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Assessing the Performance of Global Solar Radiation Empirical Models at a Sahelian Site, Sokoto, Nigeria

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Abstract

In the region where solar radiation data are scarce, the next alternative method is to use solar radiation models to estimate the data needed for some applications such as simulation of crop performance and the design of solar energy conversion devices. In this paper, the validations of fifteen models for estimating monthly mean daily global solar radiation on the horizontal surfaces were conducted at a location in sahelian region where there is great potential for solar energy utilization in electricity generation and irrigation. Evaluations of these models were carried out by using the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE) and t-test. Three of these statistical performance indicators were combined to generate rank score for each model. Temperature based models made the rank of the best three during the wet season. On the annual scale and in the dry season, temperature variations and humidity were combined with sunshine duration to get the best rank of 1 to 3.

Keywords: Solar radiation, empirical models, climatic parameters, sahel.

1.0 Introduction

Radiant energy transferred from the sun to the earth's surface is called solar radiation. Global solar radiation is the combination of direct beam and the angular or diffuse component of this solar radiation received on a horizontal plane at the earth's surface. Global solar radiation is a very essential source of energy in earth's ecosystem as it provides the energy for photosynthesis in plants, affects both air and soil temperature, influences the rate of evaporation and regulates weather and climate. It is also a very important source of renewable energy. Effective harnessing and utilization of solar radiation is vital to solving the world's energy crisis and climate change problem [1].

Different locations on the earth surface have varying solar energy potentials. An understanding of these variations is therefore very important in choosing solar equipment for socio-economic uses such as irrigation, electricity generation and etc. Analysis of available global solar radiation data from locations of interest is therefore very important. However, such data are often not available. The global ratio of weather stations collecting global solar radiation data relative to those collecting temperature data is about 1:500. The possible reason for such lack could be due to high cost of solar radiation equipment and maintenance [2]. A viable alternative is to parameterize global solar radiation using routine meteorological variables such as relative sunshine hours, cloudiness, humidity and temperature. Models have been developed using this approach by [3-9]. The objective of this study is to assess the annual and seasonal performance of 15 solar radiation empirical formulas in Sokoto, Nigeria, a location in sahelian region where there is great potential for solar energy utilization in electricity generation and irrigation

2.0 Methodology

The assessment is based on the following fifteen empirical formulas that have been used in the literatures for estimation of monthly mean daily global solar radiations.

$$\frac{R_s}{R_o} = a_1 + b_1\left(\frac{n}{N}\right) \quad (1)$$

$$\frac{R_s}{R_o} = a_2 + b_2\left(\frac{T_{max}}{65}\right) \quad (2)$$

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$$\frac{R_s}{R_o} = a_3 + b_3(\theta) \tag{3}$$

$$\frac{R_s}{R_o} = a_4\left(\frac{n}{N}\right)^{b_4} \tag{4}$$

$$\frac{R_s}{R_o} = a_5 \exp\left[b_5\left(\frac{n}{N}\right)\right] \tag{5}$$

$$\frac{R_s}{R_o} = a_6 + b_6\overline{RH} \tag{6}$$

$$\frac{R_s}{R_o} = a_7 + b_7\Delta T^{0.5} \tag{7}$$

$$\frac{R_s}{R_o} = a_8 + b_8\frac{\Delta T}{N} \tag{8}$$

$$\frac{R_s}{R_o} = a_9 + b_9\left(\frac{n}{N}\right) + c_9\left(\frac{n}{N}\right)^2 \tag{9}$$

$$\frac{R_s}{R_o} = a_{10} + b_{10}\left(\frac{n}{N}\right) + c_{10}\log\left(\frac{n}{N}\right) \tag{10}$$

$$\frac{R_s}{R_o} = a_{11} + b_{11}\left(\frac{n}{N}\right) + c_{11}\left(\frac{T_{max}}{65}\right) \tag{11}$$

$$\frac{R_s}{R_o} = a_{12} + b_{12}\left(\frac{n}{N}\right) + c_{12}\overline{RH} \tag{12}$$

$$\frac{R_s}{R_o} = a_{13} + b_{13}\left(\frac{n}{N}\right) + c_{13}(\theta) \tag{13}$$

$$\frac{R_s}{R_o} = a_{14} + b_{14}\left(\frac{n}{N}\right) + c_{14}\left(\frac{n}{N}\right)^2 + d_{14}\left(\frac{n}{N}\right)^3 \tag{14}$$

$$\frac{R_s}{R_o} = a_{15} + b_{15}\left(\frac{n}{N}\right) + c_{15}(\theta) + d_{15}\overline{RH} \tag{15}$$

Where R_s is the global solar radiation in $MJm^{-2}day^{-1}$, R_o is the Extraterrestrial radiation in $MJm^{-2}day^{-1}$, n is the Sunshine duration in hours, N is the daylight hour in hours, T_{max} is the maximum temperature, ΔT is the difference between maximum temperature and minimum temperature values, $\overline{RH}$ is the relative humidity and θ is the ratio of minimum temperature to maximum temperature. a_i, b_i, c_i and d_i for $i = 1,2,3,\ldots,15$ are constants which are to be determined by regression analysis.

The Angstrom[3] correlation and the modified form [4] known as the Angstrom-Prescott model ((Equation (1)) has served as a basic approach to estimate global solar radiation for a long time. A quadratic and cubic form of Equation (1) known as the second order Angstrom-Prescott model Equation (9) and the third-order Angstrom Prescott model Equation (14) respectively were proposed [9-12].

Togrul and Togrul [13] used Equation (4) to estimate monthly mean of global solar radiation in Turkey. Elagib and Mansell [14] used Equation (5) to estimate global solar radiation in Sudan. The comparison of measured and estimated values using this model showed a mean absolute percentage error below 4.9%. Equation (10) was formulated and tested using data from Macau, on the southern coast of China by [15].

Mubiru et al.[16] formulated equations (2) and (11) based on the assumption of a strong relationship between global solar radiation and maximum temperature when used as a single parameter or in combination with sunshine duration. Equations (6) and (12) were developed to investigate the relationship between solar radiation and relative humidity [16].

Hargreaves and Samani[5] regressed global solar radiation with the square root of the difference between maximum and minimum temperature to develope Equation (7). Garcia [7] formulated equation (8) as an adaptation of Equation (1) to estimate global solar radiation in Peru. Equations (3) and (13) simply combine relative sunshine duration and the ratio of the minimum to maximum air temperature. Equation (15) is a linear combination of relative sunshine duration, the ratio of the minimum to maximum air temperature, and relative humidity.

3.0 Study Area and Data Measurements

The study site is located in Sokoto, Nigeria. Sokoto is a city located in the extreme northwest of Nigeria, near to the confluence of the Sokoto River and the Rima River.Sokoto is in the dry Sahel region surrounded by sandy savannah and isolated hills. With an annual average temperature of 28.3 °C (82.9 °F), Sokoto is one of the hottest cities in the world, however the maximum daytime temperatures are most of the year generally under 40 °C (104.0 °F), and the dryness makes the heat bearable. The warmest months are February to April, where daytime temperatures can exceed 45 °C (113.0 °F).

Rainfall starts late and ends early with mean annual falls ranging between 500 mm to 1,300 mm. The showers rarely last long and are a far cry from the regular torrential showers known in many tropical regions. The humidity is generally high and the Harmattan (hot, dry northeast trade wind), a cold and fairly dusty wind is experienced between November and February. There are two major seasons in Sokoto namely the wet and dry seasons. The rainy season is from June to October while the dry season is from November to May.

The data used in this study was collected from the Nigerian Metrological Agency (NIMET), Oshodi, Lagos which has been given the mandate to collect meteorological data for climatology, agricultural and aviation purposes in the country. At the site used in this study, global solar radiation was measured by using Gunn Bellani radiometer (GB) which is a simple, cheap and easy to maintain instrument commonly used for solar radiation estimation and evaporation studies. The instrument provides a time-integrated assessment of radiation falling on a black body by measuring the volume of liquid distilled by the radiation. It does not require power or any special skill to operate and is ideal for field estimation of daily total radiation. Periodically, or at the end of each day, radiation level is recorded. Folayan [17] calibrated GB readings with pyranometer readings and came up with a conversion factor which may be mathematically expressed as:

$$1ml_{GB} = 1.357(\pm 0.176)MJm^{-2} \quad (16)$$

The maximum and minimum thermometers were used to measure the highest and lowest temperature reached by air in each day at the observatory. These thermometers were kept at a height of 1.5 meters above the ground in a white wooden louvered shelter called Stevenson screen. Maximum and minimum thermometers are liquid in glass thermometers used for determining daily maximum and minimum temperatures. Sunshine hour was measured using the Campbell-stokes sunshine recorder. The device is designed to record the hours of bright sunshine which will burn a hole through the card.

18 years of monthly mean hourly solar radiation, sunshine hour, minimum and maximum temperature, relative humidity data were collected and used in this study. 15 years of data (1981-1995) was used for obtaining the regression coefficients a_i, b_i, c_i and d_i for $i = 1,2,3,\ldots,15$ while 3 years (1996-1998) was used for testing the performance of the models.

The site specific inputs for the calculation of extraterrestrial solar radiation (R_o) are latitude(φ) and sunset hour angle(ω_s). The extraterrestrial daily solar radiation (in $MJm^{-2}day^{-1}$) is determined by the sets of equations given below [18].

$$R_o = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_s] \quad (17)$$

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi J}{365}\right) \quad (18)$$

$$\delta = 0.409 \sin\left(\frac{2\pi J}{365} - 1.39\right) \quad (19)$$

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \quad (20)$$

Where R_o is the extraterrestrial radiation ($MJm^{-2}d^{-1}$), G_{sc}, solar constant = 0.082 $MJm^{-2}d^{-1}$, d_r is the inverse relative distance Earth-Sun, δ is the solar declination (radians), J is the Number of the day in the year between 1(1 January) and 365 or 366 (31 December).

The daylight hours N (hours) is also calculated using the equation given below [18]

$$N = \frac{24}{\pi}\omega_s \quad (21)$$

The extraterrestrial radiation and daylight hours for stations used in this research were calculated and are shown in the table below.

4.0 Error Analysis

In this study, the performance indicators used are the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE) and the *t*-statistic test:

$$\mathrm{MBE} = \left[\textstyle\sum_1^n (R_{est} - R_{obs})\right]/n \quad (22)$$

$$\mathrm{RMSE} = \left[\textstyle\sum_1^n (R_{est} - R_{obs})^2/n\right]^{1/2} \quad (23)$$

$$\mathrm{MPE} = \left[\sum_1^n \left(\frac{R_{obs} - R_{est}}{R_{obs}} \times 100\right)\right]/n \quad (24)$$

Where R_{obs} and R_{est} are respectively the observed and estimated values of global solar radiation and n is the number of observations used. Generally, the lower the MBE, RMSE and MPE, the better the model.A positive MBE or MPE value indicates overestimation in calculated values, while a negative MBE or MPE value indicate underestimation. The MBE provides information about the long-term performance of the model while the RMSE provides information about the short-term performance of the model.

Low values of RMSE are desirable, but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable, but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE values at the same time a small MBE or vice versa. Therefore, the use of RMSE and MBE as indicators is not adequate for the evaluation of model performance [19].

The t-statistic is used in conjunction with the MBE and RMSE in order to test model performance more reliably [20]. The *t*-statistic is given by

$$t = \sqrt{\left((\mathrm{N}-1)\mathrm{MBE}^2\right)/(\mathrm{RMSE}^2 - \mathrm{MBE}^2)} \quad (25)$$

The estimates from the model will only be statistically significant if the calculated *t* is less than a critical *t*-value obtained from standard statistical tables.

The best performing models were determined using a ranking method. The MBE and RMSE were normalized by dividing each by the mean of the measured dataset. A rank score was obtained for each model. The model with the lowest rank score received the high estranking.

$$\text{RankScore} = \frac{\text{Abs(MBE)}}{\text{Mean}} + \frac{\text{RMSE}}{\text{Mean}} + t \tag{26}$$

Table 1: Extraterrestrial radiation and Daylight hours for Sokoto.

MONTH	EXTRATERRESTRIAL RADIATION ($MJm^{-2}day^{-1}$)	DAYLIGHT HOURS (hour)
JANUARY	30.5472	11.3259
FEBRUARY	33.3608	11.5822
MARCH	36.3080	11.9290
APRIL	37.9904	12.3000
MAY	38.1575	12.6065
JUNE	37.8492	12.7559
JULY	37.8501	12.6832
AUGUST	37.8023	12.4171
SEPTEMBER	36.6553	12.0587
OCTOBER	34.0240	11.6886
NOVEMBER	31.0298	11.3852
DECEMBER	29.5174	11.2435

Table 2: Regression coefficients.

Equation (	R	a_i	b_i	c_i	d_i
1	0.333	0.535	0.185	-	-
2	0.602	0.448	0.375	-	-
3	0.824	1.046	-0.617	-	-
4	0.747	0.682	0.104	-	-
5	0.787	0.535	0.303	-	-
6	0.744	0.750	-0.002	-	-
7	0.832	0.195	0.129	-	-
8	0.828	0.440	0.198	-	-
9	0.620	0.623	-0.219	0.395	-
10	0.837	0.317	0.443	-0.249	-
11	0.786	0.320	0.189	0.392	-
12	0.775	0.683	0.094	-0.002	-
13	0.873	0.953	0.086	-0.554	-
14	0.615	0.511	0.839	-2.026	1.602
15	0.937	0.735	0.087	-0.089	-0.002

Table 3: Regression coefficients for wet season.

Equation (	R	a_i	b_i	c_i	d_i
1	0.716	0.451	0.245	-	-
2	0.808	-0.092	1.310	-	-
3	0.841	1.249	-0.933	-	-
4	0.713	0.637	0.125	-	-
5	0.781	0.461	0.423	-	-
6	0.776	0.834	-0.004	-	-
7	0.781	0.142	0.142	-	-
8	0.882	0.377	0.261	-	-
9	0.875	0.552	-0.315	0.616	-
10	0.598	0.010	0.790	-0.459	-
11	0.872	-0.067	0.174	1.067	-
12	0.868	0.690	0.162	-0.003	-
13	0.915	0.982	0.180	-0.704	-
14	0.811	0.621	-1.049	2.389	-1.228
15	0.971	0.846	0.154	-0.272	-0.002

Table 4: Regression coefficients for dry season.

Equation ([illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	0.860	0.647	0.067	-	-
2	0.878	0.833	-0.256	-	-
3	0.895	0.851	-0.268	-	-
4	0.922	0.700	0.033	-	-
5	0.868	0.647	0.097	-	-
6	0.893	0.730	-0.002	-	-
7	0.879	0.482	0.055	-	-
8	0.895	0.578	0.092	-	-
9	0.853	0.705	-0.177	0.224	-
10	0.860	0.518	0.216	-0.158	-
11	0.906	0.782	0.048	-0.220	-
12	0.955	0.698	0.045	-0.001	-
13	0.902	0.819	0.029	-0.245	-
14	0.867	0.636	0.419	-1.088	0.848
15	0.944	0.780	0.030	-0.142	-0.001

Table 5: Performance test result and ranking of models for Sokoto.

Equation	**PERFORMANCE INDICATORS**				**RankScore**	**Rank**
	MBE	**RMSE**	**MPE (%)**	[illegible]		
1	0.397	2.401	2.485	0.992	1.115	9
2	0.268	2.004	1.576	0.797	0.897	7
3	0.091	1.659	1.063	0.323	0.401	2
4	-0.175	1.557	-0.509	0.668	0.744	4
5	0.178	1.418	1.048	0.749	0.819	5
6	0.452	1.548	2.449	1.808	1.896	15
7	0.170	1.243	1.115	0.815	0.877	6
8	0.147	1.291	1.099	0.677	0.741	3
9	0.375	1.910	2.091	1.184	1.284	12
10	0.224	1.246	1.218	1.081	1.146	10
11	0.246	1.437	1.330	1.026	1.100	8
12	0.300	1.430	1.739	1.271	1.347	13
13	0.231	1.179	1.417	1.185	1.247	11
14	0.391	1.865	2.207	1.267	1.366	14
15	-0.017	0.784	0.103	0.132	0.167	1

Table 6: Performance test result and ranking of models for Sokoto (wet season).

Equation	**PERFORMANCE INDICATORS**				**RankScore**	**Rank**
	MBE	**RMSE**	**MPE (%)**	[illegible]		
1	0.604	1.354	3.198	1.864	1.956	9
2	0.082	1.082	0.531	0.283	0.338	1
3	0.102	1.062	0.842	0.362	0.416	2
4	0.432	1.307	2.431	1.310	1.391	7
5	0.556	1.237	2.957	1.881	1.965	10
6	-0.563	1.236	-2.331	1.915	1.999	11
7	0.218	1.154	1.412	0.720	0.784	4
8	0.148	0.987	1.049	0.569	0.622	3
9	0.718	1.119	3.624	3.135	3.222	15
10	1.112	1.782	5.726	2.990	3.126	14
11	0.319	0.932	1.616	1.365	1.424	8
12	0.246	0.919	1.417	1.041	1.096	6
13	0.520	0.999	2.744	2.280	2.352	12
14	0.798	1.301	4.068	2.905	3.004	13
15	0.103	0.466	0.447	0.848	0.875	5

Table 7: Performance test result and ranking of models for Sokoto (dry season).

Equation	**PERFORMANCE INDICATORS**				**RankScore**	**Rank**
	MBE	**RMSE**	**MPE (%)**	[illegible]		
1	-0.213	1.127	-0.881	0.861	0.917	7
2	-0.269	1.018	-1.080	1.224	1.278	14
3	-0.174	0.921	-0.683	0.862	0.908	6
4	-0.217	0.878	-0.952	1.141	1.187	13
5	-0.259	1.081	-1.066	1.104	1.161	12
6	-0.712	1.145	-2.954	3.548	3.626	15
7	-0.154	1.010	-0.621	0.690	0.739	4
8	-0.108	0.900	-0.396	0.539	0.581	3
9	-0.208	1.098	-0.813	0.863	0.918	8
10	-0.192	1.064	-0.742	0.819	0.872	5
11	-0.190	0.917	-0.795	0.945	0.991	11
12	-0.042	0.582	-0.139	0.320	0.346	1
13	-0.174	0.888	-0.681	0.894	0.939	9
14	-0.208	1.050	-0.826	0.902	0.955	10
15	-0.074	0.668	-0.293	0.501	0.532	2

5.0 Results and Discussion

Table 2 shows regression coefficients a_i, b_i, c_i, d_i and the correlation coefficient R of the model equations (1) - (15) for Sokoto. The equations produced correlation coefficient of over 0.6 except for equation (1) with equation (15) giving the best correlation coefficient of 0.937. Table 3 and 4 show the regression coefficients and the correlation coefficient R of equations (1) - (15) for Sokoto during the wet (June - October) and dry (November - May) seasons respectively.Table 3 shows that all the equation produced good correlation coefficient of over 0.50 during the wet season with the worst and best correlation coefficients of 0.598 and 0.971 observed for equations (10) and (15) respectively. During the dry season, the best correlation coefficient of 0.955 was produced by equation (12). All the equations produced better correlation coefficient during the dry season except for the equations (9), (13) and (15).

Table 5 shows the MBE, RMSE, MPE, *t*-value and rank scores for the 15 equations developed for estimating solar radiation at the study site. Based on the obtained MBE values, all the equations overestimated solar radiation except for equations (4) and (15) which gave negative MBE values. The lowest and highest MBE values of -0.017 and 0.452were obtained for equation(15) and equation (6) respectively. Equation (1) gave the highest RMSE value of 2.401 while equation (15) gave the lowest RMSE of 0.748. All the equations gave MPE values less than 2.5% with the lowest MPE value of 0.103% observed for equation (15). The critical *t*-value at 95% confidence level for the equations in Table 5 is 2.030. All the *t*-values are all less than the critical value of 2.030;therefore the estimates from all the equations are statistically significant. Using the rank scores, the best and worst performance was exhibited by equation (15) and equation (6) respectively. Equation (6) gave the worst performance while equations (3), (8) and (15) are recommended for estimating solar radiation in Sokoto with equation (15) giving the best performance.

For the wet season, equation (2) gave the lowest MBE value of 0.082 while equation (10) gave the highest MBE value of 1.112. Except for equation (6) with a negative MBE of -0.563 all the equations overestimated global solar radiation as they all gave positive MBE and MPE values. Equation (10) with the highest MPE of 5.726% also gave the highest RMSE of 1.782. Equation (15) gave the lowest RMSE and MPE values of 0.466 and 0.447% respectively. The critical *t*-value at 95% confidence level for the equations in Table 6 is 2.145. All the *t*-values are all less than the critical value of 2.145 except for equations (9), (10), (13) and (14).Equation (2) performed best in Sokoto for the wet season as it gave the lowest rank score while equation (9) gave the highest rank score. During the wet season, equations (2), (3) and (8) are recommended for estimating solar radiation in Sokoto.

For the models developed for the dry season, all the equations underestimated global solar radiation as they produced negative MBE and MPE values. Equation (12) gave the lowest MBE and MPE values of -0.042 and -0.139% respectively. Equation (6) produced the highest MBE and MPE values of 0.712 and -2.954% respectively. As the critical *t*-value at 95% confidence level for the equations in Table 7 is 2.086, the best formulation for Sokoto during the dry season is equation (12) with the lowest RMSE of 0.582 and the lowest rank score of 0.346. Except for equation (6) with a *t*-value of 3.548, all the *t*-values are all less than the critical value of 2.086.Hence, the estimates from all the equations except equation (6) are statistically significant.Equation (8), (12) and (15) are recommended for estimating global solar radiation in Sokoto for the dry season.

6.0 Conclusion

From the monthly average values of sunshine hour, maximum temperature, minimum temperature and relative humidity, 15 empirical equations were used in the estimation of global solar radiation in Sokoto, located in the sahelian region of Nigeria.

Comparison of these 15 equations was carried out using the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), *t*-test and rank score as performance indicators. For the annual estimation, equation (15) given by $\boldsymbol{Rs / Ro = 0.735 + 0.087(n / N) - 0.089(\theta) - 0.002(RH)}$ gave the best MBE, RMSE and MPE values.All the *t*-values are all less than the critical value of 2.030 and therefore all the 15 equations gave estimates that are statistically significant with the measured radiation data. Performance wise, equation (3) and equation (8) given by $\boldsymbol{Rs / Ro = 1.046 - 0.617(\theta)}$ and $\boldsymbol{Rs / Ro = 0.440 + 0.198(\Delta T / N)}$ respectively are also recommended for estimating solar radiation in Sokoto.

For the wet season in Sokoto, except for equation (6) all the equation generally overestimated global solar radiation. Equation (2) gave the lowest MBE value of 0.082 and the lowest rank score while equation (15) gave the lowest RMSE and MPE values of 0.466 and 0.447% respectively. All the *t*-values are all less than the critical value of 2.145 except for equations (9), (10), (13) and (14).During the wet season, the temperature based equations (2), (3) and (8) given by $\boldsymbol{Rs / Ro = -0.092 + 1.310(Tmax / 65)}$, $\boldsymbol{Rs / Ro = 1.249 - 0.933(\theta)}$ and $\boldsymbol{Rs / Ro = 0.377 + 0.261(\Delta T / N)}$ respectively are recommended for estimating solar radiation in Sokoto.

For the dry season,all the equations underestimated global solar radiation as they produced negative MBE and MPE values. Equation (12) with the lowest MBE, RMSE and MPE values of -0.042, 0.582 and -0.139% respectively also performed best as it has the lowest rank score.Except for equation (6) with a *t*-value of 3.548, all the *t*-values are all less than the critical value of 2.086. Hence, the estimates from all the equations except equation (6) are statistically significant.Equation (8), (12) and (15) given by $\boldsymbol{Rs/Ro = 0.578 + 0.092(\Delta T/N)}$, $\boldsymbol{Rs / Ro = 0.698 + 0.045(n / N) - 0.001(RH)}$ and $\boldsymbol{Rs / Ro = 0.780 + 0.030(n / N) - 0.142(\theta) - 0.001(RH)}$ are recommended for estimating global solar radiation in Sokoto for the dry season.

Calculation of global solar radiation at the location of this study is generally temperature dependent as temperature values in various forms were used to obtain optimal estimate. Temperature based models made the rank of the best three during the wet season. On the annual scale and in the dry season, various variations of temperature and relative humidity were used with sunshine duration to arrive at the best three models. Sunshine duration based models, Angstrom-Prescott first, second and third order equations (1), (9) and (14) generally performed poorly. In our next study, we shall investigate relative advantages of combining both the sunshine and temperature based models across latitudes for estimation of global solar radiation.

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