The International Journal Of Engineering And Science (IJES)
|| Volume || 4 || Issue || 3 || Pages || PP.44-51|| 2015 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Estimation of Solar Radiation over Ibadan from Routine Meteorological Parameters

[1] Olatona Gbadebo I., [2] Adeleke Ademola E.

[1] *Department of Physics, Osun State University, P.M.B. 4494, Osogbo, Nigeria*
[2] *Department of Mechanical Engineering, Osun State University, P.M.B. 4494, Osogbo, Nigeria*

ABSTRACT

The dearth of solar radiation data from most meteorological stations necessitates the development of empirical models to determine it. Some simple models for the prediction of monthly mean daily solar radiation on a horizontal surface for Ibadan, from sunshine hours as well as minimum and maximum temperatures, the frequently measured meteorological parameters, are presented. The models follow that of Hargreaves and Samani. Two of the models were used for backward and two for forward predictions. The models showed very good agreement with the measured data; however a model based on sunshine hours has lower mean errors than those based on minimum and maximum temperatures which consistently produced an over estimation.

Keywords: Maximum and Minimum Temperature, Mean error, Solar radiation, Sunshine hours,

Date of Submission: 09 December 2014 Date of Accepted: 20 March. 2015

I. INTRODUCTION

An accurate knowledge of solar radiation distribution at a particular geographical location is desirable for the development of many solar energy devices and for estimates of their performances. It is a known fact that a number of commonly measurable atmospheric and meteorological parameters such as turbidity, relative humidity, degree of cloudiness, temperature and sunshine duration taken severally or jointly, affect the magnitude of the global irradiation incident on a given location in varying degrees. However, recently [1] proposed a temperature-based model for predicting the monthly mean global solar radiation on horizontal surfaces for some cities in Nigeria. Prior to this time many researchers [2], [3], [4] have developed correlations involving global solar radiation and sunshine hours for different locations in Nigeria.

When solar radiation enters the atmosphere, a part of the incident energy is removed through the processes of scattering, absorption, and reflection. The scattering of solar radiation is mainly by atmospheric molecules and aerosols while its absorption is mainly by ozone, water vapor, oxygen, carbon (IV) oxide, as well as clouds.

The reflection of solar radiation is mainly by clouds and this plays an overriding part in reducing the energy density of the solar radiation reaching the surface of the Earth [5]. The encounter of solar radiation, particularly with clouds leads to the variation in intensity of sunshine and the number of sunshine hours, at the ground surface. The variation, however, is not due only to the clouds but also to the angle of incidence of the Sun's rays with the ground surface and its azimuth [6]. These in turn, are due to the rotation of the Earth around the Sun and the inclination of its axis with the plane of its orbit round the Sun. The result is the variation in the number of hours of sunshine and its intensity on the Earth's surface.

The variation is from latitude to latitude. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the number possible in the day i.e. the length of the day. The ratio is known as fraction of sunshine hours, n/N. It is found to vary daily and seasonally [7] and [8].

Ideally, the best solar radiation information is that obtained from experimental measurements of the global and diffuse components of the solar insolation at the location in question. The main problem is the non-availability of directly measured solar radiation in many of the developing country's meteorological stations which has prompted a number of researchers [9], [10], [11], [12] to develop models for estimating it.

This study determined the regression constants a_s and b_s for the sunshine hours as well as K_r and n for the minimum and maximum temperatures for the meteorological location of interest. The parameters were in turn used to estimate the global solar radiation at the location of study. The calculated values obtained were then compared with the measured global solar radiation at the same meteorological station. The errors involved in the estimates were also determined.

II. MATERIALS AND METHODS

The data used in this study were obtained from International Institute of Tropical Agriculture (IITA) meteorological station at Ibadan. The station is located within the boundary of rainforest and savanna climatic zones of Western Nigeria and lies within latitude 7° 30´ N and longitude 3° 54´ E.

The data obtained were mean monthly of daily averages of solar radiation, sunshine hours and maximum and minimum temperatures. The data obtained covered a period of twenty years (1992-2011).

The solar radiation was computed from measured sunshine hours for mean monthly solar flux from which the mean monthly daily solar radiation fluxes were calculated for January to December using Penman-Monteith equation[13].

$$R_s = (a_s + b_s * \frac{n}{N}) * R_a \quad \text{……………..(1)}$$

From which a regression of

$$\frac{R_s}{R_a} = a_s + b_s * \frac{n}{N} \quad \text{…………………….(2)}$$

was computed, and the geographical factors a_s and b_s were determined from the linear regression.

R_s: Solar or shortwave radiation ($MJ.m^{-2}day^{-1}$)

n: actual duration of sunshine (hour)

N: maximum possible duration of sunshine or daylight hours (hour)

R_a: extraterrestrial radiation ($MJ.m^{-2}.day^{-1}$)

a_s regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0)

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r [(\omega_2 - \omega_1)\sin(\varphi)\cos(\delta)(\sin(\omega_2) - \sin(\omega_1))] \quad \text{…….(3)}$$

Where

G_{sc}: Solar constant = $0.0820 MJm^{-2}.min^{-1}$

d_r: inverse relative distance Earth-Sun

δ: solar declination [rad]

φ: latitude [rad]

ω_1: solar time angle at beginning of period [rad]

ω_2: solar time angle at end of period [rad]

On the other hand the solar radiation was computed from measured minimum and maximum temperatures for mean monthly solar flux from which the mean monthly solar radiation fluxes were calculated for January to December using [14] model,

$$R_s = R_a K_r (T_{max} - T_{min})^n \quad \text{……………. (4)}$$

Where the model suggested n = 0.5. However a linear regression was used in correlating the measured global solar radiation data with maximum and minimum temperatures which yields an equation given by

$$\frac{R_s}{R_a} = K_r (T_d)^n \quad \text{……..………………..(5)}$$

This equation reduces to

$$\log y = n \log T_d + \log K_r \quad \text{……………………..(6)}$$

Where $y = R_s/R_a$, T_d is the difference between maximum and minimum temperatures, thus obtaining the index n and K_r for the station.

III. RESULTS AND DISCUSSION

The preliminary analysis of the data showed that four years data out of the available twenty years had linear coefficient of correlation of less than 0.5 and were thus discarded. Hence the mean values of the remaining sixteen years were divided into the first eight years and the last eight years and the annual means of the regression constants for each of the periods under study were calculated.

Table 1a: Regression constants, standard deviations and correlation coefficients for first eight years of Model 1.

Year	a	b	a+b	sd	R
1992	0.27	0.31	0.58	0.03	0.78
1993	0.22	0.33	0.55	0.03	0.82
1994	0.23	0.39	0.62	0.03	0.91
1995	0.29	0.26	0.55	0.03	0.79
1996	0.25	0.36	0.61	0.05	0.71
1997	0.22	0.41	0.63	0.03	0.86
2000	0.23	0.34	0.57	0.04	0.80
2001	0.21	0.41	0.62	0.05	0.82
Mean 1	0.24	0.35	0.59	0.04	0.81

Table 1b: Regression constants, standard deviations and correlation coefficients for last eight years of Model 1

Year	a	b	a+b	sd	R
2002	0.28	0.22	0.50	0.03	0.77
2003	0.27	0.24	0.51	0.03	0.85
2004	0.29	0.24	0.53	0.04	0.67
2005	0.18	0.45	0.53	0.03	0.91
2006	0.20	0.33	0.53	0.04	0.84
2007	0.28	0.23	0.51	0.03	0.75
2009	0.23	0.35	0.58	0.03	0.86
2011	0.15	0.45	0.60	0.04	0.87
Mean 2	0.24	0.31	0.54	0.03	0.82

Tables 1a and 1b show the regression constants derived using equation 2 for the first and the last eight years respectively. Substituting the mean values of the regression constants for the first and the last eight years give a final Models M1a and M1b equations respectively as

$$\frac{R_s}{R_a} = 0.24 + 0.35 * \frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{M1a}$$

$$\frac{R_s}{R_a} = 0.24 + 0.31 * \frac{n}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots. \text{M1b}$$

The correlation coefficient ranges from 0.71 (1996) to 0.91 (1994) for the first eight years and 0.67 (2004) to 0.91 (2005) for the last eight years. The fourth column in Tables 1a and 1b, labeled a+b, represents the regression constants for a condition in which the actual sunshine hours equals the maximum possible sunshine hours. This indicates that an average of 0.56 of the solar radiation at the top of the atmosphere reaches the surface on a clear day. The sd column in the tables represent the standard deviation while column R represents the correlation coefficient.

Table 2a: Regression constants, standard deviations and correlation coefficients for the first eight years of Model 2.

Year	Kr	n	sd	R
1992	0.028	1.003	0.023	0.96
1993	0.025	1.037	0.024	0.91
1994	0.148	0.451	0.049	0.75
1995	0.177	0.371	0.038	0.75
1996	0.140	0.490	0.056	0.74
1997	0.150	0.441	0.056	0.70
1999	0.130	0.518	0.046	0.75
2000	0.168	0.390	0.055	0.65
Mean 1	0.121	0.587	0.043	0.78

Table 2b: Regression constants, standard deviations and correlation coefficients for the last eight years of Model 2.

Year	Kr	n	sd	R
2001	0.097	0.632	0.060	0.81
2002	0.210	0.281	0.037	0.68
2003	0.090	0.667	0.018	0.95
2004	0.130	0.515	0.015	0.96
2005	0.102	0.624	0.058	0.81
2006	0.113	0.541	0.047	0.80
2009	0.115	0.574	0.055	0.72
2011	0.107	0.559	0.079	0.64
Mean 2	0.121	0.549	0.046	0.80

On the other hand Tables 2a and 2b show the regression constants derived from equation 5 for the first and the last eight years respectively. Substituting the mean values of the regression constants gives Models 2a and 2b equations for the first and the last eight years respectively as.

$$\frac{R_s}{R_a} = 0.125(T_d)^{0.587} \quad \text{………. M2a}$$

$$\frac{R_s}{R_a} = 0.125(T_d)^{0.549} \quad \text{……..….M2b}$$

The correlation coefficient ranges from 0.65 (2000) to 0.96 (1992) and 0.64 (2011) to 0.96 (2004) for the first and the last eight years respectively. These showed that there is a very good agreement in the data used for the derivation of the regression constants.

The regression constants derived for the first eight years were then used to estimate the monthly mean monthly daily solar radiation for the last eight years in a forward prediction. Also the regression constants derived for the last eight years were used to estimate the mean monthly daily solar radiation for the first eight years in a backward prediction. The estimated values were then compared with the measured values and their root-mean square error, mean bias error and mean percentage error were computed.

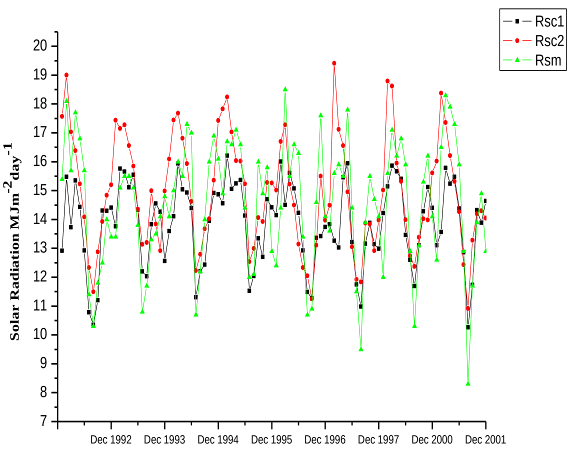

Figure 1: Comparison of Measured Data (Rsm) with those Estimated Rsc1 and Rsc2 using Models M1b and M2b respectively.

The mean monthly daily solar radiation estimated by equation model M1a and model M2a, labeled Rsc1 and Rsc2 respectively compared with measured mean monthly daily solar radiation, labeled Rsm are shown in Figure 1 for the first eight years under study.

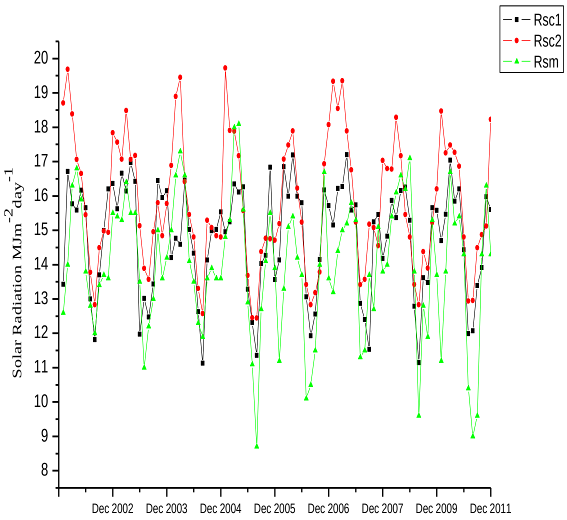

Figure 2: Comparison of Measured Data (Rsm) with those Estimated Rsc1 and Rsc2 using Models M1a and M2a respectively.

On the other hand Figure 2 showed a similar result for the last eight years for the mean monthly daily solar radiation estimated by equation model M1b and model M2b, labeled Rsc1 and Rsc2 respectively compared with measured mean monthly daily solar radiation, labeled Rsm.

The root mean square error, mean bias error, and mean percentage error for models M1a and M2a for backward predictions are shown in Tables 3a and 3b respectively while the same error indicators for models M1b and M2b for forward predictions are shown in Tables 3c and 3d respectively.

Table 3a: Error Indicators of Model 1a for backward prediction

	Model 1a		
Year	RMSE	MBE	MPE
1992	1.85	1.05	6.17
1993	0.90	0.25	-2.18
1994	1.48	-1.09	6.63
1995	1.40	-0.89	5.47
1996	2.01	-0.77	3.78
1997	1.52	-0.95	5.56
2000	1.26	-0.38	1.54
2001	1.73	-0.63	2.35

Table 3b: Error Indicators of Model 2a for backward prediction

Model 2a			
Year	RMSE	MBE	MPE
1992	1.38	1.40	-5.02
1993	1.77	1.26	-9.47
1994	1.66	0.27	2.59
1995	1.44	0.37	-2.99
1996	1.77	-0.41	1.54
1997	1.81	0.16	-2.03
2000	1.84	0.38	-3.48
2001	1.75	0.30	-4.22

Table 3c: Error Indicators of Model 1b for forward prediction

	Model 1b		
Year	RMSE	MBE	MPE
2002	1.38	0.75	-5.57
2003	1.38	0.89	-6.45
2004	1.32	0.07	-1.03
2005	1.27	0.33	-3.93
2006	2.03	1.68	-13.66
2007	1.52	0.91	-6.80
2009	1.12	0.29	-2.99
2011	1.93	1.34	-12.40

Table 3d: Error Indicators of Model 2b for forward prediction

Model 2b			
Year	RMSE	MBE	MPE
2002	2.72	2.03	-14.74
2003	1.79	1.73	-12.43
2004	1.46	1.32	-9.14
2005	2.09	1.23	-10.38
2006	2.70	2.33	-18.58
2007	3.15	2.41	-17.81
2009	1.91	1.06	-8.80
2011	2.36	2.52	22.07

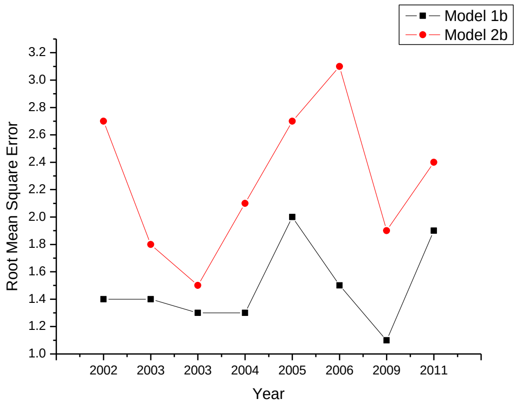

Figure 3a: Root mean square errors of Models 1b and 2b.

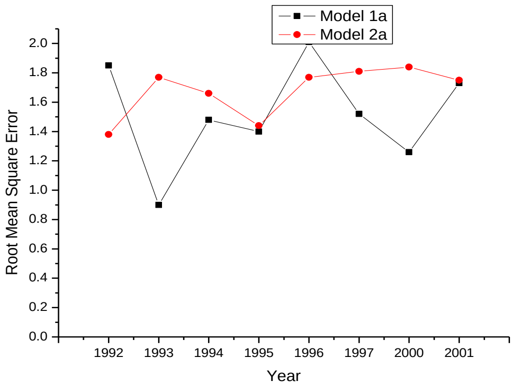

Figure 3b: Root mean square errors of Models 1a and 2a.

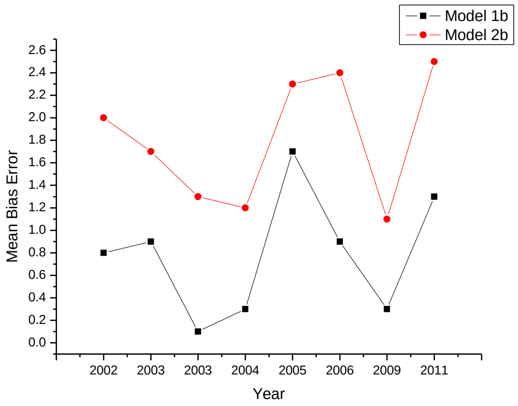

Figure 4a: Mean Bias errors of Models 1b and 2b.

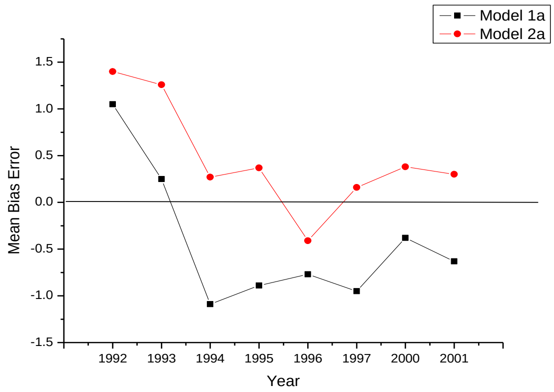

Figure 4b: Mean Bias errors of Models 1a and 2a.

Figures 3a and 3b showed the plots of the root mean square error for backward and forward predictions respectively., Figures 4a and 4b showed mean bias error for backward and forward predictions respectively while Figures 5a and 5b showed mean percentage errors for both the backward and forward predictions.

A very low mean error indicates a better accuracy, thus zero mean error showed a perfect match between the measured and the estimated data. A negative error showed an under estimation while a positive error implies an over estimation.

The two models showed very good agreement with the measured data but estimates made with Models M1a and M1b give better correlation than those made with those estimated from Models M2a and M2b.

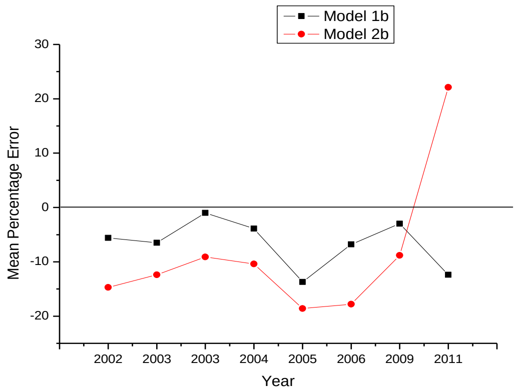

Figure 5a: Mean Percentage errors of Models 1b and 2b.

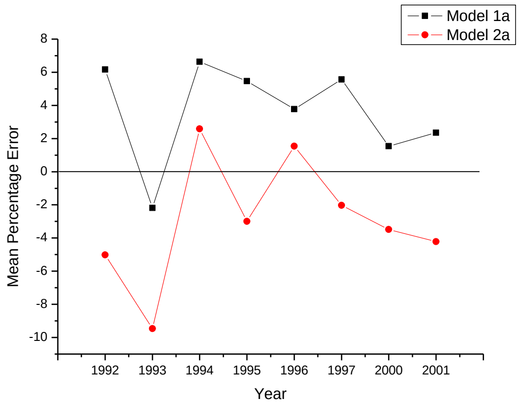

Figure 5b: Mean Percentage errors of Models 1a and 2a .

IV. CONCLUSION

The results of estimates of mean monthly daily solar radiation on a horizontal surface obtained from sunshine hours, Models 1a and 1b as well as minimum and maximum temperatures, Models 2a and 2b were compared with measured data. Estimates computed from Models 1a and 2a are used for backward prediction while Models 2a and 2b are used for forward prediction. The estimates from the two models compared favourably well with the measured data. However estimates made from sunshine hours give generally less mean error than those made with minimum and maximum temperatures.

Thus estimates of solar radiation can now be fairly accurately estimated using the models for locations where direct measurements of solar radiation are not available but sunshine hours and minimum and maximum temperatures are available.

REFERENCES

[1] S. Okundamiya and A. N. Nzeako "Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria," Research Journal of Applied Science, Engineering and Technology, 2(8),2010, 805–812.

[2] C. Augustine and M. N. Nnabuchi, "Relationship between global Solar radiation and sunshine hours, foe Calabar, Port Harcourt and Enugu., Nigeria", International Journal of Physical Sciences, 4(4), 2009, 182- 188.

[3] R.O. Fagbenle. Estimation of total solar radiation in Nigeria using meteorological data. Nig. J. Renewable Energy, 14, 1993, 1-10.

[4] A. S. Sambo. "Empirical models for the correlation of global solar radiation with meteorological data for northern Nigeria". Solar and wind Technol. 3(2), 1986, 829.

[5] R.H.B. Exell *The Intensity of Solar Radiation*. King Mongkut's University of Technology Press: Thonburi, Thailand. 2000.

[6] E.B. Babatunde "Solar Radiation Modeling for a Tropical Station". Ph.D. thesis: Ilorin, Nigeria. 1988.

[7] M. Iqbal "A study of Canadian diffuse and total solar radiation data, part I. Monthly average daily horizontal radiation," Solar Energy, 23(2),1979, 169–173.

[8] R.D. Shears, R.G Flocchini, and J.L. Hatfield ."Technical note on Correlation of Total, Diffuse and Direct Solar Radiation with Percentage of Possible Sunshine for Davis, California". *Solar Energy*. 27(4), 1981.

[9] F.O. Akinbode. Solar radiation in Mina: A correlation with Meteorological data, Nigeria Journal of Renewable Energy, 3,1992, 9-17.

[10] L.E. Akpabio, S.O. UDO, and S.E. Etuk Empirical correlations of global solar Radiation with meteorological data for Onne, Nigeria. Turk. J. Physics 28, 2004, 205- 212.

[11] E.O. Falayi and A.B. Rabiu. Modeling global solar radiation using sunshine duration data, Nigeria Journal of Physics, 17S, 2005,181-186.

[12] M. Halouani, C.T. Nguyen and D. Vo Ngoc. Calculation of monthly average global solar radiation on horizontal surface for five stations using daily hour of bright sunshine, *Solar Energy*, 50, 1993, 247-255.

[13] R.G. Allen, L.S. Pereira, D. Raes and M. Smith. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56; Food and Agricultural Organization of the United Nations, Rome, 1998.

[14] G.H. Hargreaves and Z.A. Samani, Estimating potential evaporation. J. Irrig. Drain. Eng. 108, 1982. 225- 230.