Modelling of Clearness Index and Total Solar Radiation with Some Important Climatological Independent Variables for Some Meteorological Stations in Nigeria

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

HARUNA MA'AJI NDAHI
Department of Basic Science
Yobe State College of Agriculture
P.M.B. 1104, Damaturu, Yobe State
NIGERIA
harunasambo2016@gmail.com

Abstract: Modelling of clearness index and total solar radiation with some important climatological independent variables have been well demonstrated. In previous studies, similar equations have been used to analyze the data for Calabar and Yola, the result of the analyses shows high correlations. In this study, we have proposed four new model equations, where we have used the equations to analyze the data for Bauchi, Calabar, Gusau, Ikom, Jos and Yola, the result shows excellent correlation for both yearly and seasonal fits. For yearly variation, high correlations, $R_a^2 > 0.967$ were obtained, Se $\leq$ 0.0088 except for Ikom which has Se = 0.0113, LPE $\leq$ 4% and AAPE $\leq$ 1.2% for all the stations.

Keywords: modelling, independent variables, correlation, solar radiation,

1 Introduction

Equations correlating total solar radiation on a horizontal surface, H, unavailable solar radiation, H_0 – H (where H_0 is the total extraterrestrial solar radiation on a horizontal surface) or clearness index, H/H_0 in terms of some important climatological parameters, such as relative sunshine duration, S/S_0 (S is the bright sunshine duration and S_0 is the day – length, both measured in hours), relative humidity, R and maximum air temperature, T_m have widely being used by researchers [1] – [9]. Ododo and Adam [1] have used relative sunshine duration, maximum air temperature and relative humidity to model total solar radiation, the equations were used to analyze the data for Calabar and Yola, the result shows high correlation for yearly fits in a six parameter (k = 6) and eight parameter (k = 8) equations respectively. In this paper, we have proposed four model equations (with k = 5, 6, 7, 8) and some of the equations used by [1] to model available data for six (6) meteorological stations in Nigeria, the stations are: Bauchi, Calabar, Gusau, Ikom, Jos and Yola, results obtained will be compared with existing results where available.

2 Model equations

In this paper we have proposed to use the following equations to analyze available data:

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{102}(S/S_0)R^2 + \alpha_{462}(S/S_0)^4 T_m^6 R^2 \quad (1)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{001}R + \alpha_{101}(S/S_0)R + \alpha_{241}(S/S_0)^2 T_m^4 R \quad (2)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{001}R + \alpha_{103}(S/S_0)R^3 + \alpha_{241}(S/S_0)^2 T_m^4 R + \alpha_{305}(S/S_0)^3 R^5 \quad (3)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{001}R + \alpha_{103}(S/S_0)R^3 + \alpha_{241}(S/S_0)^2 T_m^4 R + \alpha_{305}(S/S_0)^3 R^5 + \alpha_{618}(S/S_0)^6 T_m R^8 \quad (4)$$

Together with some of those used by [1] given as:

$$H/H_0 = \alpha_{000} + \alpha_{110}(S/S_0)T_m \quad (5)$$

$$H/H_0 = \alpha_{000} + \alpha_{001}R + \alpha_{110}(S/S_0)T_m \quad (6)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{001}R \quad (7)$$

$$H = \alpha_{000}(S/S_0)^{\alpha_{100}} T_m^{\alpha_{010}} R^{\alpha_{001}} \quad (8)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{110}(S/S_0)T_m + \alpha_{011}T_m R + \alpha_{111}(S/S_0)T_m R \quad (9)$$

$$H/H_0 = \alpha_{000} + \alpha_{100}(S/S_0) + \alpha_{010}T_m + \alpha_{001}R + \alpha_{110}(S/S_0)T_m + \alpha_{101}(S/S_0)R + \alpha_{011}T_m R + \alpha_{111}(S/S_0)T_m R \quad (10)$$

where the α_{ijk} (i,j,k = 0,1 2, . . ., 8) are constant coefficients. Equations (1) – (7), (9) and 10 are derivable from the general form proposed by [8]

$$H/H_0 = \sum_{i,j,k=0}^{8} \alpha_{ijk}(S/S_0)^i T_m^j R^k \quad (11)$$

while equation (8) is the Swartman – Ogunlade equation [8]

3 Data and analysis

The data for the six (6) stations (Bauchi, Calabar, Gusau, Ikom, Jos and Yola) have been tabulated elsewhere [1], [7] – [9]. Multiple linear regression were carried out on equations (1) – (10) for both yearly and seasonal variations, the seasonal variations considered were the dry season

(November – April) and the wet season (May - October), note that equation (8) must be transformed to linear equation by taking logarithm. For reasons explained by [7] – [9], seasonal variation was carried out on equations (1), (5) – (8) only. The goodness-of-fit indices used are; the adjusted coefficient of determination (R_a^2), standard error Se or SeH as appropriate, 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 [7] – [9].

4 Results and discussion

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

Tables 1 and 2 shows the regression parameters and goodness-of-fit indices for yearly and seasonal fits respectively. For the yearly fit with R_a^2 = 0.9881, Se = 0.0058, LPE = 1.1% and AAPE = 0.6%, model equation (3) with k = 7 gives a very satisfactory fit. The result for seasonal fit shows that R_a^2 > 0.99, SeH = 0.0673 for the dry season and Se = 0.0029 for the wet season, LPE $\leq$ 0.4%, AAPE $\leq$ 0.2% for the two seasons. Model equation (8) and (1) gives best fit for the seasonal data.

4.2 Calabar (4.9757^{0}N, 8.3417^{0}E)

Regression parameters for both yearly and seasonal variation are listed in Tables 3 and 4 respectively. From the Tables it can be seen that for yearly fit, equation (3) gives a quite satisfactory result, with R_a^2 = 0.9985, Se = 0.0024, $\Delta \approx 0$ and LPE = 0.9%. The result obtained by [1] (see Table 9 of [1]) had R_a^2 = 0.9978, Se = 0.0029, $\Delta \approx 0.076$ and LPE = 1.1%, clearly, model equation (3) has a relatively improved goodness-of-fit indices when compared to that used by [1]

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

Yearly and seasonal regression parameters are presented in Tables 5 and 6 respectively. The result for yearly variation gives a quite satisfactory fit with R_a^2 = 0.9878, Se = 0.0088, Δ = 0.0004, LPE = 1.8% and AAPE = 0.8%. The result of seasonal fit shows that equations (1) and (6) gives best fit for the dry and wet seasons respectively, however, the values of Se (0.0172) and LPE (3.7%) for the wet season are relatively high.

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

Parameters of regression analysis for both yearly and seasonal fits are respectively shown in Tables 7 and 8. The result for yearly fit is not quite satisfactory, the values of Se (0.0113), Δ(0.006), LPE (4%) and AAPE (1.2%) are relatively high. The result of seasonal variation with $R_a^2 \geq 0.9112$, LPE $\leq$ 1.5%, AAPE $\leq$ 0.9% is quite satisfactory, equation (1) with five parameters gives the best fit for the two seasons.

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

The yearly regression parameters are shown in Table 9. Equations (1), (2), (3), (4), (9) and (10) have $R_a^2 \geq 0.99$, LPE $\leq$ 2%, values of Se, Δ and AAPE. These values are satisfactory, thus, any of these equations can be used on the data. The data presented in Table 10 is the result of regression analysis for seasonal variation, equations (1) and (7) gives best fit for the dry and wet seasons respectively. For the two seasons, R_a^2 > 0.99, LPE $\leq$ 1.9% and AAPE $\leq$ 0.7%. This result shows that seasonal fit is quite satisfactory.

4.6 Yola (9.2035^{0}N, 12.4954^{0}E

Data of regression analysis for yearly and seasonal fits are presented in tables 11 and 12 respectively. Model equation (4) with eight parameters gives a very satisfactory fit with R_a^2 = 0.99, Se = 0.0074, Δ = 0.0002, LPE = 1.9% and AAPE = 0.7%. The corresponding eight parameter equation used by [1] had for the yearly fit, R_a^2 = 0.9893, Se = 0.0077, Δ = 0.297 and LPE = 2% (see Table 3 of [1]). For the seasonal fits, model equation (1) gives best fit for the two seasons where R_a^2 > 0.91 with relatively high values of Se (0.0173), LPE (2.3%) and AAPE (1.3%) for the wet season.

4.7 Plot of observed and best fit model equations

Fig.1 (a) – (b) shows the plots of yearly observed clearness index and best fit equation of each station versus months of the year, the plots shows that Bauchi, Calabar, Jos and Yola with $\Delta \leq$ 0.0002 gives a near perfect fit between the observed and best fit equation while Gusau (Δ = 0.0004) and Ikom (Δ = 0.0006) shows slight deviations between the two curves.

5 Conclusion

In this paper, we have attempted to model clearness index and total solar radiation with some important climatological independent variables for Bauchi, Calabar, Gusau, Ikom, Jos and Yola through the use of new and also existing model equations, the results show that high correlations are obtained mostly with a 5 or 7 parameter model equations, for Yola, high correlations are obtained with 8 parameter equation for yearly fits with R_a^2 = 0.99, Se = 0.007, LPE = 1.9%, for Calabar, high correlations are obtained for yearly fits with a 7 parameter equation, where, R_a^2 = 0.999, se = 0.002, $\Delta \approx 0$, LPE = 0.9% and AAPE = 0.4%

References

[1] Ododo J.C. & Usman A., Correlation of Total Solar Radiation with Common Meteorological Parameters for Yola and Calabar, *Energy Convers. Mgmt.*, .Vol. 37, No. 5, 1996, pp. 521 - 530

[2] Ododo J.C., Agbakwuru. J.A. & Ogbu F.A., Correlation of Solar Radiation with Cloud Cover and Relative Sunshine Duration, *Energy Convers. Mgmt.*, Vol. 37, No.10, 1995, pp. 1555-1559

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

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

[5] Aidan J., Yadima A., Ododo J.C., Modelling Unavailable Solar Radiation Using Some Climatological Parameters, *Nigerian Journal of Solar Energy*, Vol. 15, 2005, pp. 118-126.

[6] Ododo J.C., Sulaiman A.T., Aidan J., Yuguda M.M. & Ogbu F. A., The Importance of Maximum Air Temperature in the Parameterization of Solar Radiation in *Nigeria*, *Journal of Renewable Energy*, Vol. 6, No.7, 1995, pp. 751-763

[7] 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

[8] 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

[9] 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.

Table 1. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Bauchi

	Eq (1)	*Eq* (2)	*Eq* (3)	*Eq* (4)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)	*Eq* (9)	*Eq* (10)
α_{000}	-0.1244	0.1364	0.5553	0.5603	0.2235	0.3363	0.1212	0.7922	0.9312	1.0549
α_{100}	0.4807	0.1376	0.0945	0.0852	…	…	0.3400	0.0702	-0.7045	-1.0169
α_{010}	0.0110	0.0110	0.0000	-0.0001	…	…	0.0069	0.9178	-0.0083	-0.0133
α_{001}	…	-0.5424	-0.5759	-0.5312	…	-0.0689	-0.0677	0.0021	…	-1.1790
α_{011}	…	…	…	…	…	…	…	…	-0.0229	0.0164
α_{101}	…	0.9733	…	…	…	…	…	…	…	2.2051
α_{110}	…	…	…	…	0.0150	0.0109	…	…	0.0187	0.0301
α_{111}	…	…	…	…	…	…	…	…	0.0297	-0.0426
α_{102}	0.0560	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	-3.8200	5.3442	5.4502	…	…	…	…	…	…
α_{305}	…	…	0.3226	8.8858	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-4.3908	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	-2.2403	…	…	…	…	…	…
R_a^2	0.9710	0.9863	0.9881	0.9860	0.9684	0.9792	0.9771	0.8451	0.9872	0.9825
Se	0.0091	0.0062	0.0058	0.0063	0.0095	0.0077	0.0081	…	0.0060	0.0070
SeH	…	…	…	…	…	…	…	0.5738	…	…
Δ	0.0006	0.0002	0.0002	0.0002	0.0009	0.0005	0.0005	2.6342	0.0002	0.0002
LPE (%)	2.8	1.4	1.1	1.1	3.4	2.5	2.2	4.0	1.5	1.2
AAPE (%)	1.1	0.8	0.6	0.6	1.4	1.0	1.1	2.3	0.7	1.0

Table 2. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Bauchi

	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$
	dry season (November – April)					wet season (May - October)				
α_{000}	-0.2324	0.3561	0.4481	0.1342	0.1589	-0.8220	0.2333	0.1243	-0.0038	4.2498
α_{100}	0.4885	…	…	0.2913	0.1212	1.0787	…	…	0.4943	0.2797
α_{010}	0.0145	…	…	0.0083	1.3388	0.0230	…	…	0.0068	0.4527
α_{001}	…	…	-0.1289	-0.1896	-0.0873	…	…	0.0856	-0.0013	-0.0715
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0095	0.0067	…	…	…	0.0143	0.0175	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	0.5638	…	…	…	…	0.4015	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-2.4336	…	…	…	…	-2.9455	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.8333	0.5757	0.8005	0.8512	0.9977	0.9956	0.9792	0.9777	0.9674	0.7503
Se	0.0061	0.0098	0.0067	0.0058	…	0.0029	0.0063	0.0066	0.0079	…
SeH	…	…	…	…	0.0673	…	…	…	…	0.6674
Δ	0.0000	0.0004	0.0001	0.0001	0.0091	0.0000	0.0002	0.0001	0.0001	0.8909
LPE (%)	0.6	2.0	1.4	1.0	0.3	0.4	1.6	1.4	1.2	3.0
AAPE (%)	0.4	1.2	0.7	0.5	0.2	0.2	0.9	0.9	0.9	2.1

Table 3. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Calabar

	$Eq\,(1)$	$Eq\,(2)$	$Eq\,(3)$	$Eq\,(4)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(9)$	$Eq\,(10)$
α_{000}	-0.1114	-1.9840	-2.5675	-2.5551	0.2274	0.0251	-0.5486	0.0063	-0.9561	1.5837
α_{100}	0.4363	3.5317	2.6059	2.5944	…	…	0.5581	0.2778	2.9770	-0.7189
α_{010}	0.0113	0.0310	0.0337	0.0336	…	…	0.0156	2.4463	0.0217	-0.0584
α_{001}	…	1.4830	2.0555	2.0434	…	0.2159	0.3761	1.3283	…	-2.7940
α_{011}	…	…	…	…	…	…	…	…	0.0233	0.1114
α_{101}	…	-2.9433	…	…	…	…	…	…	…	3.3964
α_{110}	…	…	…	…	0.0178	0.0210	…	…	-0.0439	0.0717
α_{111}	…	…	…	…	…	…	…	…	-0.0499	-0.1554
α_{102}	0.2352	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	-16.013	-18.159	-18.102	…	…	…	…	…	…
α_{305}	…	…	-1.6721	-1.7398	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-19.198	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	0.0481	…	…	…	…	…	…
R_a^2	0.9952	0.9979	0.9985	0.9982	0.9751	0.9762	0.9919	0.9857	0.9976	0.9966
Se	0.0044	0.0029	0.0024	0.0027	0.0100	0.0097	0.0057	…	0.0031	0.0037
SeH	…	…	…	…	…	…	…	0.2831	…	…
Δ	0.0001	0.0000	0.0000	0.0000	0.0010	0.0009	0.0003	0.6410	0.0001	0.0001
LPE (%)	1.9	0.9	0.9	0.9	6.0	5.1	2.9	2.8	1.1	1.1
AAPE (%)	0.7	0.4	0.4	0.4	2.3	2.0	1.0	1.4	0.5	2.0

Table 4. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Calabar

	Eq (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)	*Eq* (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)
	Dry season (November – April)					wet season (May - October)				
α_{000}	0.9164	0.3240	0.3440	0.0664	0.0689	-0.4584	0.2144	-0.9926	-1.6167	0.0000
α_{100}	-0.3454	…	…	0.3413	0.0808	-1.0805	…	…	0.7459	0.1592
α_{010}	-0.0114	…	…	0.0064	1.6487	0.0236	…	…	0.0269	4.3855
α_{001}	…	…	-0.0203	0.0529	0.7268	…	…	1.3141	1.2085	1.9686
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0096	0.0092	…	…	…	0.0200	0.0353	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	-0.3273	…	…	…	…	2.2867	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	7.0054	…	…	…	…	4.9119	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.5691	0.8605	0.8164	0.7560	0.3677	0.9985	0.9780	0.9841	0.9977	0.9988
Se	0.0072	0.0041	0.0047	0.0054	…	0.0023	0.0087	0.0074	0.0029	…
SeH	…	…	…	…	0.4061	…	…	…	…	0.0690
Δ	0.0001	0.0001	0.0001	0.0001	0.3298	0.0000	0.0003	0.0002	0.0000	0.0095
LPE (%)	1.1	1.3	1.2	1.1	2.4	0.5	3.9	2.5	0.8	0.5
AAPE (%)	0.6	0.6	0.7	0.6	1.3	0.2	1.9	1.5	0.4	0.3

Table 5. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Gusau

	$Eq\,(1)$	$Eq\,(2)$	$Eq\,(3)$	$Eq\,(4)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(9)$	$Eq\,(10)$
α_{000}	0.2788	0.3905	0.1828	0.1945	0.1803	0.4435	0.1613	0.5895	-2.0139	1.0472
α_{100}	0.3621	0.3835	0.4385	0.4359	…	…	0.3488	0.2054	4.0610	-0.7927
α_{010}	0.0044	0.0014	0.0044	0.0044	…	…	0.0090	1.0247	0.0635	-0.0202
α_{001}	…	-0.0153	0.2911	0.2141	…	-0.1844	-0.1752	-0.0065	…	-2.4014
α_{011}	…	…	…	…	…	…	…	…	0.0134	0.0727
α_{101}	…	-0.5315	…	…	…	…	…	…	…	3.0727
α_{110}	…	…	…	…	0.0209	0.0116	…	…	-0.0937	0.0385
α_{111}	…	…	…	…	…	…	…	…	-0.0312	-0.1016
α_{102}	-0.4603	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	3.7636	-0.9612	-0.7305	…	…	…	…	…	…
α_{305}	…	…	3.2637	1.0851	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	4.7426	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	0.2647	…	…	…	…	…	…
R_a^2	0.9770	0.9633	0.9878	0.9856	0.7173	0.9470	0.9571	0.8588	0.9568	0.9697
Se	0.0120	0.0152	0.0088	0.0095	0.0423	0.0183	0.0165	…	0.0165	0.0138
SeH	…	…	…	…	…	…	…	0.7279	…	…
Δ	0.0010	0.0014	0.0004	0.0004	0.0179	0.0030	0.0022	4.2387	0.0016	0.0008
LPE (%)	3.9	4.9	1.8	1.9	12.4	7.2	5.9	6.2	3.9	2.4
AAPE (%)	1.4	1.7	0.8	0.8	6.0	2.4	2.0	2.7	1.6	2.4

Table 6. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Gusau

	Eq (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)	*Eq* (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)
	Dry season (November – April)					wet season (May - October)				
α_{000}	-0.4428	0.4112	0.4257	0.2381	0.1935	0.4783	0.2531	0.6658	0.4156	2.8598
α_{100}	0.8319	…	…	0.4097	0.2176	-0.3692	…	…	0.2753	0.2060
α_{010}	0.0165	…	…	0.0050	1.3194	0.0050	…	…	0.0064	0.5497
α_{001}	…	…	-0.1083	-0.0771	-0.0586	…	…	-0.4126	-0.3583	-0.2036
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0109	0.0115	…	…	…	0.0152	0.0082	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	3.7971	…	…	…	…	-0.2032	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-8.4345	…	…	…	…	2.3798	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.8381	0.6265	0.8392	0.8346	0.7460	0.8998	0.6460	0.9319	0.9099	0.6758
Se	0.0087	0.0132	0.0087	0.0088	…	0.0209	0.0393	0.0172	0.0198	…
SeH	…	…	…	…	0.7917	…	…	…	…	0.9631
Δ	0.0001	0.0007	0.0002	0.0002	1.2536	0.0004	0.0062	0.0009	0.0008	1.8550
LPE (%)	1.0	3.6	1.6	1.1	4.7	3.4	10.1	3.7	3.6	5.1
AAPE (%)	0.4	1.2	0.8	0.7	1.7	1.4	5.8	2.2	2.1	2.7

Table 7. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Ikom

	$Eq\,(1)$	$Eq\,(2)$	$Eq\,(3)$	$Eq\,(4)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(9)$	$Eq\,(10)$
α_{000}	0.3327	1.2904	-3.7615	-3.7617	0.221	-0.1186	0.4399	2135.0	2.7894	20.4196
α_{100}	0.8510	-0.5064	3.9951	3.9709	…	…	0.7188	0.4568	-4.6741	-36.7553
α_{010}	-0.0061	-0.0171	0.0204	0.0203	…	…	-0.0079	-1.3664	-0.0195	-0.5715
α_{001}	…	-0.7127	4.0639	4.1006	…	0.3449	-0.0407	-0.7521	…	-19.4360
α_{011}	…	…	…	…	…	…	…	…	-0.0823	0.5234
α_{101}	…	1.2687	…	…	…	…	…	…	…	32.5685
α_{110}	…	…	…	…	0.0175	0.0245	…	…	0.0329	1.0276
α_{111}	…	…	…	…	…	…	…	…	0.1777	-0.8200
α_{102}	-0.0799	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	4.5147	-12.730	-12.475	…	…	…	…	…	…
α_{305}	…	…	2.0232	4.5197	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-10.183	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	-0.7921	…	…	…	…	…	…
R_a^2	0.9209	0.9066	0.9671	0.9594	0.7844	0.8822	0.9284	0.9627	0.9174	0.9641
Se	0.0174	0.0190	0.0113	0.0125	0.0288	0.0213	0.0166	…	0.0178	0.0118
SeH	…	…	…	…	…	…	…	0.4325	…	…
Δ	0.0021	0.0022	0.0006	0.0006	0.0083	0.0041	0.0022	1.4966	0.0019	0.0006
LPE (%)	5.2	5.0	4.0	4.0	9.3	7.3	5.2	4.8	5.2	3.1
AAPE (%)	2.7	2.7	1.2	1.2	5.7	3.6	2.7	1.7	2.2	3.6

Table 8. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Ikom

	Eq (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)	*Eq* (1)	*Eq* (5)	*Eq* (6)	*Eq* (7)	*Eq* (8)
	Dry season (November – April)					wet season (May - October)				
α_{000}	7.7781	0.447	0.426	0.855	1068	0.924	0.217	-0.1325	1.3982	82783
α_{100}	-3.4412	…	…	0.2306	0.4578	1.8131	…	…	0.5889	0.4119
α_{010}	-0.1763	…	…	-0.0114	-1.1575	-0.0254	…	…	-0.0234	-2.5074
α_{001}	…	…	0.0149	-0.1565	-0.6536	…	…	0.3713	-0.6033	-1.5915
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0023	0.0031	…	…	…	0.0169	0.0231	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	-3.7185	…	…	…	…	-1.5189	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	33.020	…	…	…	…	-4.1981	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.9122	-0.1597	-0.5430	-0.1594	0.9062	0.9746	0.8305	0.9348	0.9639	0.9343
Se	0.0042	0.0154	0.0178	0.0154	…	0.0099	0.0257	0.0159	0.0118	…
SeH	…	…	…	…	0.3788	…	…	…	…	0.5907
Δ	0.0000	0.0009	0.0009	0.0005	0.2870	0.0001	0.0026	0.0008	0.0003	0.6980
LPE (%)	0.7	5.1	5.1	3.1	2.4	1.5	7.7	4.2	3.3	4.0
AAPE (%)	0.3	1.8	1.8	1.5	0.9	0.9	5.0	2.4	1.4	2.0

Table 9. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Jos

	$Eq(1)$	$Eq(2)$	$Eq(3)$	$Eq(4)$	$Eq(5)$	$Eq(6)$	$Eq(7)$	$Eq(8)$	$Eq(9)$	$Eq(10)$
α_{000}	-0.0040	-0.1661	0.0071	0.0120	0.4519	0.6814	0.3353	18.313	0.1964	-0.6090
α_{100}	0.5112	0.5922	0.5012	0.4999	…	…	0.3967	0.3879	0.5327	1.1066
α_{010}	0.0078	0.0113	0.0078	0.0077	…	…	-0.0001	0.0414	0.0064	0.0311
α_{001}	…	0.0983	-0.0081	-0.0098	…	-0.3714	-0.1270	-0.0416	…	0.0294
α_{011}	…	…	…	…	…	…	…	…	-0.0095	-0.0039
α_{101}	…	-0.1004	…	…	…	…	…	…	…	1.4944
α_{110}	…	…	…	…	0.0036	0.0003	…	…	-0.0076	-0.0231
α_{111}	…	…	…	…	…	…	…	…	0.0098	-0.0516
α_{102}	-0.0136	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	-0.6799	-0.4780	-0.4788	…	…	…	…	…	…
α_{305}	…	…	0.8909	0.1411	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-0.3528	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	0.3438	…	…	…	…	…	…
R_a^2	0.9969	0.9969	0.9962	0.9953	0.0387	0.9261	0.9879	0.8133	0.9935	0.9938
Se	0.0055	0.0056	0.0062	0.0069	0.0983	0.0273	0.0110	…	0.0081	0.0079
SeH	…	…	…	…	…	…	…	1.2004	…	…
Δ	0.0002	0.0002	0.0002	0.0002	0.0967	0.0067	0.0010	11.529	0.0004	0.0002
LPE (%)	2.0	2.2	1.6	1.6	34.4	7.5	3.4	9.5	2.1	1.5
AAPE(%)	0.5	0.6	0.6	0.6	15.7	4.2	1.6	4.5	0.9	4.2

Table 10. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Jos

	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$
	Dry season (November – April)					wet season (May - October)				
α_{000}	-0.1617	0.1819	0.0968	-0.2757	0.1299	0.1689	0.4140	0.7978	-0.1284	30.566
α_{100}	0.5657	…	…	0.6201	0.5012	0.7940	…	…	0.8518	0.8006
α_{010}	0.0116	…	…	0.0139	1.5568	-0.0072	…	…	0.0000	0.0126
α_{001}	…	…	0.0891	0.0595	0.0220	…	…	-0.5189	0.2269	0.2565
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0196	0.0227	…	…	…	0.0016	-0.0004	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	-0.0060	…	…	…	…	0.3263	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	0.9706	…	…	…	…	0.0322	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.9999	0.9899	0.9962	0.9995	0.8990	0.9901	-0.0831	0.8957	0.9920	0.9791
Se	0.0004	0.0055	0.0033	0.0012	…	0.0062	0.0649	0.0201	0.0056	…
SeH	…	…	…	…	0.2573	…	…	…	…	0.2647
Δ	0.0000	0.0001	0.0000	0.0000	0.1324	0.0000	0.0169	0.0012	0.0001	0.1401
LPE (%)	0.1	1.1	0.7	0.1	1.2	1.3	17.7	4.7	1.2	1.8
AAPE (%)	0.0	0.7	0.3	0.1	0.7	0.5	10.4	2.9	0.6	0.8

Table 11. Yearly variation regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Yola

	$Eq\,(1)$	$Eq\,(2)$	$Eq\,(3)$	$Eq\,(4)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(9)$	$Eq\,(10)$
α_{000}	-1.2761	-2.4620	-2.9304	-3.8084	0.1841	0.2664	-0.0824	0.3674	0.9651	0.0069
α_{100}	1.0601	1.5786	1.8672	2.3327	…	…	0.4878	0.2833	-0.7791	-2.0092
α_{010}	0.0321	0.0553	0.0613	0.0779	…	…	0.0102	1.1748	-0.0051	-0.0190
α_{001}	…	0.6698	1.4001	1.4234	…	-0.0550	-0.0409	0.0581	…	-8.2644
α_{011}	…	…	…	…	…	…	…	…	-0.0307	0.2901
α_{101}	…	0.2885	…	…	…	…	…	…	…	17.1874
α_{110}	…	…	…	…	0.0170	0.0145	…	…	0.0159	0.1084
α_{111}	…	…	…	…	…	…	…	…	0.0416	-0.5711
α_{102}	0.8333	…	…	…	…	…	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	-12.006	-14.725	-19.162	…	…	…	…	…	…
α_{305}	…	…	4.9114	-23.015	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-14.830	…	…	…	…	…	…	…	…	…
α_{618}	…	…	…	4.6329	…	…	…	…	…	…
R_a^2	0.9834	0.9814	0.9853	0.9900	0.9342	0.9354	0.9383	0.8084	0.9473	0.9894
Se	0.0096	0.0101	0.0090	0.0074	0.0191	0.0189	0.0185	…	0.0171	0.0076
SeH	…	…	…	…	…	…	…	0.9604	…	…
Δ	0.0006	0.0006	0.0004	0.0002	0.0036	0.0032	0.0027	7.3794	0.0017	0.0002
LPE (%)	3.2	2.4	2.1	1.9	5.2	5.7	4.7	6.1	4.5	1.9
AAPE (%)	1.2	1.2	0.9	0.7	2.7	2.6	2.2	3.5	1.8	2.6

Table 12. Seasonal regression parameters for fits using relative sunshine duration, maximum air temperature and relative humidity for Yola

	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$	$Eq\,(1)$	$Eq\,(5)$	$Eq\,(6)$	$Eq\,(7)$	$Eq\,(8)$
	Dry season (November – April)					wet season (May - October)				
α_{000}	-2.6606	0.3896	0.4044	-0.4390	0.0073	-1.3275	0.1747	-0.3192	-1.1967	0.0244
α_{100}	1.7832	…	…	0.5916	0.5401	1.9280	…	…	0.9018	0.8688
α_{010}	0.0561	…	…	0.0186	2.2491	0.0265	…	…	0.0232	2.1573
α_{001}	…	…	-0.0717	-0.1390	-0.0420	…	…	0.4507	0.6320	0.9949
α_{011}	…	…	…	…	…	…	…	…	…	…
α_{101}	…	…	…	…	…	…	…	…	…	…
α_{110}	…	0.0091	0.0093	…	…	…	0.0174	0.0274	…	…
α_{111}	…	…	…	…	…	…	…	…	…	…
α_{102}	2.8251	…	…	…	…	0.2802	…	…	…	…
α_{103}	…	…	…	…	…	…	…	…	…	…
$\alpha_{241}/10^{-7}$	…	…	…	…	…	…	…	…	…	…
α_{305}	…	…	…	…	…	…	…	…	…	…
$\alpha_{462}/10^{-9}$	-3.8060	…	…	…	…	-3.4800	…	…	…	…
α_{618}	…	…	…	…	…	…	…	…	…	…
R_a^2	0.9636	0.4753	0.4393	0.5891	0.8276	0.9115	0.8853	0.9566	0.9463	0.9343
Se	0.0041	0.0156	0.0161	0.0138	…	0.0173	0.0197	0.0121	0.0135	…
SeH	…	…	…	…	0.6164	…	…	…	…	0.4807
Δ	0.0000	0.0010	0.0008	0.0004	0.7600	0.0003	0.0016	0.0004	0.0004	0.4621
LPE (%)	0.4	3.4	3.7	1.9	2.4	2.3	4.5	3.7	3.1	2.3
AAPE (%)	0.2	1.7	1.2	1.2	1.4	1.3	2.6	1.4	1.3	1.4

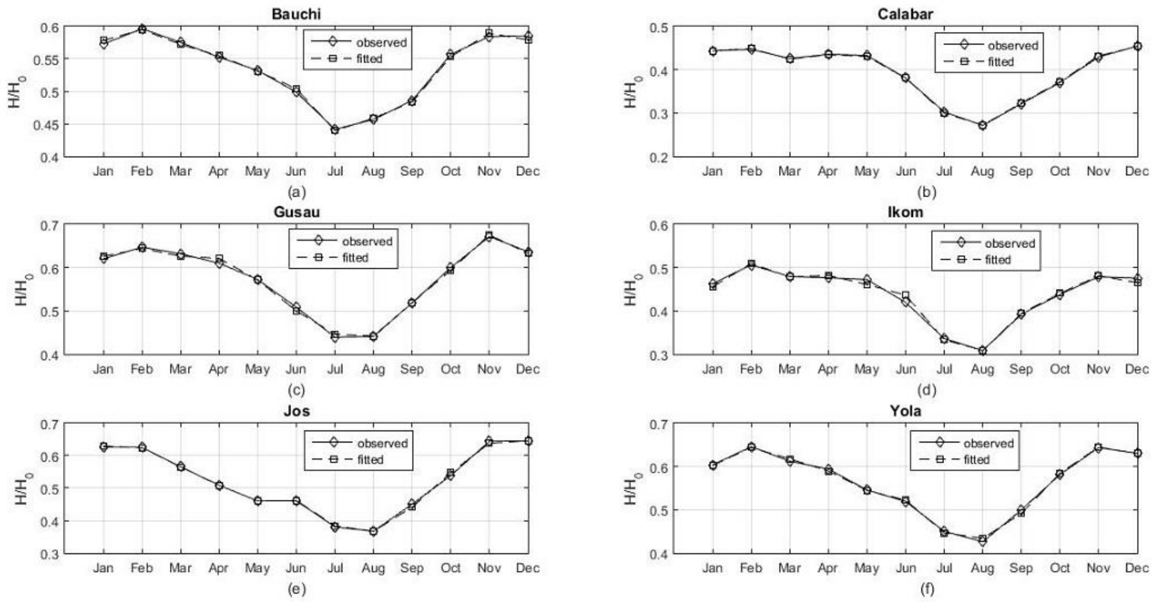

Fig. 1 plots of observed and fitted clearness index versus months of the year