Correlation of Unavailable Solar Radiation Using Some Climatological Parameters for Some Nigerian Stations

EYUBE EDWIN SAMSON
Department of Physics
School of Physical Sciences
Modibbo Adama University of Technology
P.M.B. 2076, Yola, Adamawa State
NIGERIA
edwineyubes@mautech.edu.ng

NAJOJI SUNDAY DAVID
Department of Basic Sciences
School of General and Remedial Studies
The Federal Polytechnic
P.M.B. 1006, Damaturu, Yobe State
NIGERIA
najojis@gmail.com

ALKASIM ABUBAKAR
Department of Physics
School of Physical Sciences
Modibbo Adama University of Technology
P.M.B. 2076, Yola, Adamawa State
NIGERIA
alkasimabbat@gmail.com

Abstract:- We have correlated unavailable solar radiation in terms of relative sunshine duration, relative humidity and cloud cover for fourteen (14) meteorological stations in Nigeria: Bauchi, Bida, Enugu, Gusau, Ikom, Jos, Kano, Maiduguri, Minna, Nguru, Potiskum, Yelwa, Yola and Zaria. For about 71% of the stations studied our proposed model equation gave the best-fit-equation for yearly fits, except for Gusau, Jos, Maiduguri and Potiskum where the equation proposed by Aidan et al. gave the best-fit-equation. The adjusted coefficient of determination, $R_a^2 \geq 0.95$ for most of the stations.

Key-words: cloud cover, relative humidity, relative sunshine duration, model equations

1 Introduction

Over the past years researchers have established model equations for correlating total daily solar radiation on a horizontal surface, H, clearness index, H/H_0, (H_0 is the extraterrestrial daily solar radiation on a horizontal surface), unavailable solar radiation, $H_0 - H$ in terms of climatological parameters, usually, relative humidity, R, maximum air temperature, T_m, cloud cover, C or relative sunshine duration, S/S_0, where S is the bright sunshine duration and S_0 is the day length. Some of these model equations have been applied to some Nigerian stations [1 – 10]. Aidan *et al.* [3] modelled unavailable solar radiation in terms of relative sunshine duration, relative humidity and cloud cover in a five parameter model equation, the equation was applied to seven meteorological stations in Nigeria: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola, the result shows high correlation for both yearly and seasonal fits. In this paper we have proposed a five parameter model equation involving relative sunshine duration, relative humidity and cloud cover, the equation, together with that used by [3] were applied to fourteen meteorological stations in Nigeria, the result shows that our proposed equation gives the best-model-equation for yearly fits for most of the stations except for Jos, Maiduguri, Potiskum and Gusau.

2 Model Equations

In this paper, we have used the equation proposed by Aidan *et al*. [3] in the modelling of unavailable solar radiation, given by:

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

where H' = H_0 – H is the unavailable solar radiation and the $\alpha_i's$ are constants. This equation has been used on seven meteorological stations in Nigeria: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola. We have proposed an equation similar to equation (1) where the last term in equation (1) is replaced by $\alpha_{13}(S/S_0)C$, which leads to:

$$H' = \alpha_0 + \alpha_1(S/S_0) + \alpha_2 R + \alpha_3 C + \alpha_{13}(S/S_0)C \tag{2}$$

3 Data and Analysis

All the data for the fourteen stations have been tabulated elsewhere [8 - 10]. Multiple linear regression analysis was carried out using equations (1) and (2) for both yearly and seasonal fits, the seasonal variation we have used in the analysis are dry (November - April) and wet (May – October) seasons. The goodness-of-fit indices used are the adjusted coefficient of determination R_a^2, standard error $Se\,H'$, the largest percentage error, LPE, Absolute Average Percentage Error, AAPE and the residual sum of squares Δ. These goodness-of-fit indices have been defined elsewhere [8] – [10].

4 Results and Discussion

The results of regression analysis for each of the fourteen stations are presented in Tables 1 – 14 (shown in appendix A). Plots of observed and fitted unavailable solar radiation are presented in appendix B.

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

The regression parameters for both yearly and seasonal fits are shown in Table 1(a). For yearly variation equation (2) has better values of $Se\,H'$, R_a^2 and Δ, both have LPE$\approx$3% and AAPE$\approx$1%, thus, equation (2) gives a better model equation than (1), with the near perfect fit given by equation (2), there is no need for seasonal fit, however, the fits given in the Table is a confirmation for the applicability of equation (2). Fig. 1 (a) shows a plot of observed and fitted yearly unavailable solar radiation for Bauchi.

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

Table 1(b) shows the regression parameters for Bida, for yearly variation, equation (2) with $Se\,H'$ = 0.9451, R_a^2 = 0.9220, Δ = 6.25 and LPE = 6.7% gives the best-fit-equation for yearly fits. If we consider seasonal fits, equations (1) and (2) gives best-fit-equations for dry and wet seasons respectively. For dry season, $Se\,H'$ = 0.3514, R_a^2 = 0.9562, Δ = 0.12 and LPE = 1.5%, these values show improvement above yearly fits, and for wet season $Se\,H'$ = 1.5288, R_a^2 = 0.6110, Δ = 2.34 and LPE = 5%, these values are not improvements above yearly fits. Shown in Fig. 1 (b) is a plot of observed and fitted yearly unavailable solar radiation for Bida.

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

Regression parameters and goodness-of-fit indices are shown in Table 1(c), equation (2) provides the best-fit-equation for yearly variation, where, $Se\,H'$ = 0.3431, R_a^2 = 0.9808, Δ = 0.82 and LPE = 2.3%. For seasonal fits, equations (1) and (2) give best-fit equations for dry and wet seasons respectively, the values of $Se\,H'$, R_a^2, Δ and LPE shows improvement above yearly fits except for wet season which has $Se\,H'$ = 0.4295, R_a^2 = 0.9333 below yearly fits. The plot shown in Fig. 1 (c) is a plot of observed and fitted yearly unavailable solar radiation for Enugu.

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

Table 2(a) shows the regression parameters for the data of Gusau result for yearly fits shows that equation (1) gives the best-fit with large value of LPE = 11.4%. If we consider seasonal fits, equations (2) and (1) gives best-fit-equations, where LPE = 5.1% and 0.9% for dry and wet seasons respectively, these are improvements above yearly fits. Fig. 1 (d) is a plot of observed and fitted yearly unavailable solar radiation for Gusau.

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

Regression parameters are shown in Table 2(b). Equation (2) gives best model equation for yearly variation in which $Se\,H'$ = 0.4143, R_a^2 = 0.9740, Δ = 1.2 and LPE = 3.2%, seasonal fits further confirms the applicability of yearly fits in which equation (2) gives the best model equation for both dry and wet seasons, with improved values of R_a^2, Δ, LPE and AAPE, except for dry season in which R_a^2 = 0.8863. Fig. 1 (e) is a plot of observed and fitted yearly unavailable solar radiation for Ikom.

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

Table 2(c) shows the regression parameters for yearly and seasonal variations, for yearly fits $Se\,H'$ = 0.2762, R_a^2 = 0.9962, Δ = 0.53 and LPE = 2.4%, where equation (1) gives the best model equation. Seasonal fits further affirms the result of yearly fits where $R_a^2 \geq 0.99$ for the two seasons, with slight improvements in the values of $Se\,H'$, R_a^2, Δ, LPE and AAPE. Equations (1) and (2) give best-fit-equations for dry and wet seasons respectively. Fig. 1 (f) is a plot of observed and fitted yearly unavailable solar radiation for Jos.

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

Table 3(a) shows the regression parameters. Equation (2) gives best model equation: $Se\,H'$ = 0.4167, R_a^2 = 0.9751, Δ = 1.22, LPE = 3.9%, thus, one can confidently use the data for yearly fits to predict unavailable solar radiation. If we consider seasonal fits, equation (1) gives the best model equation for both dry and wet season, where $R_a^2 \geq 0.987$, the values of $Se\,H'$, Δ, LPE and AAPE are much better when compared to yearly fits. The plot in Fig. 1 (g) is a plot of observed and fitted yearly unavailable solar radiation for Kano.

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

Shown in Table 3(b) are the regression parameters, best-fit-equation is provided by equation (1); $Se\,H'$ = 0.6685, R_a^2 = 0.9401, Δ = 3.13, and high value of LPE = 14.1%.result of seasonal fit indicates that equations (1) and (2) give best model equations for dry and wet seasons, with better values of $Se\,H'$, $R_a^2 (\geq 0.995)$, Δ, LPE and AAPE above yearly fits. Therefore, seasonal variation can best be used to obtain unavailable solar radiation. Fig. 1 (h) is a plot of observed and fitted yearly unavailable solar radiation for Maiduguri.

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

The regression parameters are shown by the entries in Table 3(c). The result for yearly fits gives R_a^2 =0.9511, $Se\,H'$ =0.8763, Δ =5.37 and LPE = 7.4% and equation (2) gives the best model equation. Result of seasonal fits shows that equation (2) and (1) gives best model equations for dry and wet seasons, with values of Δ, LPE and AAPE only slightly better than the corresponding yearly variation, and R_a^2 =0.9187 and 0.6961 for dry and wet seasons. Fig. 1 (i) is a plot of observed and fitted yearly unavailable solar radiation for Minna.

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

Table 4(a) is the result of regression analysis and goodness-of-fit indices. Equation (2) is the best-fit-equation for yearly fits, where $Se\,H'$ = 0.5771, R_a^2 = 0.9316, Δ = 2.34, LPE = 6.6%. In conformity with yearly fits, equation (2) is also the best-fit-equation for seasonal fits; R_a^2 = 0.9998 and 0.7714 for dry and wet seasons respectively, the values of Δ and AAPE are slightly better than for yearly variation. It means that equation (2) can be used to obtain an estimate of unavailable solar radiation for Nguru. The plot in Fig. 1 (j) is a plot of observed and fitted yearly unavailable solar radiation for Minna.

4.11 Potiskum (11.7072^{0}N, 11.0825^{0}E)
The data shown in Table 4(b) is the regression parameter and goodness-of-fit indices for Potiskum. Model equation (1) gives the best-fit-equation for both yearly and seasonal variation. For yearly fits, R_a^2 = 0.9841, $Se\,H'$ = 0.3615, Δ = 0.91 and LPE = 2.9%, and for seasonal fits, R_a^2 = 0.9906 and 0.9908 for dry and wet seasons respectively, the result of seasonal variation also shows that $Se\,H'$, C and LPE do not vary considerably from yearly fits, thus, it is obvious that there is no need for seasonal fits, as good estimates of unavailable solar radiation can be obtained from yearly fits. Fig. 1 (k) is a plot of observed and fitted yearly unavailable solar radiation for Potiskum.

4.12 Yelwa (10.8370^{0}N, 4.7433^{0}E)
Table 4 (c) is the result of regression analysis, model equation (2) gives best-fit-equation for yearly fits, in which case, $Se\,H'$ = 0.9142, R_a^2 = 0.9279, Δ = 5.85 and LPE = 8.7%. the result for seasonal fits indicates that R_a^2 = 0.9988 and 0.6830 for dry and wet seasons respectively, where model equations (1) and (2) gives best-fit equations for the two seasons, the values of LPE and AAPE for wet season do not vary significantly from the corresponding values of yearly fits, it means that yearly fits can be used to obtain estimates of unavailable solar radiation from model equation (2). Shown in Fig. 1 (l) is a plot of observed and fitted yearly unavailable solar radiation for Yelwa

4.13 Yola (9.2035^{0}N, 12.4954^{0}E)
Parameters of regression analysis are shown in Table 5(a). Model equation (2) gives best-fit-equation for yearly variation where the values of Δ(= 23.6), LPE (= 13.3%) and AAPE (= 6.6%) are high, $Se\,H'$ = 1.8376 and R_a^2 = 0.7947, if we consider fits for wet season, the results are not encouraging due to large values of Δ(= 13.31), LPE (= 13.2%) and AAPE (= 5.4%), only for dry season are these parameters better than yearly fits. As it appears, equation (2) gives the best-fit-equation, it does not give a good estimate of unavailable solar radiation. Fig. 1 (m) is a plot of observed and fitted yearly unavailable solar radiation for Yola.

4.14 Zaria (11.0855^{0}N, 7.7199^{0}E)
Parameters of regression analysis are shown in Table 5(b), where model equation (2) gives best-fit-equation for yearly fits, as indicated in the Table, the values of Δ(= 13.13), LPE (= 11.7%) AAPE (= 6.3%) and $Se\,H'$ = 1.3695 are high, R_a^2 = 0.8156, thus, there is the need to consider seasonal fits, equations (1) and (2) gives the best-fit-equation for dry and wet seasons, also the values of $Se\,H'$, Δ, LPE and AAPE are greatly improved and $R_a^2 \geq 0.99$ for the two seasons, thus, there is the need to employ seasonal parameters to obtain better estimates of unavailable solar radiation. Fig. 1 (n) is a plot of observed and fitted yearly unavailable solar radiation for Yola.

5 Conclusion
In this paper we have correlated unavailable solar radiation using some climatological parameters on fourteen Nigerian stations: Bauchi, Bida, Enugu, Gusau, Ikom, Jos, Kano, Maiduguri, Minna, Nguru, Potiskum, Yelwa, Yola and Zaria. Result of yearly and seasonal fits shows that high values of adjusted correlation were obtained, most of the stations (about 71% for yearly fits and 50% for seasonal fits) have our proposed model equation as the best-fit-equations, with relatively good values of $Se\,H'$, Δ, LPE and AAPE for most of the station. We intend to extend this work to cover more stations with available data.

References:

[1] Sambo A.S. (1986). Empirical Models for the Correlation of Global Solar Radiation with Meteorological Data for

Northern Nigeria. *Solar & wind technology, 3,* 89 - 93.

[2] Ojosu J.O (1990). On The Bounds for Global Solar Radiation Estimates from Sunshine Hours for Nigerian Cities. *Nigerian journal of solar energy, 9,* 123 - 132.

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

[4] 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.

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

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

[7] 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.

[8] 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 Organised in Collaboration with UNESCO/ROSTA, Bamako, Mali.

[9] 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 Organised in Collaboration with UNESCO/ROSTA, Bamako, Mali.

[10] 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.

APPENDIX A

Results of Regression Parameters for Fits Using Relative Sunshine Duration, Relative Humidity and Cloud Cover

Table 1. Regression parameters for fits using S/S_0, R and C

(a) Bauchi		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn(1)	24.0364	-15.5182	-2.4357	0.0821	…	1.1770	0.2391	0.9925	0.40	2.7	0.9
	Eqn(2)	15.2298	-3.8805	4.3051	1.9687	-2.6053	…	0.2333	0.9928	0.38	3.4	1.0
D	Eqn(1)	0.4884	-1.5303	14.0669	3.6878	…	-4.8506	0.1888	0.9857	0.04	1.0	0.4
	Eqn(2)	20.8766	-23.5028	-4.2787	-0.8880	4.7298	…	0.1549	0.9904	0.02	0.9	0.4
W	Eqn(1)	33.7065	-23.7924	-1.2337	-0.6986	…	0.9486	0.1823	0.9909	0.03	0.8	0.3
	Eqn(2)	24.8707	-15.5053	4.4317	0.7230	-1.2893	…	0.1853	0.9906	0.03	0.8	0.3
(b) Bida		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn(1)	21.9494	-23.0941	12.0052	0.8887	…	-1.1519	0.9564	0.9201	6.40	7.3	3.3
	Eqn(2)	19.1365	-13.2909	3.2569	1.4079	-1.4087	…	0.9451	0.9220	6.25	6.7	3.1
D	Eqn(1)	39.7517	-11.1185	-50.9109	-4.7496	…	12.7576	0.3514	0.9562	0.12	1.5	0.9
	Eqn(2)	24.0809	-24.5847	12.5460	-0.2569	0.4170	…	1.1724	0.5125	1.37	4.3	2.8
W	Eqn(1)	406.7277	-47.0911	-487.7324	-54.7613	…	72.9938	1.6394	0.5527	2.69	5.4	2.0
	Eqn(2)	-2691.2593	3898.7826	-86.1495	395.3277	-538.0340	…	1.5288	0.6110	2.34	5.0	1.9
(c) Enugu		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn(1)	34.4031	-16.8987	-23.1812	0.5273	…	1.7114	0.3649	0.9783	0.93	2.4	1.2
	Eqn(2)	34.6261	-28.6580	-11.0006	0.3839	1.6488	…	0.3431	0.9808	0.82	2.3	1.1
D	Eqn(1)	40.4205	-21.8692	-26.0933	-1.4263	…	4.2092	0.1190	0.9958	0.01	0.5	0.2
	Eqn(2)	21.2880	-10.3316	-0.1844	2.6126	-3.9680	…	0.3514	0.9634	0.12	1.3	0.6
W	Eqn(1)	150.9741	-20.2197	-164.2833	-17.2264	…	23.3789	0.5343	0.8967	0.29	1.6	0.9
	Eqn(2)	199.8857	-295.9624	-81.4789	-16.1379	42.1631	…	0.4295	0.9333	0.18	1.4	0.7

Table 2. Regression parameters for fits using S/S_0, R and C

(a) Gusau		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	21.1664	-7.7936	-33.1561	-1.0923	…	6.9727	0.8238	0.9523	4.75	11.4	4.1
	Eqn (2)	-0.2916	8.7021	8.5002	2.9935	-3.4715	…	1.3793	0.8662	13.32	10.5	6.5
D	Eqn (1)	30.3703	-18.0277	-31.8330	-1.7853	…	6.9415	1.2991	0.3332	1.69	11.0	3.5
	Eqn (2)	-139.0834	266.4027	-9.0105	35.5321	-62.1787	…	0.8095	0.7411	0.66	5.1	2.5
W	Eqn (1)	117.3223	-11.3074	-156.3735	-17.2610	…	28.0288	0.2312	0.9940	0.05	0.9	0.4
	Eqn (2)	-104.4879	153.8658	9.6068	19.1669	-26.0453	…	0.8609	0.9170	0.74	2.7	1.5
(b) Ikom		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	31.2050	-23.6788	-15.0941	0.3550	…	1.4491	0.4203	0.9733	1.24	3.3	1.4
	Eqn (2)	34.3889	-48.9957	-5.8192	-0.0085	3.6416	…	0.4143	0.9740	1.20	3.2	1.3
D	Eqn (1)	9.9633	-21.3467	13.3271	3.7680	…	-3.3805	0.6649	0.5479	0.44	2.1	1.5
	Eqn (2)	74.7480	-140.7060	-4.5764	-8.1593	21.7112	…	0.3335	0.8863	0.11	1.5	0.6
W	Eqn (1)	-22.6917	-28.7484	81.9180	8.4615	…	-12.6888	0.1517	0.9958	0.02	0.5	0.2
	Eqn (2)	265.4735	-496.5929	-11.6540	-31.8070	65.5458	…	0.1502	0.9959	0.02	0.5	0.2
(c) Jos		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	26.2674	-18.0583	-14.8072	0.4252	…	2.3234	0.2762	0.9962	0.53	2.4	1.1
	Eqn (2)	31.1338	-23.9416	1.8127	-0.0808	0.0877	…	0.3078	0.9952	0.66	3.3	1.0
D	Eqn (1)	32.3501	-23.5821	-8.5981	-0.1837	…	1.4608	0.0847	0.9992	0.01	0.6	0.2
	Eqn (2)	41.3229	-34.8342	3.1479	-1.7859	1.6485	…	0.0760	0.9993	0.01	0.4	0.2
W	Eqn (1)	34.1775	-24.5975	-40.5646	1.0381	…	4.3098	0.2248	0.9926	0.05	0.9	0.4
	Eqn (2)	15.6866	-11.7536	-13.2163	4.2350	-2.5402	…	0.2261	0.9925	0.05	0.9	0.4

Table 3. Regression parameters for fits using S/S$_0$, R and C

(a) Kano		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	15.2105	-9.8210	-1.4830	0.8591	…	0.8669	0.4330	0.9731	1.31	4.3	1.9
	Eqn (2)	8.6950	-1.7324	2.4226	2.6379	-2.2792	…	0.4167	0.9751	1.22	3.9	1.9
D	Eqn (1)	14.7743	-6.4688	-11.0808	0.1499	…	4.3861	0.1478	0.9868	0.02	1.2	0.4
	Eqn (2)	1.4861	9.1246	2.3739	4.9869	-5.8726	…	0.2594	0.9593	0.07	2.0	0.9
W	Eqn (1)	16.8906	-42.8075	57.9475	4.9731	…	-10.9639	0.0973	0.9978	0.01	0.4	0.2
	Eqn (2)	120.5964	-154.7698	1.4780	-15.0041	21.4657	…	0.4775	0.9460	0.23	2.6	1.1
(b) Maiduguri		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	21.2899	-13.3746	-33.0519	-0.0080	…	5.3935	0.6685	0.9401	3.13	14.1	3.9
	Eqn (2)	14.6837	-8.4143	-2.3288	2.5518	-2.9598	…	0.7330	0.9279	3.76	15.0	4.1
D	Eqn (1)	38.6266	-23.9247	-47.4076	-2.3193	…	9.6735	0.1773	0.9873	0.03	1.6	0.7
	Eqn (2)	16.1249	-4.7858	-6.5654	2.7021	-4.1705	…	0.3065	0.9620	0.09	2.8	1.2
W	Eqn (1)	2.2108	-34.8287	48.5065	6.3680	…	-9.8337	0.6219	0.9439	0.39	3.1	1.5
	Eqn (2)	57.5917	-88.1934	-6.2584	-4.5036	10.9354	…	0.5561	0.9552	0.31	2.6	1.3
(c) Minna		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	25.4302	-21.5756	-6.8887	1.5308	…	0.1145	0.8782	0.9509	5.40	7.5	2.8
	Eqn (2)	29.4869	-27.2903	-5.4963	0.8744	0.8039	…	0.8763	0.9511	5.37	7.4	2.7
D	Eqn (1)	27.0269	-24.1187	-4.8170	1.5730	…	-0.3719	0.6043	0.9184	0.37	3.6	1.5
	Eqn (2)	31.2183	-29.6238	-6.4400	0.4805	1.4594	…	0.6034	0.9187	0.36	3.6	1.5
W	Eqn (1)	-625.2750	-48.1615	886.8523	105.9435	…	-139.6802	1.7560	0.6961	3.08	5.4	2.5
	Eqn (2)	206.6846	-241.9920	-31.4304	-20.8311	29.7339	…	1.9670	0.6187	3.87	5.0	3.2

Table 4. Regression parameters for fits using S/S_0, R and C

(a) Nguru		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	18.4572	-13.2209	5.5434	0.4299	…	0.0402	0.5908	0.9285	2.44	6.2	2.7
	Eqn (2)	8.0268	0.2164	5.2260	2.4216	-2.5411	…	0.5779	0.9316	2.34	6.6	2.4
D	Eqn (1)	25.4950	-14.1507	-19.9306	-1.0164	…	5.8855	0.3754	0.8699	0.14	2.2	1.2
	Eqn (2)	-6.4313	22.9918	6.2625	5.6071	-7.6644	…	0.0133	0.9998	0.00	0.1	0.0
W	Eqn (1)	5.6379	-13.0134	1.0297	3.5640	…	-0.9001	0.8799	0.7758	0.77	4.4	1.9
	Eqn (2)	4.3776	-4.7069	-3.3951	3.9739	-1.8527	…	0.8767	0.7774	0.77	5.0	1.9
(b) Potiskum		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	7.4890	-5.2958	-24.1252	1.8932	…	3.9982	0.3615	0.9841	0.91	2.9	1.8
	Eqn (2)	-20.4995	29.0046	-0.8301	7.4993	-7.0824	…	0.4375	0.9767	1.34	4.9	2.3
D	Eqn (1)	11.5662	-1.1966	-72.1641	0.5562	…	13.0569	0.1574	0.9906	0.02	1.3	0.4
	Eqn (2)	-68.2009	94.7281	-16.8226	16.6166	-18.9875	…	0.2159	0.9823	0.05	1.7	0.6
W	Eqn (1)	7.3535	-17.3375	0.4993	3.5040	…	-0.5864	0.2126	0.9908	0.05	0.9	0.5
	Eqn (2)	10.4170	-19.3316	-3.0584	2.9811	0.3523	…	0.2198	0.9902	0.05	1.0	0.5
(c) Yelwa		α_0	α_1	α_2	α_3	α_{13}	α_{23}	$Se\,H'$	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	26.2400	-17.3830	-7.2096	-0.4024	…	2.0783	0.9173	0.9274	5.89	9.7	3.5
	Eqn (2)	4.2111	6.8945	2.0994	3.9346	-4.6361	…	0.9142	0.9279	5.85	8.7	4.0
D	Eqn (1)	34.5885	-13.9857	-39.6498	-3.2051	…	10.1737	0.0657	0.9988	0.00	0.4	0.2
	Eqn (2)	-61.2882	98.6072	-6.8060	19.0603	-25.2949	…	0.5723	0.9081	0.33	2.7	1.7
W	Eqn (1)	151.2554	-31.6012	-183.5730	-16.8181	…	26.8756	1.6491	0.5841	2.72	6.5	2.9
	Eqn (2)	3472.7560	-4864.4346	39.5180	-513.5233	712.5534	…	1.4396	0.6830	2.07	6.1	2.5

Table 5. Regression parameters for fits using S/S_0, R and C

(a) Yola		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	45.0945	-11.4321	-101.3672	-4.1001	…	16.8636	1.8543	0.7909	24.07	15.0	5.6
	Eqn (2)	-124.7057	183.5902	3.1041	23.9695	-32.4438	…	1.8376	0.7947	23.64	13.3	6.6
D	Eqn (1)	27.4095	-6.3727	-57.4880	-1.7231	…	9.6747	1.2184	0.3513	1.48	5.4	3.3
	Eqn (2)	-81.7245	128.5886	-2.1897	17.5782	-24.0161	…	1.0564	0.5123	1.12	5.5	3.1
W	Eqn (1)	827.3135	-85.9112	-964.8591	-113.1821	…	143.6787	3.6479	-0.0038	13.31	13.2	5.4
	Eqn (2)	610.8290	-532.1582	-5.9410	-75.9080	59.0311	…	3.7499	-0.0608	14.06	12.7	5.4
(b) Zaria		α_0	α_1	α_2	α_3	α_{13}	α_{23}	SeH'	R_a^2	Δ	LPE(%)	AAPE(%)
Y	Eqn (1)	-33.2995	-19.7613	36.2869	8.6412	…	-4.8017	1.4602	0.7904	14.93	13.7	6.2
	Eqn (2)	-213.0738	250.8715	2.5280	34.4711	-38.8425	…	1.3695	0.8156	13.13	11.7	6.3
D	Eqn (1)	-38.4882	-9.0982	291.9392	8.8631	…	-46.0718	0.1945	0.9883	0.04	1.2	0.5
	Eqn (2)	-576.3516	932.0619	-16.9814	87.7763	-138.4298	…	0.2600	0.9791	0.07	1.6	0.7
W	Eqn (1)	-167.8404	-15.0819	24.6388	27.7740	…	-3.3334	0.9366	0.8305	0.88	4.0	1.9
	Eqn (2)	447.1730	-1121.4166	4.2848	-61.3568	160.0246	…	0.1864	0.9933	0.03	0.7	0.4

APPENDIX B

Plot of Observed and Fitted Yearly Unavailable Solar Radiation versus Months of the Year

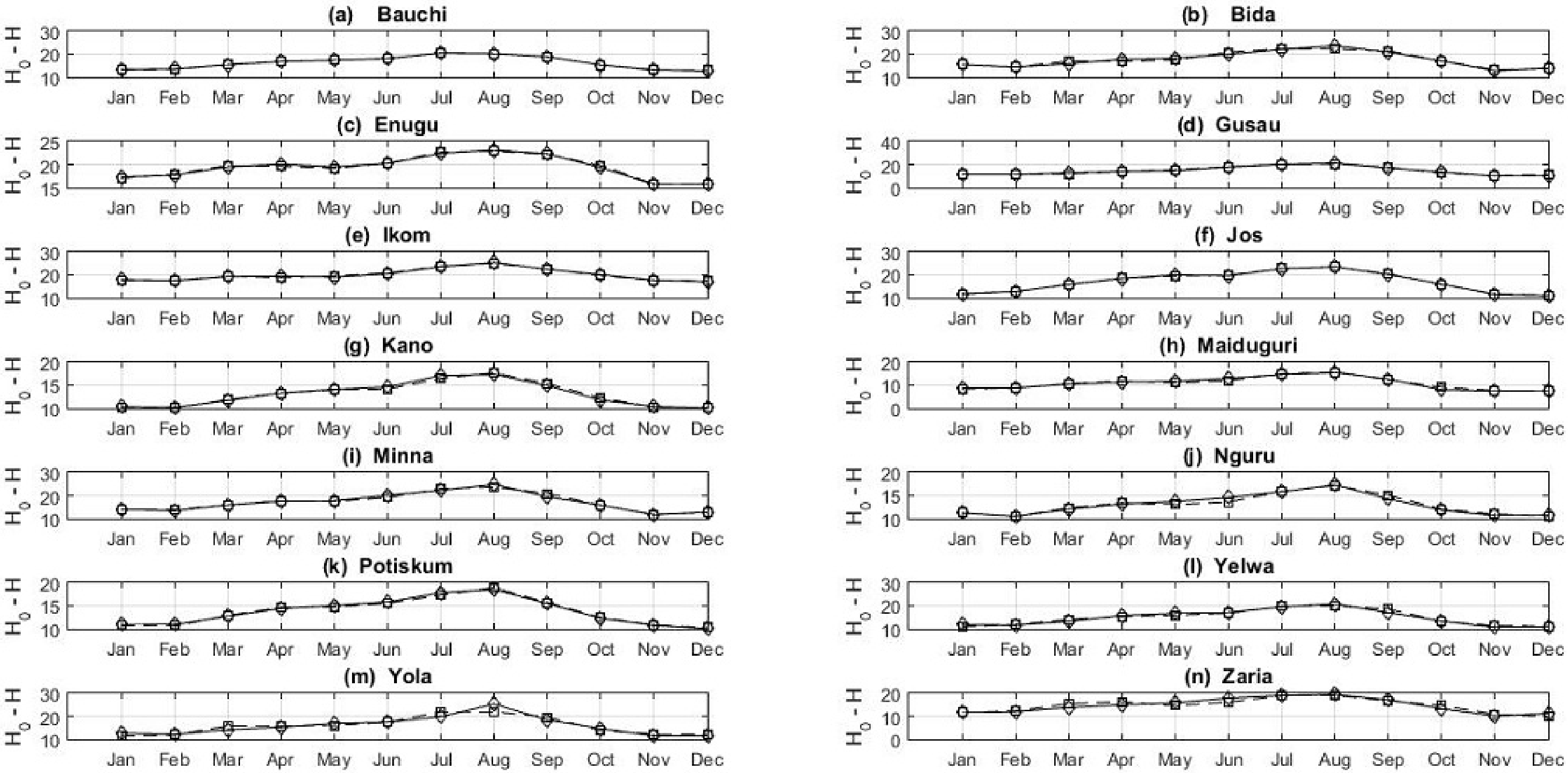

Fig. 1. Plot of observed (solid line) and fitted (dash line) yearly unavailable solar radiation versus months of the year for the fourteen station