, 63–68.

Al-Salaymeh, A., 2006. Modelling of global daily solar radiation on horizontal surfaces for Amman city. Emirates Journal for Engineering Research 11, 49–56.

Augustine, C., Nnabuchi, M.N., 2009. Relationship between global solar radiation and sunshine hours for Calabar, Port Harcourt and Enugu, Nigeria. International Journal of Physical Sciences 4, 182–188.

Augustine, C., Nnabuchi, M.N., 2010. Analysis of some meteorological data for some selected Cities in the Eastern and Southern zone of Nigeria. Afr J. Environ Sci. Technol 4, 92–99.

Balogun, E.E., 1981. Seasonal and spatial variations in thunderstorm activity over Nigeria. Weather 36, 192–197.

Bindi, M., Miglietta, F., 1991. Estimating daily global radiation from air temperature and rainfall measurements. Climate Research 1, 117–124.

Dairo, O.F., Kolawole, L.B., 2018. Radio refractivity gradients in the lowest 100 m of the atmosphere over Lagos, Nigeria in the rainy-harmattan transition phase. Journal of Atmospheric and Solar-Terrestrial Physics 167, 169 – 176. doi:https://doi.org/10.1016/j.jastp.2017.12.001.

Davies, J.A., McKay, D.C., 1982. Estimating solar irradiance and components. Solar Energy 29, 55–64.

El-Metwally, M., 2009. Sunshine and global solar radiation estimation at different sites in Egypt. J Atmos Solar Terr. Phys. 67, 1331–1342.

Fagbenle, R.O., 1992. A comparative study of some simple models for global solar irradiation in Ibadan, Nigeria. Int. J. Energy Res. 16, 583–595.

Fagbenle, R.O., 1993. Total solar radiation estimates in nigeria using a maximum likelihood quadratic fit. Renewable Energy 3, 813–817.

Gopinathan, K.K., 1992. Solar Sky Radiation Estimation Techniques. Solar Energy 49, 9–11.

Gopinathan, K.K., Soler, A., 1995. Diffuse Radiation Models and Monthly-Average, Daily, Diffuse Data For A Wide Latitude Range. Energy 20, 657–667.

Hussein, T.A.T., 2012. Estimation of Hourly Global Solar Radiation in Egypt Using Mathematical Model. Int. J. Latest Trends Agr. Food Sci. 2, 74–82.

Kolebaje, O.T., Mustapha, L.O., 2012. On the performance of some predictive models for global solar radiation estimate in tropical stations: Port Harcourt and Lokoja. The African Review of Physics 7, 145–163.

Majumdar, N.C., Marthur, B.L., Kaushik, S.B., 1972. Prediction of direct solar radiation for low atmospheric turbidity. Solar Energy 13, 383–394.

Mubiru, J., 2011. Using artificial neural networks to predict direct solar irradiation. Hindawi Publishing Corporation, Advances in Artificial Neural Systems 2011 Art. ID 142054.

Ododo, J.C., Usman, A., 1996. Correlation of total solar radiation with common meteorological parameters for Yola and Calabar, Nigeria. Energy Conversion Management 37, 521–30.

Ogolo, E., 2010. Evaluating the performance of some predictive models for estimating global solar radiation across varying climatic conditions in nigeria. Indian Jour. of Radio and Space Physics 39, 121–131.

Ogolo, E., Adeyemi, B., 2009. Variations and Trends of Some Meteorological Parameters at Ibadan, Nigeria. The Pacific Journal of Science and Technology 10, 981–987.

Ohunakin, O.S., Adaramola, M.S., Oyewola, O.M., Matthew, O.J., Fagbenle, R., 2015. The Effect of Climate change on solar radiation in Nigeria. Solar Energy 116, 272–286.

Okundamiya, M., Nzeako, A., 2010. Empirical Model for Estimating Global Solar Radiation on Horizontal Surfaces for Selected Cities in the Six Geopolitical Zones in Nigeria. Research Journal of Applied Sciences, Engineering and Technology 2, 805–812.

Okundamiya, M.S., Emagbetere, J.O., Ogunjor, E.A., 2016. Evaluation of various global solar radiation models for Nigeria. Int. Journal of Green Energy 13, 505–512.

Rahoma, U.A., Hassan, A.H., 2007. Fourier transforms Investigation of Global Solar Radiation at True Noon: in the Desert climatology. American Journal of Applied Sciences 4, 902–907.

Reddy, S., 1971. An empirical method for estimation of the total solar radiation. Solar Energy 13, 289–291.

Sabbagh, J.A., Sayigh, A.A., El-Salam, M.A., 1977. Estimation of the total solar radiation from meteorological data. Solar Energy 19, 307–11.

Sezai, I., Tasdemiroglu, E., 1995. Evaluation of the meteorological data in northern Cyprus. Energy Conversion Management 36, 953–961.

Singh, O.P., Srivastava, S., Gaur, A., 1996. Empirical relationship to estimate global radiation from hours of sunshine. Energy Conversion Management 37.

Togrul, I.T., Onat, E.A., 1999. Study for estimating solar radiation in Elazig using geographical and meteorological data. Energy Conversion Management 40, 1577–84.

Umoh, M.D., Udo, S.O., Udoakah, Y.N., 2014. Estimating global radiation on a horizontal surface from sunshine hours over Port Harcourt, Nigeria. Journal of electrical and electronics engineering research 6, 1–5.

Willoughby, A.A., Aro, T.O., Owolabi, I.E., 2002. Seasonal variations of radio refractivity gradients in Nigeria. Journal of Atmospheric and Solar-Terrestrial Physics 64, 417–425.

Willoughbya, A.A., Ndubuisi, A.O., Dairo, O.F., Aizebeokhai, P.A., Oludotun, J.O., 2019. Performance analysis of temperature models for environmental monitoring in southwest nigeria. Nigerian Journal of Environment and Health 2, 20–29.

Yang, K., Koike, T., 2002. Estimating solar radiation from upper-air humidity. Solar Energy 72, 177–186.