Turk J Phys
29 (2005) , 63 – 68.

Modeling Global Solar Radiation for a Tropical Location: Onne, Nigeria

Louis E. AKPABIO[1], **Sunday O. UDO**[2], **Sunday E. ETUK**[3]
[1]*Department of Physics, P.O.Box 4205, University of Uyo, Akwa Ibom State-NIGERIA*
e-mail: leabio2002@yahoo.com
[2]*Department of Physics , University of Calabar, Calabar-NIGERIA*
[3]*Department of Physics, P.O.Box 4206, University of Uyo, Akwa Ibom State-NIGERIA*

Received 14.09.2004

Abstract

Monthly average daily values of clearness index and relative sunshine over a period of sixteen years, using quadratic form of the Angstrom-Prescott model have been developed to estimate global solar radiation at Onne (Lat. 4° 46′ N, Long. 7° 10′ E), a tropical location. The predictive efficiencies of the models are also compared with those developed for the Nigerian environment, and those which are believed to be applicable globally. The applicability of the developed equations was tested in terms of mean percentage error (MPE), mean bias error (MBE) and root mean square error (RMSE).

Key Words: Global solar radiation, Tropical location, Onne

1. Introduction

One of the most important requirements in the design of any solar energy conversion system is the information on the intensity of solar radiation at a given location. Such data are required in many applications ranging from crop growth models, evapotranspiration estimates to design of photovoltaic systems, solar collector systems, solar crop drying systems and building sciences [1]. For the developing countries (such as Nigeria) where there is an acute shortage of conventional source of energy, solar radiation data is still very scarce. However, many attempts have been made to develop models that can predict the amount of solar radiation available at a given place from a few input parameters.

Even though modeling is an economical and essential tool for the estimation of solar radiation, the accuracy of such models depends on long-term measurements of the data used. Though less accurate, modeling is a better tool for the estimation of solar radiation at places where measurements are not available but have similar climatic conditions to the measured location.

Several empirical correlations have been developed to predict the correlation between the global solar radiations to the percentage of bright sunshine hours in a simple linear regression form (the Angstrom-Prescott type one-parameter) [2–26]. Some authors have also developed quadratic correlation models [27–30] and multiple linear regression form [31]. The present study is to establish quadratic correlation for the estimation of monthly global solar radiation for Onne, Nigeria. The developed quadratic model is compared with others in terms of their predictive abilities for other locations in general and Nigeria (in particular).

2. Place and Measurement

The global solar radiation and sunshine duration data reported in this paper were supplied by the IITA (International Institute of Tropical Agriculture) station at Onne, Nigeria, a high rainfall station located at latitude 4° 46′ N, longitude 7° 10′ E with an altitude of 10 m and is as presented in Table 1 for the sixteen year period 1984–1999. The agroecology of Onne is lowland humid forest zone merging with freshwater swamp forest, now widely disturbed and covered with secondary regrowth. The monthly average temperature is 25.7 °C while the average annual rainfall is about 2471.76 mm.

Table 1. Relevant meteorological and solar radiation data (H, H_o, S, S_o) for Onne.

	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
H	11.23	14.10	13.67	14.99	13.82	13.24	10.66	10.36	11.36	11.89	12.27	12.08
H_o	34.52	36.37	37.61	37.42	36.09	35.11	35.40	36.61	37.30	36.53	34.83	33.81
S	4.03	4.71	3.70	4.01	4.14	3.34	2.18	1.64	2.63	3.56	4.54	4.41
S_o	11.78	11.87	11.98	12.10	12.19	12.24	12.22	12.14	12.02	11.90	11.81	11.76

The prevailing winds in Onne and of course Nigeria, are the South-Westerly (SW) and North-Easterly (NE) trade winds. The SW wind blows from the Atlantic and brings rain to the West African Coast, including Nigeria from about April and October—this is the rainy season period. The NE wind, a very dry wind, blows across the country between November and March bringing the harmattan dust with it—this is the dry season period.

2.1. Prediction formulae

The clearness index K_T (= H / H_o) represents the percentage deflection by the sky of the incoming global solar radiation and therefore indicates both the level of availability of solar radiation and changes in atmospheric conditions in a given locality, while relative sunshine S_R (= S / S_o) is a measure of the cloud cover. Here, H represents the daily global radiation, H_o the daily extraterrestrial radiation, S the daily sunshine duration and S_o the maximum sunshine duration or day-length. H_o and S_o were evaluated according to equations reported in Akpabio and Etuk [4].

The quadratic correlation equations to be considered are of the form

$$K_T = a + bS_R + cS_R^2, \tag{1}$$

where a, b and c are the constant coefficients. The models to be considered for comparison under this form are as follows.

(i) Ogelman et al.model: Ogelman et al.[27] proposed a correlation that relates the global solar radiation to S_R in a quadratic form as

$$K_T = 0.195 + 0.675S_R - 0.142S_R^2. \tag{2}$$

The above correlation equation represents daily data spread over a three- year period at Ankara and Adana, Turkey.

(ii) Akinoglu and Ecevit model: Akinoglu and Ecevit [28] suggested a quadratic correlation between K_T and S_R to estimate the values of global solar radiation for 58 locations in several countries. The equation is given as

$$K_T = 0.145 + 0.845S_R - 0.280S_R^2. \quad (3)$$

(iii) Fagbenle's model: This model developed by Fagbenle [29] for Nigerian environment is represented as

$$K_T = 0.375 + 0.128S_R + 0.660S_R^2. \quad (4)$$

(iv) Udo's model: Udo [30] developed a quadratic correlation equation that relates global solar radiation to S_R for daily data spread over a two-year period at Ilorin, Nigeria. His correlation equation is given as

$$K_T = 0.053 + 1.280S_R - 0.830S_R^2. \quad (5)$$

3. Results and Discussion

A non-linear (quadratic) regression equation was developed using sixteen years data set of monthly mean of daily value of K_T and S_R. The corresponding quadratic model with its correlation coefficient R is given as

$$K_T = 0.147 + 1.125S_R - 1.416S_R^2; R = 79.9\% \quad (6)$$

Further more, carrying out analysis based on seasons (rainy and dry) led to the following equations with their respective correlation coefficients as:

$$K_T = 0.181 + 0.781S_R - 0.626S_R^2; R = 86.8\% \quad (7)$$

$$K_T = 2.014 - 9.445S_R + 13.412S_R^2; R = 42.4\% \quad (8)$$

It can be observed from this analysis that the dry season period (November–April) has a poor correlation coefficient as a result of greater differences in the characteristic of the sky conditions during this period. The rainy season model is satisfactory when compared with that of the dry season. There are two distinct weather conditions during the dry season period in Onne: (i) Harmattan period (December and January) when cold and dust-laden North-Easterly trade winds from the Sahara desert keep the atmosphere over this location and its environs heavily overcast with dust for many days, with characteristic hazy and cloud free weather conditions (ii) the cloud and dust-free period (November, February to April) of mainly high irradiation and clear weather conditions.

To determine the predictive efficiency of the model developed in this study, it is pertinent to compare this model (Equation (6)) with those believed to be universally applicable (Equations (2) and (3)) and those established for the Nigerian environment (Equations (4) and (5)). The results of these comparisons will determine the applicability of those models to the study location (Onne), as presented in Figure 1 and Table 2. The following observations can be made from a study of the results. The RMSE values, which are a measure of the accuracy of estimation, have been found to be the lowest for Equation (6), while Equation (4) gives the highest value. The MBE values obtained from the models are positive in some cases and negative in others, which show that these models vary between under and over estimation of K_T. However, values of MBE from most of the models (Equations (2) and (4)) indicate high over-estimation. While those from Equations (3) and (5) gives little over estimation and Equation (6) has very little under estimation.

Table 2. Comparison of Error values (MJm^{-2}) for the estimated monthly average daily global solar radiation from different models.

Error Terms	Models				
	Ogelman et al. [27] (Equation (2))	Akinoglu and Ecevit [28] (Equation (3))	Fagbenle [29] (Equation (4))	Udo [30] (Equation (5))	Present Work (Equation (6))
MPE	0.8553	0.5676	1.2630	0.2158	−0.0320
MBE	10.2734	6.8201	15.1655	2.5899	−0.3741
RMSE	13.4976	12.2090	17.0247	13.1873	7.6137
% Error	−3.42 – 23.64	−7.86 – 22.00	1.25 – 32.14	−22.86 – 20.00	−15.00 – 10.91

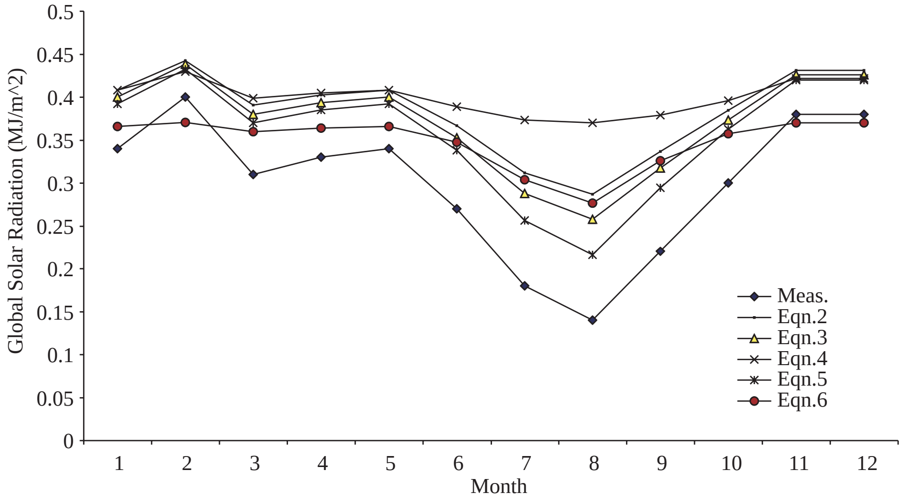

Figure 1. Comparison of measured and estimated (from different models) of monthly average daily global solar radiation.

With respect to MPE, Equation (6) gives the best correlation while Equation (4) presents the worst. Since the test of MPE gives information on the long-term; performance of the examined regression equations, a positive MPE value provides the average amount of over estimation in the calculated values, while a negative MPE value gives under estimation. On the whole, low MPE value is desirable. However, an over estimation of MPE may be cancelled by an under estimation.

Comparing the models, it is realized that the performance of the Fagbenle model (Equation (4)) is the worst, while models of Ogelman et al. (Equation (2)), Akinoglu and Ecevit (Equation (3)) and Udo (Equation (5)) are poorer than that of the model (Equation (6)) developed here. However, the performance of Akinoglu and Ecevit's model is slightly better than the rest of the models, except Equation (6); this of course, is expected since the Akinoglu and Ecevit model contained data from 58 locations spread over several countries and hence is more representative than those of the Ogelman et al. model which contains data for only two Turkey locations, Fagbenle model, which contains data for only three Nigerian locations, and Udo's model which has data for Ilorin (Nigeria) only.

The above comparisons confirm the fact that quadratic form of Angstrom-Prescott one-parameter model is, to a large extent, locality dependent. (It is expected that the performance of any general equation will always be poorer than that of the model developed for that locality.)

4. Conclusion

From the monthly average daily values of clearness index and relative sunshine, a quadratic form of Angstrom-Prescott correlation has been developed for use in estimating global solar radiation at Onne, a tropical location. Comparative analysis shows that, the predictive efficiency of Equation (6) is far better than the rest of the models considered in this study.

Moreover, the results show that the relationship between clearness index and relative shine in quadratic form is to some extent locality-dependent. Hence, the quadratic regression equation that could be employed for the purpose of estimating global solar radiation of locations that have the same climate, Latitude and altitude as Onne (Latitude 04° 46′ N, Longitude 07° 10′ E and an altitude of 10 m) within the rainforest climatic zone of Southern Nigeria is the correlation equation given as

$$K_T = 0.147 + 1.125 S_R - 1.416 S_R^2.$$

Acknowledgment

The authors are grateful to the IITA (International Institute of Tropical Agriculture) station at Onne for providing the data. They also appreciate the financial support of LASE Radiation / Radon group for this project.

References

[1] T. Muneer, Solar Radiation and Daylight Models for the Energy Efficient Design of Buildings (Architectural Press, Oxford, 1997) pp.xxi

[2] L.E. Akpabio, *Nigerian J. Physics*, **4** (1992), 15.

[3] L.E. Akpabio and E. Ekpo Eno, *Integrated J. of Sciences and Engineering*, **3**, (2001), 7.

[4] L.E. Akpabio and S.E. Etuk, *Turk. J. Physics*, **27**, (2003), 161.

[5] L.E. Akpabio, U.A. Ukpong and S.E. Etuk, *JAS*, **6**, (2003), 3607.

[6] L.E. Akpabio and A.B. Udoimuk, *GJPAS*, **9**, (2003), 139.

[7] M. R. Rietveld, *Agricultural Meteorology*, **19**, (1978), 243.

[8] A. Soler, *Solar Energy*, **45**, (1990), 365.

[9] S. M Turton, *Solar Energy*, **38**, (1987), 353.

[10] M.F. Hutchinson, T.H. Booth, J.P. McMahon and H.A .Nix, *Solar Energy*, **32** (1984), 277.

[11] N. Haluoani, C.T. Nguyen and D. Vo-Ngoc, *Solar Energy*, **50**, (1993), 246.

[12] C.C.Y. Ma and M. Iqbal, *Solar Energy*, **33**, (1984), 143.

[13] T. Feuilard and J.M. Aillion, *Solar Energy*, **43**, (1989), 359.

[14] S.D. Alaruri and M.F. Amer, *Solar Energy*, **50**, (1993), 229.

[15] I. Ahmad, N. Al-Hamadani and K. Ibrahim, *Solar Energy*, **31**, (1983), 29.

[16] M.A. Kamd, S.A. Shalaby and S.S. Mostafa, *Solar Energy*, **50**, (1993), 463.

[17] T.D.M.A. Samuel, *Solar Energy*, **47**, (1991), 333.

[18] M.M. Hawas and T. Muneer, *Solar Energy*, **30**, (1983), 289.

[19] I.A. Raja and J.W. Twidell, *Solar Energy*, **43**, (1989), 355.

[20] C.I. Ezekwe and C.O. Ezeilo Clifford, *Solar Energy*, **26**, (1981), 181.

[21] C.I. Ezekwe, *Solar and Wind Technology*, **5**, (1988), 563.

[22] A. Khogali, *Solar Energy*, **31**, (1983), 41.

[23] K. K. Gopinathan, *Solar Energy*, **48**, (1992), 3.

[24] A.S. Sambo, *Solar Wind Technology*, **3**, (1986), 89.

[25] C. T. Leung, *Solar Energy*, **25**, (1980), 485.

[26] B.T. Nguyen and T.L. Pryor, *Renewable Energy*, **11**, (1997), 47.

[27] H. Ogelman, A. Ecevit and E. Tasdemiroglo, *Solar Energy*, **33**, (1981), 619.

[28] B.G. Akinoglu and A. Ecevit, *Turk. J. Physics*, **17**, (1993), 269.

[29] R. L. Fagbenle, *Renewable Energy*, **3**, (1993), 813.

[30] S.O. Udo, *Turk. J. Physics*, **26**, (2002), 229.

[31] L.E. Akpabio, S.O. Udo and S.E. Etuk, *Turk. J. Physics*, **28**, (2004), 205.