Prediction Equations for the Parameterization of Clearness Index and Unavailable Solar Radiation in Terms of Some Climatological Parameters for Some Nigerian Stations

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Abstract: The choice of prediction equation for the parameterization of clearness index and unavailable solar radiation in terms of relative sunshine duration, relative humidity and cloud cover have been carefully analyzed. In a previous study, these equations were applied to seven meteorological stations in Nigeria: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola, the result shows that high correlation was obtained for most stations when unavailable solar radiation is used as the dependent variable. In this paper we have extended the study to include seven other meteorological stations in Nigeria: Bida, Enugu, Gusau, Ikom, Minna, Yelwa and Zaria. The result shows that with unavailable solar radiation as the dependent variable, high correlation ($R_a^2 >$ 0.92) is obtained for yearly fits for most of the stations, except for Zaria where $R_a^2 = 0.7904$

Key words: climatological parameters, model equations, unavailable solar radiation, cloud cover

1 Introduction

Previously, scientist have been engaged with the problem of measuring solar radiation using the pyranometer, this instrument, not only that it is expensive, there is also the need of true timely insolation data. In other to overcome this difficulty, researchers have developed mathematical equations to be used to obtain estimates of total daily solar radiation on a horizontal surface, H ($MJm^{-2}day^{-1}$); clearness index, H/H_0 (H_0 also in $MJm^{-2}day^{-1}$, is the extraterrestrial daily radiation on a horizontal surface) or unavailable solar radiation, $H_0 – H$, in terms of some climatological parameters, usually; relative humidity, R; maximum air temperature, T_m (^0C); cloud cover, C (in oktas) or relative sunshine duration, S/S_0 (S is the bright sunshine duration and S_0 is the day-length, both measured in hours) [1] – [8]. Aidan *et al*. [1] used both H/H_0 as well as $H_0 – H$ to model S/S_0, R and C in a five parameter model equations, the equations were applied to seven meteorological stations in Nigeria: Bauchi, Jos, Kano, Maiduguri, Potiskum, Nguru and Yola. The result shows that most of the stations have their best-fit-equations with $H_0 – H$ as the dependent variable than with H/H_0. In this study we have used equations in [1] to obtain regression parameters for seven meteorological stations in Nigeria: Bida, Enugu, Gusau, Ikom, Minna, Yelwa and Zaria and also chose best-model-equation for each of the stations, the result shows that for yearly fits, 86% of the stations, except Gusau, have their best-fit-equations when $H_0 – H$ is the independent variable, for seasonal fits, 71% of the stations excluding Bida and Gusau have their best-model-equation when $H_0 – H$ is the dependent variable for the dry season and for the wet season, 71% of the stations except Yelwa and Zaria give best-fit with H/H_0 as the dependent variable.

2 Model Equations

Aidan *et al*. modelled clearness index, H/H_0 as well as unavailable solar radiation, $H_0 – H$ in terms of three climatological parameters: relative sunshine duration, S/S_0, relative humidity, R and cloud cover, C. in a five parameter model equations, these equations are [1]:

$$H/H_0 = \alpha_0 + \alpha_1(S/S_0) + \alpha_2 R + \alpha_3 C + \alpha_{23} RC \tag{1}$$

and

$$H' = \alpha_0 + \alpha_1(S/S_0) + \alpha_2 R + \alpha_3 C + \alpha_{23} RC \tag{2}$$

where $H' = H_0 - H$ is the unavailable solar radiation and the $\alpha_i^{'}s$ are constant coefficients. Equations (1) and (2) have been used on seven Nigerian meteorological stations, viz: Bauchi, Jos, Kano, Maiduguri, Nguru, Potiskum and Yola [1].
In this paper, we have applied equations (1) and (2) on seven other Nigerian stations: Bida, Enugu, Gusau, Ikom, Minna, Yelwa and Zaria.

3 Results and Discussion

Results of regression parameters for fits using relative sunshine duration, relative humidity and cloud cover are presented in Appendix A. also, Plots of observed and fitted yearly unavailable solar radiation versus months of the year for the seven stations studied are shown in Appendix B.

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

Regression parameters for both yearly and seasonal fits are shown in Table 1 (a). For the yearly fit, equation (2) gives the best-fit-equation but SeH' (0.9564), Δ(6.4) and LPE (7.3%) are relatively high. However, if we consider seasonal fits, equation (1) gives the best-fit-equation for the two seasons with $\Delta(\approx 0)$, LPE (0.1% for the dry season and 8.4% for the wet season), Se = 0.0008 and 0.0398 for dry and wet seasons respectively, thus, seasonal fits are satisfactory.
Figure 1 (a) shows the plot of observed and fitted yearly unavailable solar radiation for Bida

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

The corresponding fits for both Enugu are shown in Table 1 (b). The yearly fit given by equation (2) as the best-fit-equation with R_a^2 = 0.9783, Δ = 0.93 and LPE = 2.4% is quite satisfactory. Therefore, there is no need for seasonal fit. Figure 1 (b) shows the plot of observed and fitted yearly unavailable solar radiation for Enugu

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

The parameters for yearly and seasonal fits are listed in Table 1 (c). Yearly fit given by equation (1) as the best-model-equation, with Se = 0.0129, R_a^2 = 0.9738, and LPE = 2.8% is satisfactory. From the Table, it can be seen that equation (1) with LPE = 1.1% for dry season and 2.3% for wet season confirms the applicability of equation (1) as the best-model-equation for Gusau. Shown in Figure 1 (c) is the plot of observed and fitted yearly clearness index for Gusau

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

Table 2 (a) shows regression parameters for both yearly and seasonal variation of Ikom. Fit given by equation (2) in which R_a^2 = 0.9733, Δ = 1.24 and LPE = 3.3% as the best-fit-equation is quite satisfactory, therefore, there is no need for seasonal fit. Figure 1 (d) shows the plot of observed and fitted yearly unavailable solar radiation for Ikom

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

The parameters of regression analysis for Minna are shown in Table 2 (b), the yearly fit given by equation (2) is the best-fit-equation, but the values of SeH'(0.8782), Δ(5.4) and LPE (7.5%) are relatively high. If we consider seasonal fits, equations (1) and (2) gives respectively the best-fit-equations for dry and wet seasons, R_a^2 > 0.927 for the two seasons, LPE is 2.6% for dry season and 6.6% for wet season, thus, seasonal fit is satisfactory for Minna. Shown in Figure 1 (e) is the plot of observed and fitted yearly unavailable solar radiation for Minna

3.6 Yelwa (10.8370^{0}N, 4.7433^{0}E)

The data shown in Table 2 (c) is the result of regression analysis for Yelwa, yearly fit given by equation (2) gives the best-fit-equation, but is not satisfactory due to relatively high LPE (9.7%), consideration of seasonal fits shows that equation (2) gives best-fit-equation for the two seasons, LPE is 2.6% for dry season and 6.6% for wet season, R_a^2 > 0.927 for both seasons. Figure 1 (f) shows the plot of observed and fitted yearly unavailable solar radiation for Yelwa

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

The corresponding fits for Zaria are listed in Table 2 (d). For the yearly fits equation (2) gives the best-fit-equation but with a relatively high value of LPE (13.7%), thus yearly fit is not satisfactory. The result for seasonal fit shows that best-model-equation is provided by equation (2), LPE is 1.5% and 3.6% for dry and wet season. R_a^2 (= 0.9803 for dry season and 0.8098 for wet season). Thus, seasonal fits are satisfactory. Figure 1 (g) shows the plot of observed and fitted yearly unavailable solar radiation for Zaria

4 Conclusion

In this study we have been able to choose the best-model-equations between the correlation of clearness index and unavailable solar radiation as dependent variables in terms of relative sunshine duration, relative humidity and cloud cover in a five-parameter model equations. The result show that for yearly and seasonal fits, best-model-equations are obtained when unavailable solar radiation is used as the dependent variable.

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 Organised 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 Organised 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.

Appendix A

Results of regression parameters for fits using relative sunshine duration, relative humidity and cloud cover

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

(a) Bida		α_0	α_1	α_2	α_3	α_{23}	Se	$Se\,H'$	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.2995	0.6597	-0.4530	0.0002	0.0359	0.0272	…	0.8702	0.01	11.6	3.2
	H_0 - H	21.9494	-23.0941	12.0052	0.8887	-1.1519	…	0.9564	0.9201	6.40	7.3	3.3
D	H/H_0	0.1693	0.5061	-0.0144	0.2071	-0.3273	0.0008	…	0.9994	0.00	0.1	0.1
	H_0 – H	30.5054	-15.1284	-20.5283	-4.2690	12.0615	…	0.4367	0.9324	0.19	1.8	1.1
W	H/H_0	-0.0843	1.3130	-2.0361	0.3096	-0.0227	0.0393	…	0.5835	0.00	8.4	3.2
	H_0 - H	87.0902	-57.4477	11.7777	-18.0070	10.5837	…	1.8859	0.4080	3.56	6.1	2.9
(b) Enugu		α_0	α_1	α_2	α_3	α_{23}	Se	$Se\,H'$	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.0161	0.3991	0.4890	0.0468	-0.0884	0.0089	…	0.9734	0.00	2.7	1.3
	H_0 - H	34.4031	-16.8987	-23.1812	0.5273	1.7114	…	0.3649	0.9783	0.93	2.4	1.2
D	H/H_0	0.1204	0.4333	0.2466	0.0472	-0.0806	0.0154	…	0.6873	0.00	1.9	1.0
	H_0 – H	38.5732	-22.4139	-22.2922	0.2524	2.5363	…	0.1572	0.9927	0.02	0.6	0.3
W	H/H_0	3.8702	0.2946	-3.4813	-1.0867	1.1592	0.0054	…	0.9842	0.00	0.9	0.5
	H_0 - H	135.4234	-19.9656	-143.9955	-17.6435	24.1623	…	0.5166	0.9035	0.27	1.5	0.9
(c) Gusau		α_0	α_1	α_2	α_3	α_{23}	Se	$Se\,H'$	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.2214	0.2112	0.8630	0.0630	-0.1865	0.0129	…	0.9738	0.00	2.8	1.5
	H_0 - H	21.1664	-7.7936	-33.1561	-1.0923	6.9727	…	0.8238	0.9523	4.75	11.4	4.1
D	H/H_0	0.2636	0.5119	-0.4768	0.2306	-0.2832	0.0086	…	0.8419	0.00	1.1	0.4
	H_0 - H	25.5698	-20.5657	1.6970	-4.1098	8.5726	…	1.2738	0.3589	1.62	10.6	3.5
W	H/H_0	-0.0781	0.3190	0.5643	0.2049	-0.2755	0.0133	…	0.9594	0.00	2.3	0.9
	H_0 - H	56.6174	-15.5033	-39.4651	-12.8784	16.7975	…	0.2434	0.9934	0.06	0.9	0.4

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

(a) Ikom		α_0	α_1	α_2	α_3	α_{23}	Se	SeH'	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	1.2375	0.6757	-1.2522	-0.1703	0.2017	0.0115	…	0.9659	0.00	4.0	1.8
	H_0 - H	31.2050	-23.6788	-15.0941	0.3550	1.4491	…	0.4203	0.9733	1.24	3.3	1.4
D	H/H_0	-2.9772	1.7404	3.8720	0.5555	-0.7984	0.0135	…	0.1056	0.00	1.8	1.0
	H_0 - H	144.7080	-61.1894	-148.3646	-18.6042	28.0239	…	0.2921	0.9127	0.09	1.1	0.6
W	H/H_0	1.4996	0.7771	-2.5804	-0.1905	0.3970	0.0033	…	0.9972	0.00	0.8	0.3
	H_0 - H	23.9560	-28.7855	26.6569	-0.2714	-2.8388	…	0.1377	0.9965	0.02	0.4	0.2
(b) Minna		α_0	α_1	α_2	α_3	α_{23}	Se	SeH'	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.1898	0.2959	0.6299	0.0284	-0.1062	0.0211	…	0.9288	0.00	6.8	2.5
	H_0 - H	25.4302	-21.5756	-6.8887	1.5308	0.1145	…	0.8782	0.9509	5.40	7.5	2.8
D	H/H_0	0.3552	0.1603	0.6829	-0.0911	0.0002	0.0340	…	0.1385	0.00	4.6	1.8
	H_0 - H	30.0427	-22.9954	-14.6789	5.2139	-3.8778	…	0.5477	0.9330	0.30	3.3	1.3
W	H/H_0	10.4491	1.2725	-14.2477	-2.1222	2.8182	0.0008	…	0.9998	0.00	0.1	0.1
	H_0 - H	-204.5766	-53.4117	340.1843	54.3890	-72.4267	…	1.7017	0.7146	2.90	5.4	2.3
(c) Yelwa		α_0	α_1	α_2	α_3	α_{23}	Se	SeH'	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.2102	0.3590	0.3477	0.0415	-0.0921	0.0228	…	0.8978	0.00	7.9	2.5
	H_0 - H	26.2400	-17.3830	-7.2096	-0.4024	2.0783	…	0.9173	0.9274	5.89	9.7	3.5
D	H/H_0	0.2545	0.3069	0.3014	0.1785	-0.3977	0.0304	…	-0.0742	0.00	2.9	1.6
	H_0 - H	31.7369	-18.7792	-15.7813	-5.8528	15.5196	…	0.4944	0.9314	0.24	2.6	1.5
W	H/H_0	-0.4918	0.8194	0.7894	0.1056	-0.1544	0.0389	…	0.5874	0.00	5.2	2.5
	H_0 - H	66.1156	-30.9934	-49.9475	-5.3145	8.9203	…	1.5867	0.6150	2.52	6.6	2.8
(d) Zaria		α_0	α_1	α_2	α_3	α_{23}	Se	SeH'	R_a^2	Δ	LPE (%)	AAPE (%)
Y	H/H_0	0.6170	0.4583	0.5366	-0.0419	-0.0915	0.0386	…	0.6542	0.01	10.8	4.3
	H_0 - H	-33.2995	-19.7613	36.2869	8.6412	-4.8017	…	1.4602	0.7904	14.93	13.7	6.2
D	H/H_0	0.3729	0.2428	-6.0205	0.9879	-0.0202	0.0168	…	0.6107	0.00	1.9	0.8
	H_0 - H	33.9973	-19.7921	363.1002	-62.8003	5.4320	…	0.2527	0.9803	0.06	1.5	0.6
W	H/H_0	0.3449	0.3886	4.2775	-0.6439	0.0275	0.0251	…	0.7758	0.00	3.1	1.7
	H_0 - H	32.3977	-23.2391	-167.0638	22.9819	1.0519	…	0.9921	0.8098	0.98	3.6	2.2

Appendix B

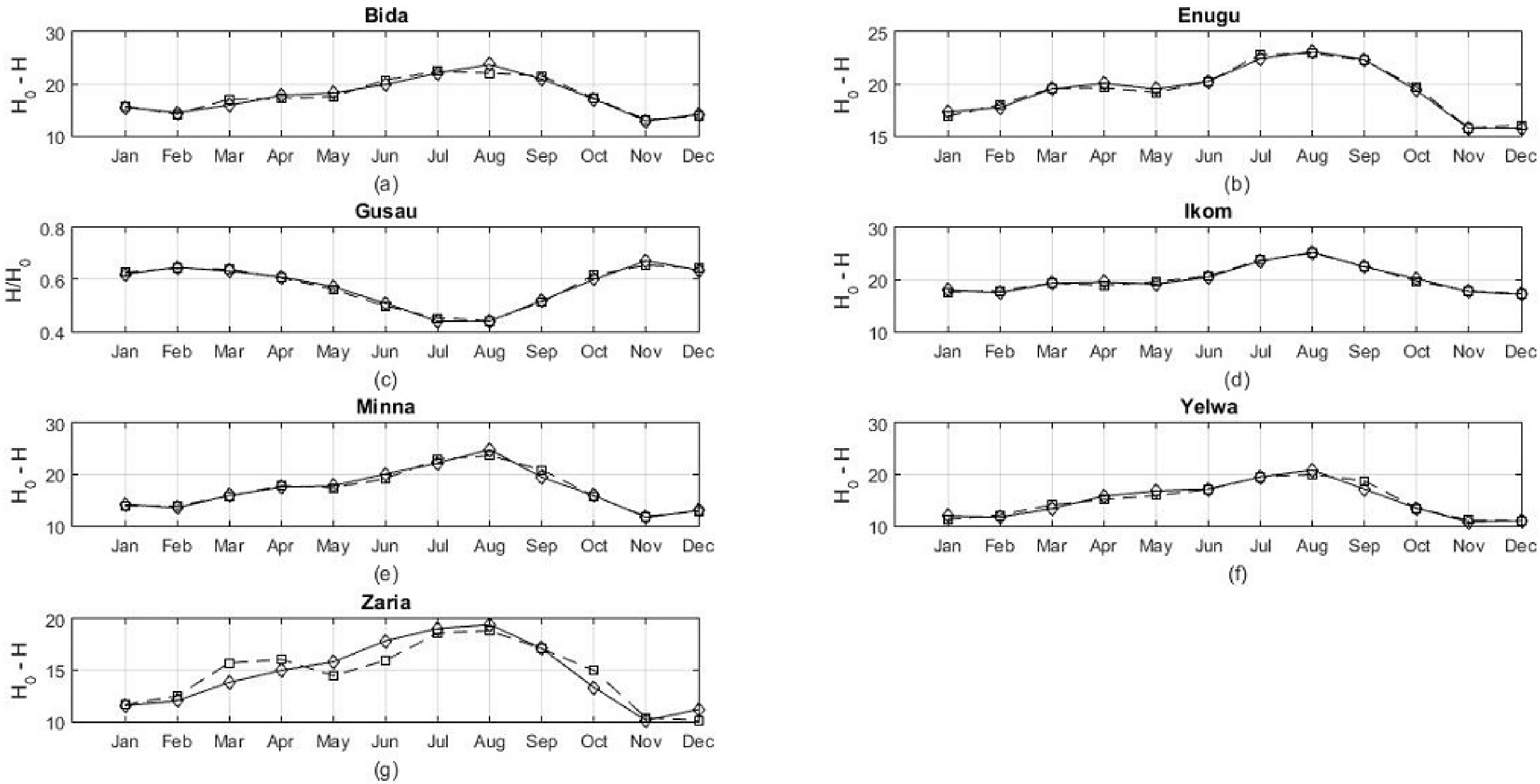

Fig. 1. Plots of observed and fitted yearly unavailable solar radiation/clearness index versus months of the year