Empirical Formulae for Parameterization of Unavailable Solar Radiation in Nigeria

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Abstract: - The usefulness of empirical formulae for parameterization of unavailable solar radiation in Nigeria cannot be over emphasized owing to the availability of the solar radiation as well as the need for its conversion to other usable solar systems. In this paper we have obtained empirical formulae for parameterization of unavailable solar radiation for fourteen meteorological stations in Nigeria: Bauchi, Bida, Enugu, Gusau, Ikom, Jos, Kano, Maiduguri, Minna, Nguru, Potiskum, Yelwa, Yola and Zaria. Most of the stations studied showed high correlation for seasonal fits ($R_a^2 \geq 0.97$). For yearly fits, relative humidity appears to be an important climatological parameter for Enugu, Jos and Potiskum, while this is not a determining factor for Ikom and Nguru

Key words: parameterization, relative humidity, best fit, regression

1 Introduction

In the design of solar systems, accurate knowledge of solar radiation data gained over a considerable time period is indispensable. However, because of uncertainty in the past of solar radiation equipment, and due to their high cost and unavailability of truly time insolation data, scientist have developed mathematical model equations to be used to estimate total solar radiation on a horizontal surface, H, clearness index, H/H_0 (H_0 is the total extraterrestrial solar radiation on a horizontal surface) or unavailable solar radiation, $H_0 - H$ in terms of climatological independent variables such as cloud cover, C, relative humidity, R, maximum air temperature, T_m or relative sunshine duration, S/S_0 (S is the bright sunshine duration and S_0 day-length both in hours) [1] – [8]. In their work, Aidan *et al.* [1] showed that there is high correlation between unavailable solar radiation and any one of relative sunshine duration, relative humidity or cloud cover, a five parameter model equations which correlates H/H$_0$ or H$_0$ – H in terms of S/S$_0$, R and C was proposed, the equations were applied to seven meteorological stations in Nigeria: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola, the result showed highest correlation for most of the stations when H$_0$ – H was used as the dependent variable , except for Kano, Nguru and Yola where H/H$_0$ gives the highest correlation for seasonal fits, also, the result does not specify which of the independent variables S/S$_0$, R or C is more relevant in contributing to the higher correlation in the five parameter model equations. In this paper, we have proposed a five and a seven parameter model equations which models H$_0$ – H in terms of only two independent variables S/S$_0$ and C as a means of solving these problems, the equations were applied to fourteen meteorological stations in Nigeria: Bauchi, Bida, Enugu, Gusau, Ikom, Jos, Kano, Maiduguri, Minna, Nguru, Potiskum, Yelwa, Yola and Zaria.

2 Model Equations

Aidan *et al*. proposed model equation for modelling unavailable solar radiation of the form [1]

$$H' = \alpha_0 + \alpha_1 (S/S_0) + \alpha_2 R + \alpha_3 C + \alpha_{23} RC \tag{1}$$

where H' = H$_0$ – H is the unavailable solar radiation and the $\alpha_i^{'}s$ are constant coefficients, the equation has been used on seven Nigerian meteorological stations, viz: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola [1].

In this paper, we have proposed two model equations given by:

$$\begin{aligned} H' = \alpha_0 + \alpha_3 (1/C) + \alpha_{33} (1/C^2) \\ + \alpha_{133} (S/S_0)(1/C^2) + \alpha_{11} (S/S_0)^2 \end{aligned} \tag{2}$$

and

$$\begin{aligned} H' = \alpha_{00} + \alpha_{01} (1/C) + \alpha_{02} (1/C^2) \\ + \alpha_{11} (S/S_0)(1/C) + \alpha_{12} (S/S_0)(1/C^2) \\ + \alpha_{20} (S/S_0)^2 + \alpha_{21} (S/S_0)(1/C) \end{aligned} \tag{3}$$

Equations (2) and (3) are derivable from the general form $H' = \sum_{i,j=0}^{2} \alpha_{ij} (S/S_0)^i (1/C^j)$, proposed by J.C. Ododo

3 Data and Analysis

The data for the fourteen (14) stations (Bauchi, Bida, Enugu, Gusau, Ikom, Jos, Kano, Maiduguri, Minna, Nguru, Potiskum, Yelwa, Yola and Zaria) have been tabulated elsewhere [1], [6] – [8]. Multiple linear regression were carried out on equations (1), (2) and (3) for both yearly and seasonal variations, the seasonal variations considered were the dry (November – April) and wet (May - October) seasons. For reasons explained by [6] – [8], seasonal variation were carried out on equations (1) and (2) only. The goodness-of-fit indices used are: the adjusted coefficient of determination (R_a^2), standard error ($S e H'$), largest percentage error (LPE), Absolute Average Percentage Error (AAPE) and the residual sum of squares (Δ), the seasonal variation and the goodness-of-fit indices are defined elsewhere [6-8].

4 Results and Discussion

4.1 Bauchi (10.6371^{0}N, 10.0807^{0}E)

Table 1 shows the regression parameters for both yearly and seasonal variation, equation (1) with R_a^2 = 0.9925, LPE = 2.7% gives the best fit for the data, however, SeH' = 0.2391 is relatively high. On the other hand if we consider seasonal fits, equation (2), with R_a^2 > 0.999 gives best fit for both dry and wet seasons, SeH' = 0.0394 for the dry season and 0.0082 for the wet season. The applicability of equation (2) to seasonal fits also confirms that relative humidity is not a useful climatological variable for estimating unavailable solar radiation for seasonal data this is because this equation is independent of relative humidity. We have also shown a plot of observed and best fit unavailable solar radiation versus months (Fig. 1), where it can be seen that yearly variation (Δ = 0.51) shows tight fit between observed and best fit equation. The result for seasonal variation where $\Delta \approx 0$ indicates a near perfect fit between the observed and best fit equation, this means that seasonal fit is quite satisfactory.

Table 1. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Bauchi	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	24.0364	39.8729	99.6224	0.4884	43.5709	33.7065	-1131.3292
α_1	-15.5182	…	…	-1.5303	…	-23.7924	…
α_2	-2.4357	…	…	14.0669	…	-1.2337	…
α_3	0.0821	-78.0368	-926.1143	3.6878	-411.6194	-0.6986	20598.2334
α_{11}	…	-28.4843	-21.6088	…	44.1663	…	-1540.0885
α_{13}	…	…	-608.1706	…	…	…	…
α_{23}	1.1770	-348.3967	…	-4.8506	1740.3520	0.9486	-102177.3660
α_{33}	…	…	5479.8820	…	…	…	…
α_{113}	…	…	1414.1836	…	-1306.4823	…	66534.3771
α_{133}	…	653.3929	-5767.2659	…	…	…	…
$Se\,H'$	0.2391	0.5429	0.3999	0.1888	0.0394	0.1823	0.0082
R_a^2	0.9925	0.9611	0.9789	0.9857	0.9994	0.9909	1.0000
Δ	0.40	2.06	0.80	0.04	0.00	0.03	0.00
LPE(%)	2.7	5.7	3.3	1.0	0.3	0.8	0.0
AAPE(%)	0.9	2.0	1.1	0.4	0.1	0.3	0.0

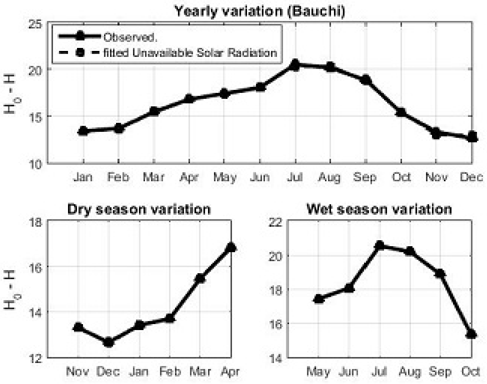

Fig. 1 plots of observed and fitted unavailable solar radiation

4.2 Bida (9.0797^{0}N, 6.0097^{0}E)

Table 2 list the regression parameters for both yearly and seasonal variation, also shown in Fig. 2 is the corresponding plots of observed and best fit equation against months. From the Table, equation (1) with R_a^2 = 0.9201 for yearly variation gives the best fit equation with relatively larges values of LPE and $Se\,H'$, from the plot it can be seen that the curves of observed and best fit equation shows significant deviations (Δ = 6.4) between the months of February – May as well as between June – September, this shows that yearly fit is not quite satisfactory. For seasonal fits, like for yearly variation, equation (1) is the best fit equation and also re-affirms the usefulness of relative humidity for estimating unavailable solar radiation for the data. However, from the plot in Fig. 2 dry season (Δ = 0.12) gives an excellent fit as opposed to wet season (Δ = 2.69), where the deviation between the two curves between June – September is significant. The values of SeH' for wet season is relatively large.

Table 2. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Bida	Yearly variation			Seasonal variation			
				Dry season		Wet season	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	21.9494	34.3521	45.5791	39.7517	30.5466	406.7277	462.2388
α_1	-23.0941	…	…	-11.1185	…	-47.0911	…
α_2	12.0052	…	…	-50.9109	…	-487.7324	…
α_3	0.8887	-71.9830	-190.1693	-4.7496	-103.8700	-54.7613	-6879.5031
α_{11}	…	-23.6008	-50.7918	…	0.4340	…	439.0228
α_{13}	…	…	4.6599	…	…	…	…
α_{23}	-1.1519	46.9328	…	12.7576	274.3715	72.9938	30372.0116
α_{33}	…	…	514.6172	…	…	…	…
α_{113}	…	…	287.9381	…	-197.9227	…	-18001.9458
α_{133}	…	101.2820	-646.4362	…	…	…	…
SeH'	0.9564	1.0301	1.0945	0.3514	1.1985	1.6394	1.8310
R_a^2	0.9201	0.9073	0.8954	0.9562	0.4905	0.5527	0.4420
Δ	6.40	7.43	5.99	0.12	1.44	2.69	3.35
LPE(%)	7.3	9.9	6.4	1.5	5.0	5.4	6.0
AAPE(%)	3.3	3.2	2.9	0.9	2.6	2.0	2.7

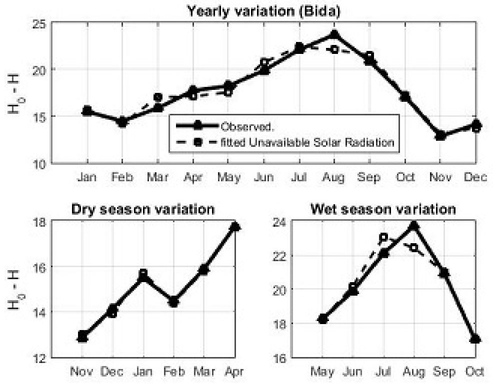

Fig. 2 plots of observed and fitted unavailable solar radiation

4.3 Enugu (6.458^{0}N, 7.546^{0}E)

Listed in Table 3 is the result of regression analysis for both yearly and seasonal fits. R_a^2 = 0.9783, LPE = 2.4% and AAPE = 1.2% for yearly fits where equation (1) gives the best fit for the data, also, the plots in Fig. 3 shows that for yearly fit (Δ = 0.93) the two curves fits excellently except for some few points, clearly, yearly fit is satisfactory, the result also shows that relative humidity is a useful parameter for yearly fits. For seasonal variation, equations (1) and (2) gives best fit for dry and wet seasons respectively, with R_a^2 > 0.97 and LPE < 1%, the result shows that seasonal fits are satisfactory (also see plots, for dry season, $\Delta = 0.01$ and wet season $\Delta = 0.08$) and that relative humidity is an important parameter for the data of wet season.

Table 3. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Enugu	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	34.4031	24.6457	-48.3077	40.4205	31.9208	150.9741	124.8895
α_1	-16.8987	…	…	-21.8692	…	-20.2197	…
α_2	-23.1812	…	…	-26.0933	…	-164.2833	…
α_3	0.5273	-0.5988	1005.3039	-1.4263	-28.9594	-17.2264	-1831.6627
α_{11}	…	-21.3752	272.2247	…	-32.8956	…	343.4064
α_{13}	…	…	-1468.5986	…	…	…	…
α_{23}	1.7114	16.9447	…	4.2092	-41.6057	23.3789	9397.3544
α_{33}	…	…	-2666.8993	…	…	…	…
α_{113}	…	…	-1074.0213	…	150.0023	…	-10392.5127
α_{133}	…	-49.8346	5274.5316	…	…	…	…
SeH'	0.3649	0.5072	0.4691	0.1190	0.3342	0.5343	0.2842
R_a^2	0.9783	0.9580	0.9641	0.9958	0.9669	0.8967	0.9708
Δ	0.93	1.80	1.10	0.01	0.11	0.29	0.08
LPE(%)	2.4	4.3	3.4	0.5	1.1	1.6	1.0
AAPE(%)	1.2	1.3	1.1	0.2	0.6	0.9	0.5

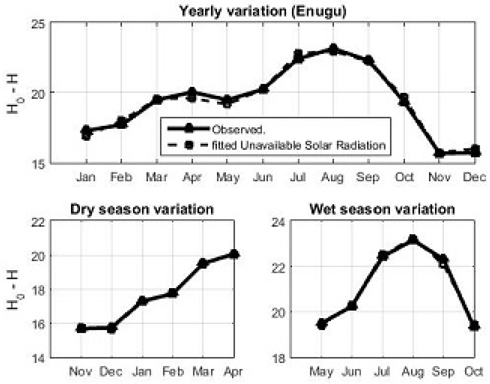

Fig. 3 plots of observed and fitted unavailable solar radiation

4.4 Gusau (12.1628^{0}N, 6.6745^{0}E)

The corresponding parameters for yearly and seasonal fits are listed in Table 4. For yearly fit equation (1) with R_a^2 = 0.9523 gives best fit for the data with relatively large values of $Se\,H'$ and LPE (11.4%), the curves of observed and best fit equation (shown in Fig. 4) indicates significant deviations between the months of February – June and also between July – August due to large value of Δ = 4.75, therefore, yearly fit is not satisfactory. The result of seasonal fits shows that equation (2) gives the best model equation for both seasons – an indication that relative humidity is not a necessary climatological variable for predicting unavailable solar radiation for seasonal data. The plots in Fig. 4 shows excellent fit between observed and best fit equation for wet season (Δ = 0.05). Unlike for wet season, dry season with Δ = 0.81, shows significant deviations between November – January and also between January – March.

Table 4. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Gusau	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	21.1664	119.8713	418.8304	30.3703	44.3170	117.3223	439.5881
α_1	-7.7936	…	…	-18.0277	…	-11.3074	…
α_2	-33.1561	…	…	-31.8330	…	-156.3735	…
α_3	-1.0923	-1023.4297	-5761.6716	-1.7853	243.7968	-17.2610	-5123.8523
α_{11}	…	1.5190	-867.0294	…	-179.6945	…	65.2438
α_{13}	…	…	4839.3157	…	…	…	…
α_{23}	6.9727	2471.1444	…	6.9415	-2932.4362	28.0288	16324.8036
α_{33}	…	…	20541.4167	…	…	…	…
α_{113}	…	…	5451.5239	…	4125.8384	…	-2893.7344
α_{133}	…	-147.5561	-30754.0197	…	…	…	…
$Se\,H'$	0.8238	1.1215	0.8537	1.2991	0.9027	0.2312	0.2136
R_a^2	0.9523	0.9115	0.9487	0.3332	0.6781	0.9940	0.9949
Δ	4.75	8.80	3.64	1.69	0.81	0.05	0.05
LPE(%)	11.4	9.7	8.8	11.0	6.7	0.9	0.7
AAPE(%)	4.1	5.4	3.5	3.5	2.6	0.4	0.4

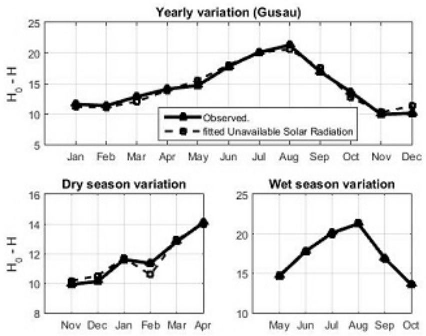

Fig. 4 plots of observed and fitted unavailable solar radiation

4.5 Ikom (5.9617^{0}N, 8.7206^{0}E)

The parameters of regression analysis for yearly and seasonal fits are listed in Table 5. Equation (3) with R_a^2 = 0.9847, LPE = 2.2% and AAPE = 0.8% gives best fit for the data, as revealed by the plot in Fig. 5, the curves of observed and best fit equation shows tight fit (Δ = 0.51), this shows that yearly variation is quite satisfactory and therefore, relative humidity is not an important factor for estimating unavailable solar radiation for yearly data. Equation (2) and (1) with R_a^2 > 0.994, LPE $\leq$ 0.5% gives best fit for seasonal data. SeH' for dry season is better than for wet season, equation (2) being the best fit for dry season further confirms that relative humidity is not a necessary parameter to be considered for estimating unavailable solar radiation for yearly data.

Table 5. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Ikom	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	31.2050	19.0846	154.9496	9.9633	127.8956	-22.6917	542.3160
α_1	-23.6788	…	…	-21.3467	…	-28.7484	…
α_2	-15.0941	…	…	13.3271	…	81.9180	…
α_3	0.3550	-69.3571	-1746.6053	3.7680	-1190.3779	8.4615	-7111.0279
α_{11}	…	64.0167	-370.8732	…	-35.0366	…	41.0930
α_{13}	…	…	1066.1316	…	…	…	…
α_{23}	1.4491	1278.6389	…	-3.3805	2590.3888	-12.6888	24808.7808
α_{33}	…	…	6247.2688	…	…	…	…
α_{113}	…	…	2907.4900	…	1853.6485	…	-2272.7499
α_{133}	…	-3059.7543	-9812.4236	…	…	…	…
SeH'	0.4203	0.4570	0.3181	0.6649	0.0737	0.1517	0.2199
R_a^2	0.9733	0.9684	0.9847	0.5479	0.9944	0.9958	0.9912
Δ	1.24	1.46	0.51	0.44	0.01	0.02	0.05
LPE(%)	3.3	4.0	2.2	2.1	0.3	0.5	0.7
AAPE(%)	1.4	1.5	0.8	1.5	0.1	0.2	0.4

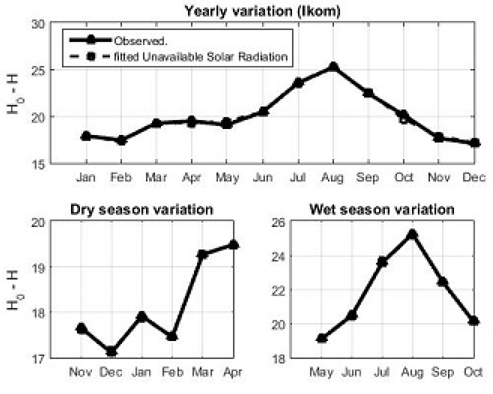

Fig. 5 plots of observed and fitted unavailable solar radiation

4.6 Jos (9.8965^{0}N, 8.8583^{0}E)

Yearly and seasonal regression parameters are shown in Table 6. Equation (1) for yearly fits with $R_a^2 = 0.9962$, $Se\,H' = 0.2762$ and LPE = 2.4% gives the best fit, as can be seen from the plot in Fig. 6, the curves of observed and best fit equation gives excellent fit ($\Delta = 0.53$), therefore, yearly variation is quite satisfactory. From the Table it can be seen that the applicability of equation (1) to yearly fit also holds for seasonal fits, thus confirming the usefulness of relative humidity for predicting unavailable solar radiation for the data of Jos, this is further revealed by the excellently fitted curves of observed and best fit equations for dry and wet seasons (Fig. 6).

Table 6. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Jos	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	26.2674	25.2191	51.8972	32.3501	25.9439	34.1775	254.0187
α_1	-18.0583	…	…	-23.5821	…	-24.5975	…
α_2	-14.8072	…	…	-8.5981	…	-40.5646	…
α_3	0.4252	53.1517	-330.3686	-0.1837	-15.6889	1.0381	-4608.0925
α_{11}	…	-32.7292	-38.2189	…	-18.3240	…	437.2420
α_{13}	…	…	13.2774	…	…	…	…
α_{23}	2.3234	-403.7950	…	1.4608	-11.3144	4.3098	25051.5097
α_{33}	…	…	1367.4106	…	…	…	…
α_{113}	…	…	321.5403	…	52.6582	…	-19208.1697
α_{133}	…	392.4884	-1443.5372	…	…	…	…
$Se\,H'$	0.2762	0.4566	0.3171	0.0847	0.2276	0.2248	0.3250
R_a^2	0.9962	0.9895	0.9949	0.9992	0.9941	0.9926	0.9846
Δ	0.53	1.46	0.50	0.01	0.05	0.05	0.11
LPE(%)	2.4	3.4	2.5	0.6	1.0	0.9	1.3
AAPE(%)	1.1	1.9	1.0	0.2	0.6	0.4	0.5

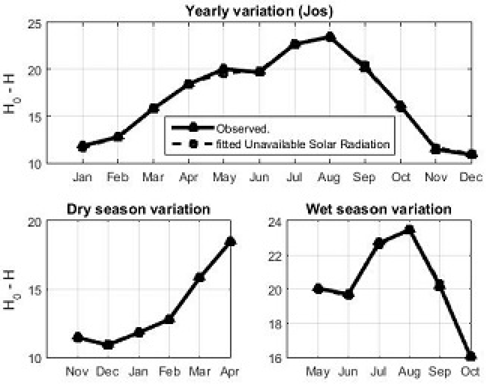

Fig. 6 plots of observed and fitted unavailable solar radiation

4.7 Kano (12.0022^{0}N, 8.5920^{0}E)

Shown in Table 7 are regression parameters for both yearly and seasonal fits. From the Table it can be seen that equation (2) gives the best fit for the yearly data, however, SeH', Δ, LPE and AAPE are relatively large, thus yearly fit is not satisfactory, plots of curves of observed and best fit equation (see Fig. 7) shows small deviations between the two curves in the months of April – August. If seasonal variation is considered, equations (2) and (1) with $R_a^2 > 0.997$, LPE = 0.4% gives best fit for dry and wet season, SeH' = 0.0428 for dry season and 0.0973 for wet season, the plots of the curves of observed and best fit equations are excellently fitted ($\Delta \approx 0$ for dry season and 0.01 for wet season), thus, seasonal fits are satisfactory. Relative humidity as a climatological variable is only useful for wet season data since equation (1) requires relative humidity.

Table 7. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Kano	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	15.2105	32.0601	27.6939	14.7743	22.3389	16.8906	0.3008
α_1	-9.8210	…	…	-6.4688	…	-42.8075	…
α_2	-1.4830	…	…	-11.0808	…	57.9475	…
α_3	0.8591	-65.8502	126.6020	0.1499	-65.4702	4.9731	83.8034
α_{11}	…	-16.3126	-2.2526	…	5.3144	…	6.6221
α_{13}	…	…	-583.9205	…	…	…	…
α_{23}	0.8669	-31.5368	…	4.3861	121.1098	-10.9639	864.5796
α_{33}	…	…	77.0373	…	…	…	…
α_{113}	…	…	409.1731	…	-68.9169	…	-1491.0258
α_{133}	…	155.5603	32.4244	…	…	…	…
SeH'	0.4330	0.4111	0.4565	0.1478	0.0428	0.0973	0.4289
R_a^2	0.9731	0.9758	0.9701	0.9868	0.9989	0.9978	0.9564
Δ	1.31	1.18	1.04	0.02	0.00	0.01	0.18
LPE(%)	4.3	3.5	3.9	1.2	0.3	0.4	2.3
AAPE(%)	1.9	2.0	1.5	0.4	0.1	0.2	0.8

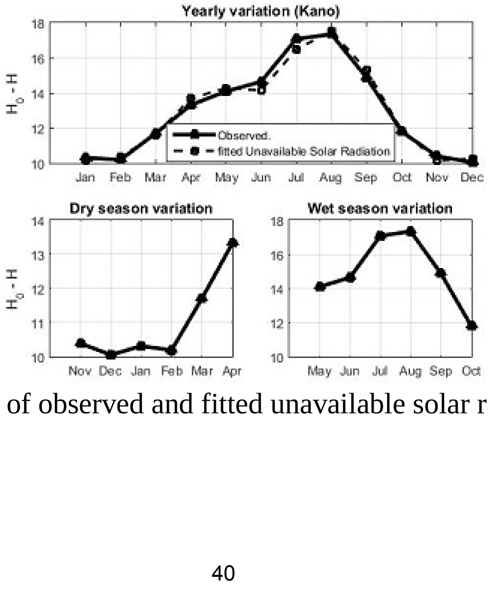

Fig. 7 plots of observed and fitted unavailable solar radiation

4.8 Maiduguri (11.8311^{0}N, 13.1510^{0}E)

Corresponding regression parameters for yearly and seasonal variations are listed in Table 8. Equation (2) with R_a^2 = 0.9437 for yearly variation gives best fit for the data but with relatively large values of $Se H'$, Δ, LPE and AAPE, the plots in Fig. 8 shows the deviations between the curves of observed and best fit equation which occur in the months of May – June as well as September – November, clearly, yearly fit is not satisfactory. From the Table, result for seasonal fit shows $R_a^2 >$ 0.948, LPE < 0.4%, AAPE < 2% for the two seasons, $Se H'$ = 0.1773 for dry season and 0.5945 for wet season. It is obvious that seasonal fit is quite satisfactory, this is further corroborated by the excellent fits of the two curves of observed and best fit equations for dry season (with Δ = 0.03) and wet season (Δ = 0.35).

Table 8. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Maiduguri	Yearly variation			Seasonal variation			
				Dry season		Wet season	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	21.2899	50.7926	136.8641	38.6266	59.7340	2.2108	393.2207
α_1	-13.3746	…	…	-23.9247	…	-34.8287	…
α_2	-33.0519	…	…	-47.4076	…	48.5065	…
α_3	-0.0080	-390.6491	-1702.7887	-2.3193	-817.3954	6.3680	-5835.5035
α_{11}	…	-1.8061	-230.8428	…	74.8586	…	332.6517
α_{13}	…	…	1933.3171	…	…	…	…
α_{23}	5.3935	1346.0522	…	9.6735	3792.3477	-9.8337	25611.4278
α_{33}	…	…	3982.9373	…	…	…	…
α_{113}	…	…	452.2829	…	-2638.6102	…	-14317.0850
α_{133}	…	-550.5451	-5257.5137	…	…	…	…
$Se H'$	0.6685	0.6477	0.7253	0.1773	0.3031	0.6219	0.5945
R_a^2	0.9401	0.9437	0.9294	0.9873	0.9629	0.9439	0.9487
Δ	3.13	2.94	2.63	0.03	0.09	0.39	0.35
LPE(%)	14.1	14.0	11.2	1.6	2.7	3.1	2.7
AAPE(%)	3.9	4.1	4.0	0.7	1.0	1.5	1.7

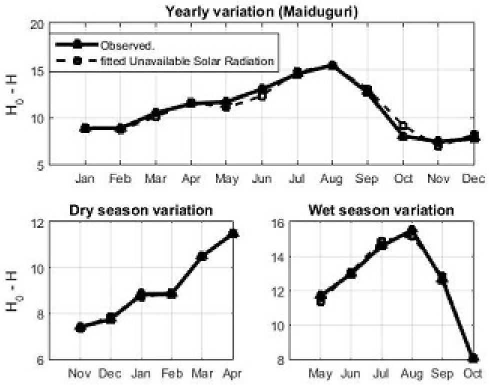

Fig. 8 plots of observed and fitted unavailable solar radiation

4.9 Minna (9.5836^{0}N, 6.5463^{0}E)

The yearly and seasonal regression parameters are shown in Table 9. Equation (1) gives best fit for the data with relatively large value of $Se\,H'$, Δ, LPE and AAPE, with $\Delta = 5.4$, the plots of observed and best fit equation (see Fig. 9) shows small deviations between May – June and also between September – November, thus yearly fits are not quite satisfactory. For seasonal variation, model equations (1) and (2) gives best fit for dry and wet seasons, also as can be seen from the figure, the curves of observed and best fit equation for dry season gives a tight fit, however, that of wet season shows small deviations between May – June and between July – September, therefore, seasonal variation gives satisfactory fits

Table 9. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Minna	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	25.4302	27.8771	-164.6091	27.0269	32.5445	-625.2750	-201.3915
α_1	-21.5756	…	…	-24.1187	…	-48.1615	…
α_2	-6.8887	…	…	-4.8170	…	886.8523	…
α_3	1.5308	-22.0831	2933.5723	1.5730	101.4080	105.9435	2394.2973
α_{11}	…	-20.8915	417.2729	…	-65.2030	…	100.7879
α_{13}	…	…	-2756.3372	…	…	…	…
α_{23}	0.1145	57.2114	…	-0.3719	-866.0798	-139.6802	-4469.0084
α_{33}	…	…	-10383.6963	…	…	…	…
α_{113}	…	…	-2525.4324	…	964.9271	…	-5563.4239
α_{133}	…	-36.3586	15557.6837	…	…	…	…
$Se\,H'$	0.8782	0.9894	0.8934	0.6043	0.7083	1.7560	1.6231
R_a^2	0.9509	0.9377	0.9492	0.9184	0.8879	0.6961	0.7404
Δ	5.40	6.85	3.99	0.37	0.50	3.08	2.63
LPE(%)	7.5	8.8	5.8	3.6	3.4	5.4	4.9
AAPE(%)	2.8	3.0	2.4	1.5	1.9	2.5	2.8

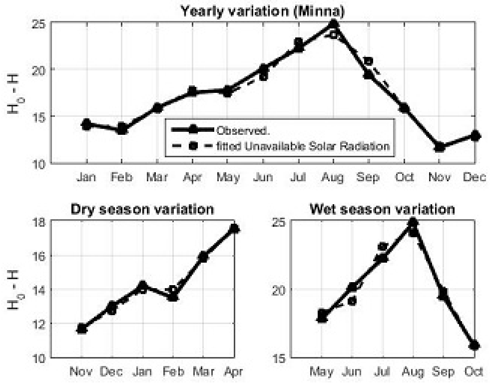

Fig. 9 plots of observed and fitted unavailable solar radiation

4.10 Nguru (12.878^{0}N, 10.457^{0}E)

The parameters of regression analysis for yearly and seasonal fits are listed in Table 10. Equation (3) with R_a^2= 0.9457, LPE = 5% and AAPE = 2.2% gives best fit for the data, as can be seen from the plot shown in Fig. 10, the curves of observed and best fit equation are slightly deviated from each other (Δ= 1.32) between January – March and between May – July. The result for yearly variation is satisfactory and clearly shows that relative humidity is not an important factor for estimating unavailable solar radiation. Equation (2) and (1) gives best fit for dry and wet seasons, application of equation (2) for dry season, is a re-affirmation that relative humidity is not an important factor in estimating unavailable solar radiation for the data of Nguru. Plots of observed and best fit equation for seasonal fits are also shown in Fig. 10.

Table 10. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Nguru	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	18.4572	71.4663	197.3557	25.4950	64.4740	5.6379	-0.5173
α_1	-13.2209	…	…	-14.1507	…	-13.0134	…
α_2	5.5434	…	…	-19.9306	…	1.0297	…
α_3	0.4299	-558.8003	-2843.7371	-1.0164	-483.8935	3.5640	526.2281
α_{11}	…	6.9219	-454.7516	…	0.2211	…	-60.0467
α_{13}	…	…	4758.1611	…	…	…	…
α_{23}	0.0402	1472.4356	…	5.8855	1240.8157	-0.9001	-2908.4980
α_{33}	…	…	3680.3403	…	…	…	…
α_{113}	…	…	-22.6952	…	-196.9295	…	1933.8765
α_{133}	…	-344.3573	-7272.3573	…	…	…	…
SeH'	0.5908	0.6486	0.5147	0.3754	0.1928	0.8799	0.9175
R_a^2	0.9285	0.9138	0.9457	0.8699	0.9657	0.7758	0.7563
Δ	2.44	2.95	1.32	0.14	0.04	0.77	0.84
LPE(%)	6.2	7.0	5.0	2.2	1.4	4.4	4.9
AAPE(%)	2.7	2.9	2.2	1.2	0.5	1.9	2.1

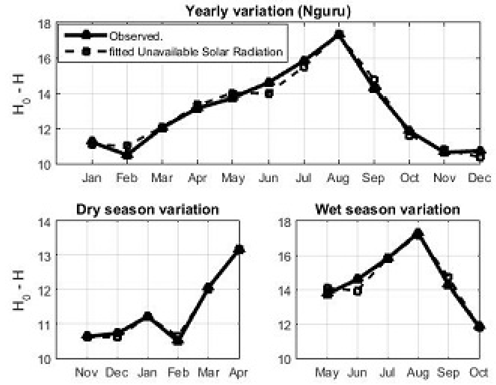

Fig. 10 plots of observed and fitted unavailable solar radiation

4.11 Potiskum (11.7072^{0}N, 11.0825^{0}E)

The data in Table 11 list the parameters of regression analysis for both yearly and seasonal fits. Equation (1) for yearly fits with R_a^2= 0.9837, $Se\,H'$ = 0.3657 and LPE = 3% gives the best fit, as can be seen from the plot in Fig. 11, the curves of observed and best fit equation gives excellent fit (Δ = 0.94), therefore, yearly variation is quite satisfactory. From the Table it can be seen that the applicability of equation (1) to yearly fit also applies for seasonal fits, thus confirming the usefulness of relative humidity for predicting unavailable solar radiation for the data of Jos, this is further revealed by the tightly fitted curves of observed and best fit equations for dry and wet seasons in Fig. 11.

Table 11. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Potiskum	Yearly variation			Seasonal variation			
				Dry season		Wet season	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	7.2438	57.3982	124.5996	11.5662	93.5690	6.4575	86.2839
α_1	-5.0909	…	…	-1.1966	…	-17.9980	…
α_2	-24.1278	…	…	-72.1641	…	4.5129	…
α_3	1.9142	-294.7293	-1353.8563	0.5562	-1209.2239	3.7282	-933.1313
α_{11}	…	-19.7504	14.5033	…	98.0241	…	37.1118
α_{13}	…	…	-690.2743	…	…	…	…
α_{23}	3.9938	237.8229	…	13.0569	5223.7923	-1.2577	3947.4910
α_{33}	…	…	7791.5460	…	…	…	…
α_{113}	…	…	1359.5100	…	-3428.9433	…	-2243.7085
α_{133}	…	495.3730	-7044.9052	…	…	…	…
$Se\,H'$	0.3657	0.4201	0.4233	0.1574	0.5975	0.2132	0.5588
R_a^2	0.9837	0.9785	0.9782	0.9906	0.8646	0.9908	0.9366
Δ	0.94	1.24	0.90	0.02	0.36	0.05	0.31
LPE(%)	3.0	5.9	5.0	1.3	4.5	0.9	3.1
AAPE(%)	1.8	2.3	1.8	0.4	1.7	0.5	1.1

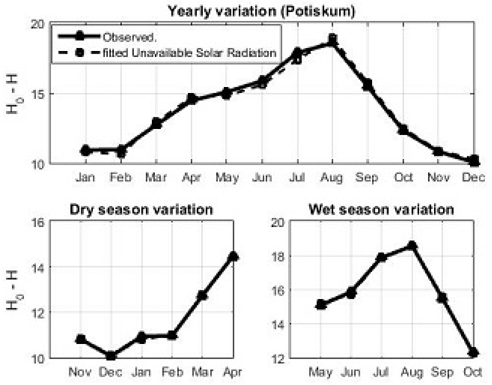

Fig. 11 plots of observed and fitted unavailable solar radiation

4.12 Yelwa (10.8370^{0}N, 4.7403^{0}E)

Regression parameters for the two variations are shown by the entries in Table 12, where it can be seen that equation (3) gives the best fit for the data, however, values of Δ, LPE and AAPE are relatively high, thus yearly fit is not satisfactory. On the other hand if we consider seasonal variation, equations (1) and (2) with $R_a^2 > 0.925$, LPE $\leq$ 2.6% gives best fit for dry and wet seasons, plots of observed and best fit equation shows excellent fit (see Fig. 12) for seasonal variation. The result also shows that relative humidity is a useful parameter for estimating solar radiation in the dry season.

Table 12. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Yelwa	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	26.2400	36.1721	30.2213	34.5885	45.3773	151.2554	184.7549
α_1	-17.3830	…	…	-13.9857	…	-31.6012	…
α_2	-7.2096	…	…	-39.6498	…	-183.5730	…
α_3	-0.4024	-59.1411	315.0578	-3.2051	-446.0412	-16.8181	-6109.2851
α_{11}	…	-28.1662	117.3808	…	56.1309	…	820.8786
α_{13}	…	…	-3066.2651	…	…	…	…
α_{23}	2.0783	-267.7014	…	10.1737	1474.0249	26.8756	45284.0876
α_{33}	…	…	4748.4907	…	…	…	…
α_{113}	…	…	2458.2343	…	-973.1462	…	-41907.7392
α_{133}	…	484.0309	-4917.3922	…	…	…	…
$Se\,H'$	0.9173	0.9113	0.6646	0.0657	0.1747	1.6491	0.6991
R_a^2	0.9274	0.9283	0.9619	0.9988	0.9914	0.5841	0.9253
Δ	5.89	5.81	2.21	0.00	0.03	2.72	0.49
LPE(%)	9.7	8.6	5.7	0.4	1.2	6.5	2.6
AAPE(%)	3.5	3.0	2.3	0.2	0.4	2.9	0.9

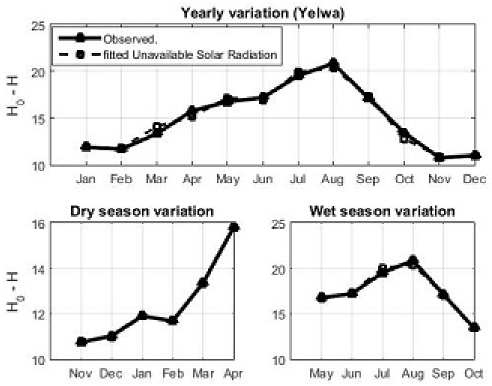

Fig. 12 plots of observed and fitted unavailable solar radiation

4.13 Yola (9.2035^{0}N, 12.4954^{0}E)

The corresponding regression parameters for both yearly and seasonal variation are shown in Table 13, yearly fit with R_a^2 = 0.7909 given by equation (1) is not satisfactory due to relatively high values of SeH', Δ, LPE and AAPE, also see plots of observed and best fit equation in Fig. 13. From the data of seasonal fits, equation (2) gives best fit equation for the two seasons, also, R_a^2 = 0.4191 and 0.0777 for dry and wet seasons respectively, however, the wet season values of SeH', Δ, LPE and AAPE are relatively large, thus, fit for wet season is not satisfactory, also shown in Fig. 13 are the plots of observed and best fit equations for seasonal fit, the result shows a moderately better fit for dry season.

Table 13. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Yola	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	45.0945	132.3985	1075.3378	27.4095	-80.1194	827.3135	-1089.6169
α_1	-11.4321	…	…	-6.3727	…	-85.9112	…
α_2	-101.3672	…	…	-57.4880	…	-964.8591	…
α_3	-4.1001	-492.9089	-17762.1639	-1.7231	1950.2585	-113.1821	9113.2119
α_{11}	…	-140.6913	-1320.6565	…	-164.4860	…	928.3240
α_{13}	…	…	10650.4417	…	…	…	…
α_{23}	16.8636	-3442.0147	…	9.6747	-10360.9878	143.6787	5362.0430
α_{33}	…	…	77791.9857	…	…	…	…
α_{113}	…	…	11298.8155	…	6982.0883	…	-52939.7426
α_{133}	…	6508.1946	-91662.7170	…	…	…	…
SeH'	1.8543	2.1411	1.8802	1.2184	1.1530	3.6479	3.4966
R_a^2	0.7909	0.7212	0.7850	0.3513	0.4191	-0.0038	0.0777
Δ	24.07	32.09	17.68	1.48	1.33	13.31	12.23
LPE(%)	15.0	17.3	12.7	5.4	4.4	13.2	12.7
AAPE(%)	5.6	7.5	4.3	3.3	3.2	5.4	4.8

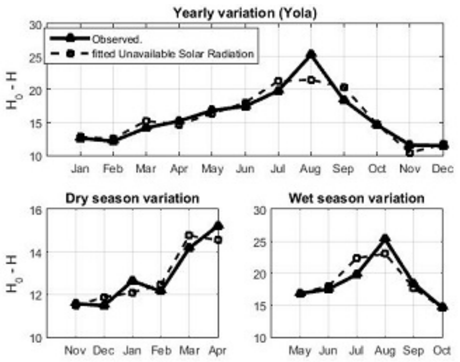

Fig. 13 plots of observed and fitted unavailable solar radiation

4.14 Zaria (11.0855^{0}N, 7.7199^{0}E)

Table 14 list the regression parameters for yearly and seasonal fits. From the Table it can be seen that equation (2) with $R_a^2 = 0.827$ is the best fit for the data, but the values of $Se\,H'$, Δ, LPE and AAPE are relatively high. The result of seasonal fit also shows that equation (2) is the best-fit-equation for the data with: $R_a^2 > 0.986$, $\Delta < 0.1$, LPE $\leq 1\%$ and AAPE $\leq 0.4\%$ for the two seasons. Plots of observed and best fit equation is shown in Fig. 14 where it can be seen that seasonal variation fits almost perfectly, the result clearly reveals that relative humidity is not a required climatological parameter for modelling unavailable solar radiation for Zaria.

Table 14. Regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

Zaria	**Yearly variation**			**Seasonal variation**			
				Dry season		**Wet season**	
	Eqn (1)	Eqn (2)	Eqn (3)	Eqn (1)	Eqn (2)	Eqn (1)	Eqn (2)
α_0	-33.2995	1322.8786	-3149.7862	-38.4882	466.3396	-167.8404	-581.0466
α_1	-19.7613	…	…	-9.0982	…	-15.0819	…
α_2	36.2869	…	…	291.9392	…	24.6388	…
α_3	8.6412	-17637.2195	69735.5867	8.8631	-5237.0931	27.7740	9706.7047
α_{11}	…	84.3768	7790.4995	…	-109.0635	…	-135.8550
α_{13}	…	…	-73636.9439	…	…	…	…
α_{23}	-4.8017	61271.5249	…	-46.0718	12923.1697	-3.3334	-40190.3815
α_{33}	…	…	-331839.2525	…	…	…	…
α_{113}	…	…	-54330.9046	…	5907.4381	…	6660.0340
α_{133}	…	-5475.4206	512721.8243	…	…	…	…
$Se\,H'$	1.4602	1.3268	1.4226	0.1945	0.0816	0.9366	0.2703
R_a^2	0.7904	0.8270	0.8011	0.9883	0.9979	0.8305	0.9859
Δ	14.93	12.32	10.12	0.04	0.01	0.88	0.07
LPE(%)	13.7	13.6	15.3	1.2	0.5	4.0	1.0
AAPE(%)	6.2	4.9	4.0	0.5	0.2	1.9	0.4

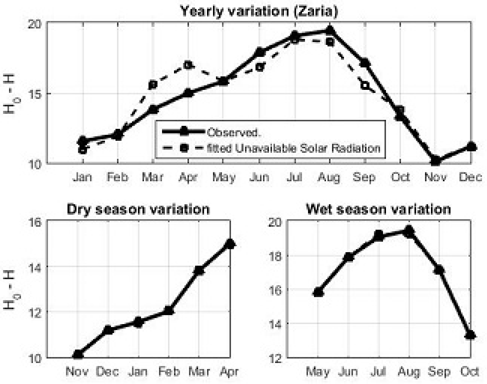

Fig. 14 plots of observed and fitted unavailable solar radiation

5 Conclusion

In this paper we have obtained empirical formulae for estimating unavailable solar radiation in terms of cloud cover, relative sunshine duration and relative humidity for fourteen (14) meteorological stations. For yearly fits, equation (1) gives the best fit Enugu, Jos and Potiskum, meaning that relative humidity is an important climatological independent variable for estimating unavailable solar radiation for these stations, equation (3) gives best fit for the data of Ikom and Nguru, these stations do not require relative humidity for correlating unavailable solar radiation.

References:

[1] Aidan J., Yadima A., Ododo J.C. (2005). Modelling Unavailable Solar Radiation Using Some Climatological Parameters. *Nigerian Journal of Solar energy*, *15,* 118-126.

[2] Ododo J.C., Agbakwuru. J.A. & Ogbu F.A. (1995). Correlation of Solar Radiation with Cloud Cover and Relative Sunshine Duration. *Energy Convers. Mgmt*, *.37*(10), 1555-1559

[3] Ojosu J.O. (1990). A Correlation of Global Solar Radiation with Cloud Cover and Sunshine Hours. *Nigerian Journal of Solar Energy, 9,* 133-142

[4] Fagbenle R.O. (1990). Estimation of Total Radiation in Nigeria Using Meteorological data. *Nigerian Journal of Renewable Energy, 1,* 1 – 10

[5] Ododo J.C., Sulaiman A.T., Aidan J., Yuguda M.M. & Ogbu F. A. (1995). The Importance of Maximum Air Temperature in the Parameterization of Solar Radiation in Nigeria. *Journal of Renewable Energy 6(7),* 751-763

[6] Ododo J.C. & Sulaiman A.T. (1994, May). Angstrom’s Regression Coefficients for Nigerian Stations. Paper presented at the 2nd OAU/STRC Symposium on New, Renewable and Solar Energies Organized in Collaboration with UNESCO/ROSTA, Bamako, Mali

[7] Ododo J.C. (1994, May). New Model Equations for the Prediction of Solar Radiation in Nigeria. Paper presented at the 2nd OAU/STRC Symposium on New, Renewable and Solar Energies Organized in Collaboration with UNESCO/ROSTA, Bamako, Mali

[8] Ododo J.C., Sulaiman A.T., Aidan J. & Ogbu F.A (1994, May). Modelling of Solar Radiation in North-Eastern Nigeria. Paper presented at the 2nd OAU/STRC Symposium on New, Renewable and Solar Energies Organized in Collaboration with UNESCO/ROSTA, Bamako, Mali.